

Motivational Modulation of On-Line Attention Control Processes

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## ABSTRACT

### Motivational Modulation of On-Line Attention Control Processes

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This thesis brings together two broad subdisciplines of psychology -- cognition and motivation -- in order to explore how motivational processes interact on-line with cognitive mechanisms in directing human behaviour and performance. A series of five experiments were conducted in which the Rogers and Monsell (1995) task switching paradigm was combined with motivational manipulations involving earned point incentives (Derryberry, 1993) to investigate the effects of prior and current motivation on task execution, attention switching, and inhibition. Using a left/right button press, participants alternated every second trial between vowel/consonant (letter task) and even/odd (digit task) judgments in response to target-foil stimulus pairs (e.g., A3, G#, ?6) presented on a computer monitor. Participants responded to the letter or digit target while inhibiting the competing (letter or digit) or neutral (symbol) foil. Task motivation was manipulated by assigning participants equal or differential incentives for letter and digit task performance during an initial training phase or during the switch task itself. Motivational incentives were found to have a large and selective influence on attention switching, evidenced by faster switching to the high-valued than low-valued task, but had no effect on either simple task execution processes or the inhibition of task-set cuing by a competing foil. In addition, *prior* motivational experience with

differential task incentives during training had a greater and more reliable impact on attention switching than did *current* differential incentives applied during the switch task itself. These results reveal that motivation does not simply have a global facilitating influence on performance, but rather operates through highly specific mechanisms to bias goal-directed behaviour. Results are interpreted in terms of the apparent differential sensitivity to motivational input exhibited by attention control mechanisms versus automatic, stimulus-triggered processes. A further distinction is made between implicit motivational modulation of executive control mechanisms versus the engagement of an optional, incentive-based performance strategy. Also discussed are speculations regarding underlying neural mechanisms mediating these motivational influences on attention and the potential implications of these results for skill development and performance.

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## INTRODUCTION

Understanding and enhancing learning and performance has long been an objective of psychologists and educators. Specialization within the field of psychology itself has resulted in separate approaches to achieving these goals.

*Cognitive* psychologists have typically focussed on issues of memory and attention, such as effective encoding and retrieval strategies, information processing demands of a task, the balance between automatic and controlled processing, and more recently, the development of attentional control.

*Motivational* psychologists for their part have examined broader dynamics of motivation and performance such as goal selection, effort, and persistence over time. Although significant advancements in our understanding of skill development have resulted from these two approaches, there has been surprisingly little research into how motivational processes interact on-line with cognitive mechanisms in directing human behaviour and performance. How important are motivational dispositions in guiding attention during performance? To what extent can an individual override motivational influences through voluntary control of attention?

In this thesis, I bring together two broad areas of psychology -- cognition and motivation -- to enhance our understanding of attentional processes in skilled performance. More specifically, I investigate the role of prior and current motivational incentives on attention control mechanisms during performance, in particular, on the ability to intentionally switch attention

between tasks and inhibit irrelevant information in order to enhance performance.

### The Concepts of Attention and Motivation

Both attention and motivation are complex and multifaceted constructs that encompass a variety of related processes and functions. Because of this, these terms have come to have multiple meanings, depending on the context and theoretical tradition of the researcher. In addition to the more specific operational definitions presented later, I will, therefore, briefly sketch the approach to attention and motivation taken in this thesis.

#### Attention

Attention has been variously described by experiential state (e.g., conscious awareness, alertness, clearing of consciousness, absorption); by metaphor (e.g., bottleneck, cognitive resource(s), spotlight, zoom lens, executive controller); by modality (e.g., visual, auditory, motor or attention-to-action); by function (e.g., selection, preparation, maintenance, vigilance, control); by source and degree of control (endogenously-cued, voluntary, controlled; exogenously-cued, involuntary, automatic); and by mechanism (e.g., facilitation, inhibition) (Broadbent, 1958; Fernandez-Duque & Johnson, 1999; Kahneman, 1973; Posner & Boies, 1971; Schneider, Dumais, & Shiffrin, 1984; Styles, 1997).

Based on the results of studies combining cognitive paradigms and functional neuroimaging techniques, Posner and Petersen (Posner & Dehaene, 1994; Posner & Petersen, 1990; see also Posner & Rothbart, 1992) found

evidence of three interacting attentional networks subserving distinct functions. In their model, the *anterior* network, associated with activation of the anterior cingulate, left lateral frontal lobe, and basal ganglia, is implicated in target detection, focal awareness, and voluntary control of thought and action. The *posterior* network, involving the posterior parietal lobes, superior colliculus and thalamus, is involved in spatial orienting of attention. Lastly, the *vigilance* network, mediated by noradrenergic projections from the locus coeruleus to the right frontal lobe and right parietal lobe, influences the efficient operation of the other two networks through arousal and the maintenance of an alert state. These three attentional networks, though not exhaustive, are quite consistently distinguished throughout much behavioural and neuropsychological research (Parasuraman, 1998) and can serve as a broad framework for investigating the influence of both cognitive and motivational factors. It is important to remember, however, that these three components may be involved to varying degrees in the performance of any single task, and can themselves be further broken down into more basic processes and subsystems.

In this thesis, I focus primarily on attention processes involved in the control of action, what Posner and Petersen (1990) referred to as the anterior attention system. Both endogenous (voluntary) and exogenous (automatically triggered) control of action within this system is considered and is described as operating through the combined mechanisms of facilitation and inhibition of action schemata.

## Motivation

Motivation has been explored within diverse theoretical and empirical traditions, including behavioural, neurophysiological and social psychological approaches. At a basic level, motivation concerns the energization, direction, and persistence of behaviour. One approach to motivation, and the approach adopted in this thesis, is to view it in terms of the positive or negative incentive value of a behavioural goal. As Dickinson (1995) states, "Although knowledge of an instrumental contingency mediates the selection of the appropriate action for bringing about a particular outcome, motivational processes determine whether or not the outcome is a goal to be pursued or, in other words, whether the outcome has *incentive value*. Thus, instrumental behavior is mediated not only by a representation of the action-outcome relation, but also by a representation of the incentive value of the outcome" (pp. 162-163). He further argues that incentive value is acquired through experience with hedonic reactions to a goal, such that previously neutral stimuli will develop motivational significance and influence future goal-directed behaviour. In his research with rats, these hedonic reactions are related to basic biological need states such as hunger and thirst; in humans, higher-level motivational states, such as the need for achievement or success (Atkinson, 1964; McClelland, 1961; Weiner, 1992), may be implicated in determining the incentive value of a goal.

In this thesis, incentive value is manipulated through the awarding of points toward the goal of achieving a maximal score. However, the focus of this research is not the computations or processes involved in determining the

incentive value, but rather the impact of that incentive value on the control of attention during performance.

### Attention Control Processes and Skilled Performance

Central to most cognitive models of attention in skill development is the distinction between controlled and automatic processing. While definitions of these two processing modes are still a source of considerable debate (e.g., Pashler, 1998), controlled processes are typically described as relatively slow, effortful, resource-demanding, volitional, and accompanied by awareness; in contrast, automatic processes are relatively fast, effortless, resource-independent, and ballistic, and can operate outside of conscious awareness. The progression from novice to expert is, in part, characterised by increasing automatization of repetitive, lower-level component processes, which then function independently of deliberate control and free up attentional resources for the higher-level, strategic components of performance (Ackerman, 1989; Anderson, 1983).

Another important aspect of skill development is proficient deployment of control processes themselves (Gopher, 1993). Complex skills in natural environments cannot be carried out in an invariant fashion. Skilful performance requires flexibility of attention and processing in response to one's goals and to the changing characteristics of the environment. When performing even a moderately complex skill, the performer must flexibly attend and respond to sources of relevant information, while inhibiting attention and responses to irrelevant information. Failure to switch attention appropriately

among sources of relevant information can result in rigid, suboptimal performance (Gopher, Weil, & Siegel, 1989; Tipper, Weaver, & Houghton, 1994). Conversely, the switching of attention to off-task stimuli as well as interference resulting from poor inhibition of unrelated information can lead to inconsistent and distracted performance (Gernsbacher & Faust, 1995; Tipper, Eissenberg, & Weaver, 1992).

#### Theories of Attention Control

In recent years, considerable interest has been shown in explicating the control of attention (e.g., Baddeley & Della Sala, 1996; Gopher, 1996; Meyer & Kieras, 1997; Monsell, 1996; Posner & DiGirolamo, 1998; Shallice, 1994; see also Styles, 1997). These models again pick up on the controlled and automatic processing distinction, but place greater emphasis on how these modes of processing together contribute to the coordination of coherent action and thought, and begin to address the functional architecture of voluntary, executive control mechanisms.

#### The Norman-Shallice Model

Norman and Shallice (1986; Shallice, 1988; Shallice, 1991; Shallice, 1994; Stuss, Shallice, Alexander, & Picton, 1995) proposed an attentional framework in which schemata (defined broadly as programmes that coordinate processes carried out by special-purpose cognitive subsystems) compete for control of action (internal thoughts or external behaviours). A lateral inhibitory mechanism called *contention scheduling* allows only the most strongly activated schema to operate at any given moment. The schema selected by

contention scheduling continues to operate until the activation level of a competing schema is strong enough to overcome lateral inhibition, resulting in a switch of attention. A schema is likely to be at a high level of activation if it has been activated frequently (e.g., habits) or recently, and can be automatically triggered by environmental stimuli or the output of other schemata.

Contention scheduling mechanisms are sufficient for the coordination of routine activities and automatic components of complex skills, but cannot alone account for controlled performance under novel or variable conditions. Norman and Shallice therefore posit a *supervisory attentional system* (SAS) that enables, for example, voluntary control of goal-directed action. The SAS operates through a top-down bias on contention scheduling by selectively raising or lowering the activation level of competing schemata to meet current goals. This feature is of central importance since it suggests that the SAS cannot direct attention or action independently of contention scheduling. Rather, it can only function by enhancing or overcoming lower-level activation influences. Norman and Shallice contend that the SAS is required for deliberate control of attention during planning and decision making, troubleshooting, novel action sequences, dangerous or technically difficult tasks, and in the inhibition of habitual actions or temptations. More specifically, it may be called into play for a number of attention control functions (Stuss et al., 1995) including the two of interest in this thesis, voluntary attention switching and deliberate inhibition of competing schemata.

Consistent with this framework, patients with frontal lobe damage exhibit selective impairment of supervisory control of attention and behaviour (Shallice, 1988), including difficulty in voluntary switching of attention (perseverative errors) and in inhibiting inappropriate habitual responses or responses cued by environmental stimuli (utilization behaviours). Similar phenomena are occasionally observed in normal individuals during momentary lapses of attention control (Reason, 1984).

#### Motivation and Attention Control Processes

Consideration of the influence of motivation on executive control of attention raises questions of how voluntary attention processes may be enhanced or limited by motivational dispositions. Within their model of attention-to-action, Norman and Shallice (1986) only briefly consider the potential impact that motivation may have on the resolution of schema competition and action selection. They propose that, like the SAS, motivation may influence contention scheduling by biasing schema activation levels, but suggest that motivational influences would operate over a longer time frame than the SAS. This view takes into account the role of long-term dispositions toward stimuli and their associated action schemata, but does not acknowledge the potentially strong impact of immediate motivational states on the guidance of attention. Furthermore, they do not discuss the possible implications of such motivational influences for the efficient operation of on-line supervisory attention control.

Simon (1994) has suggested that attention may act as a mediator between motivation and behaviour. In very broad terms, he proposed that strong motivation would serve to maintain attention on current behaviours or tasks, whereas weak motivation would allow attention to be captured by irrelevant information, resulting in a shift to new goals or tasks. In line with Simon's proposal, one possibility is that the ease of an attentional switch during task engagement is, in part, a function of the relative motivational significance of the current activity versus that of competing action schemata and stimuli developed through prior experience. This entails that greater intervention by the SAS would be required to switch away from a highly motivated activity since underlying biases would tend to maintain attention on this task. In contrast, an attentional switch would be easier or more likely if the competing stimulus and its action schema are highly motivating to the individual. This would facilitate SAS intervention in a task-appropriate switch, but would present a greater challenge to SAS intervention in the inhibition of a task-inappropriate switch.

According to this view, motivational significance of current and competing tasks could have both beneficial and deleterious influences on attention during skill development and performance. At a broad level, poorly motivated performance could be more susceptible to distraction and switching of attention to off-task sources of stimulation, whereas highly motivated performance would be resistant to exogenous capture of attention. In addition, where task motivation is high, the motivational bias associated with the currently activated schema may further spread activation to other relevant

schemata and inhibition to unrelated schemata, thereby facilitating both relevant attention switching and inhibition of irrelevant attention switching. Such a process may be related to the feeling of effortless attentional control experienced by an individual who is fully absorbed in an activity, a state that has been referred to as 'flow' (Csikszentmihalyi & Csikszentmihalyi, 1988; Csikszentmihalyi, Rathunde, Whalen, & Wong, 1993). Finally, in many learning environments performers are guided primarily by explicit goals or instructions provided by the teacher or trainer. If supervisory attention can only partially engage or inhibit a switch of attention and control remains susceptible to other influences on contention scheduling, task performance may nevertheless suffer. In extreme cases such as during strong visceral states, supervisory control may even be insufficient to overcome strong lower-level motivational influences on schema activation values (Loewenstein, 1996).

At a finer level, motivational signals may play an important role in guiding the selection and coordination of task processing components that lead to successful outcomes, facilitating appropriate switching and inhibiting inappropriate switching. In research on decision making under conditions of uncertainty, Bechara and colleagues (Bechara, Damasio, Damasio, & Anderson, 1995; Bechara, Damasio, Tranel, & Damasio, 1997; Bechara, Tranel, Damasio, & Damasio, 1996) found that normal individuals develop early biasing signals, based on prior rewards and penalties, that guide performance advantageously before they are able to formulate a cognitive strategy or even express a hunch. Such implicit motivational signals may

plausibly operate during attention switching as well. These early motivational signals should generally lead to performance improvements, but in some circumstances the reverse may occur. For example, in complex tasks that require frequent strategic switching of attention, initial patterns of positive and negative feedback may lead to premature commitment to suboptimal strategies and limit further exploration of riskier, but ultimately more optimal, attention strategies (Erev & Gopher, 1999).

Consideration of even just these few potential implications of motivated attention processes for skill development underscore the merit of developing a better understanding of the interactions between motivation and attention, their underlying mechanisms, and their combined impact on learning and skilled performance. Recent theoretical interest in attention control has been accompanied by the development of relevant empirical paradigms that permit more fine-grained investigation of the cognitive components of attention switching and action control. These cognitive studies will be reviewed in the next section. While, to the best of my knowledge, this thesis represents the first investigation into the influence of motivational factors on these control mechanisms, recent research by Derryberry and colleagues (e.g., Derryberry, 1988; Derryberry, 1989; Derryberry, 1991; Derryberry, 1993; Derryberry & Reed, 1994; Derryberry & Reed, 1998) has combined motivational manipulations with cognitive paradigms to investigate immediate influences of motivational states on attentional arousal, focusing and orienting. Application of their methodological techniques for studying motivational influences on

on-line attention control processes will be discussed in the final section of the introduction.

#### Empirical Investigations of Control Mechanisms in Attention Switching

Several cognitive experimental paradigms have been developed to examine the role of attention during task switching (Allport, Styles, & Hsieh, 1994; Los, 1999; Meiran, 1996; Rogers & Monsell, 1995; Rubinsten, Meyer, & Evans, in press; Segalowitz, Poulsen, & Segalowitz, 1999) and its implications for skilled performance (Gopher, 1996; Segalowitz, O'Brien, & Poulsen, 1998). These paradigms attempt to isolate and measure the contribution of executive and stimulus-triggered control of action during task switching under various experimentally-manipulated conditions. In this thesis, I extend these manipulations to include consideration of motivational factors. Consequently, the results of these studies and the various interpretational issues that have emerged regarding underlying cognitive mechanisms will be given close consideration here.

#### Early Evidence of Supervisory Attention Control in Task Switching

In a paradigm first employed by Jersild (1927), the pure versus alternating block paradigm, participants perform two tasks, A and B, in pure blocks where the same task is repeated across trials (i.e., AAA . . . ; BBB . . . ) and in alternating blocks where participants must switch between tasks across trials (i.e., ABABA . . . ). Here, performance on pure blocks serves as a baseline for calculating the cost associated with switching between tasks in

alternating blocks. Factors that may influence switch costs are explored by varying, for example, the nature of the stimuli, task cues, or task complexity.

Interestingly, task switching does not always incur reaction time costs. One determinant of whether costs are incurred in switching is whether the stimuli unambiguously cue the task to be performed. With univalent stimuli -- stimuli that unambiguously cue the task -- there is often no difference in completion times between pure and mixed blocks, and there may even be a slight benefit for alternating blocks. For example, in one experiment by Jersild and later replicated by Spector and Biederman (1976), participants were marginally *faster* when alternating between subtracting three from two-digit numbers and giving the antonym to common words in alternating blocks than when performing these two tasks repeatedly in pure blocks. In contrast, with bivalent stimuli -- stimuli that do not unambiguously cue which task is to be performed -- substantial switch costs are virtually always observed (but see Allport & Wylie, 1999 for an exceptional case). For example, when participants had to alternate between adding three and subtracting three from two-digit number stimuli, they were on average 402 ms slower per item in alternating than in pure lists (Spector & Biederman, 1976, Experiment 3). This result is consistent with the view that when no exogenous cue is available to unambiguously trigger the appropriate task set, an endogenous, supervisory control mechanism must intervene to assist in task set selection.

### Distinguishing Supervisory and Contention Scheduling Control Mechanisms

Further evidence for the engagement of supervisory attention control in task switching was provided by Rogers and Monsell (1995), who developed the 'alternating runs' paradigm to address two weaknesses they perceived in the pure versus alternating block paradigm. First, as compared to pure blocks, alternating blocks require not only switching between task sets, but also the maintenance of two task sets in working memory rather than just one task set, leading to a potential overestimate of switch costs with this paradigm. Second, they argued, the perceived difficulty of alternating blocks may have led to enhanced effort or arousal, possibly accounting for the absence of costs and even benefits sometimes obtained in alternating blocks with univalent stimuli. Rogers and Monsell's alternating runs paradigm overcomes these problems by including both switch and repeat trials within blocks. Rather than alternating on every trial between task A and B (i.e., ABAB . . .), participants alternated on every second trial (i.e., AABBAA . . .). Here, performance on repeat trials serves as baseline, and RT switch costs are computed by subtracting mean RT on these repeat trials from mean RT on switch trials (errors costs can be similarly computed).

Another particularly advantageous feature of the Rogers and Monsell paradigm is the inclusion of a condition (called the crosstalk condition) in which both univalent and bivalent stimuli are intermixed within blocks across switch and repeat trials. A brief description of their paradigm should help clarify this. Stimuli consisted of target-foil pairs (e.g., 2E, A#, ?6) presented in one of four quadrants on a computer monitor. Targets were either letters or digits.

Bivalent stimuli were created by pairing the target with a competing foil (i.e., letter target with a digit foil or vice versa; e.g., U4, 6E), and univalent stimuli were created by pairing the target with a neutral symbol foil (e.g., 2#, ?K). With a left/right button press, participants performed vowel/consonant (letter task) and even/odd (digit task) judgments. Thus, bivalent stimuli afforded both letter and digit task sets, whereas univalent stimuli uniquely specified only one of these two task sets on a given trial. Quadrant position further cued the task to be performed (e.g., letter task in the top two quadrants, digit task in the bottom), and stimulus presentation rotated in clockwise fashion. This resulted in regular alternation between two letter task and two digit task trials, the first trial of each requiring task switching and the second trial requiring only task repetition. Stimuli on one third of all trials were univalent and on two thirds were bivalent and were counterbalanced across switch and repeat trials. Thus, in contrast to the pure versus alternating block paradigm, the crosstalk condition of the Rogers and Monsell paradigm permitted the simultaneous assessment of two distinct challenges to attention control: switching of task set (performance on switch versus repeat trials) and inhibition of inappropriate task set cuing from the competing foil (performance on bivalent versus univalent stimulus trials).

Across all five of their experiments, Rogers and Monsell found a substantial increase in RT on switch trials compared to repeat trials (switch cost), and on bivalent stimulus trials compared to univalent stimulus trials (task-set cuing cost). In the crosstalk condition of Experiment 1, for example, the mean switch cost was 289 ms and the mean task-set cuing cost was

approximately 175 ms (estimated from Figure 2, p. 215). However, contrary to earlier studies by Jersild (1927) and Spector and Biederman (1976), Rogers and Monsell also found a relatively large and significant switch cost of 161 ms in a no-crosstalk condition where only univalent stimuli, which unambiguously cued the required task, were used. A critical issue, and the source of much current debate, concerns the interpretation of these costs. For example, while these reaction time costs suggest the presence of additional challenges to task performance, do they necessarily entail the intervention of a supervisory attention control mechanism? If not, what other evidence can be brought to bear on this issue? If supervisory control *is* implicated, can the size of the cost be used to index the duration of a discrete supervisory attention process?

Evidence from additional experiments in the Rogers and Monsell (1995) paper suggest that supervisory processes are indeed implicated in the control of task switching between two potentially competing task sets, but that the duration of this inferred endogenous control process cannot be determined by the size of the switch cost. First, Rogers and Monsell found that the size of the switch cost declined by up to one third with increasing response-stimulus interval (RSI) when RSI (150, 300, 450, 600, or 1200 ms) was varied across blocks (Experiment 3), but not when the same RSIs were randomly intermixed within blocks (Experiment 2). This suggests that an active, preparatory process can be strategically deployed to facilitate switching. However, the decline in switch cost reached asymptote at 600 ms, leaving a large residual switch cost of over 100 ms when RSI was increased to 1200, long past the largest switch cost observed at the original 150 ms RSI. Thus, even when

provided with maximal preparation time, a persistent switch cost remained. Rogers and Monsell attributed these results to a two-phase switching process, an endogenously-cued preparatory phase that can be executed in advance of stimulus presentation, and an exogenously-triggered phase that engages the required task set upon presentation of a task-relevant stimulus. They argue that task switching requires the combined suppression of the just-executed and now-irrelevant task set, and activation of the previously-suppressed but now-relevant task set, a process they termed *task set reconfiguration*. They further conclude from these results that an endogenous component can begin this reconfiguration process, but completed task set reconfiguration must await an exogenous cue.

This endogenous, preparatory process also seemed to be engaged in the no-crosstalk condition. Here, not only was there a significant switch cost, but as in the crosstalk condition it declined significantly with increasing RSI (again reaching asymptote at a 600 ms RSI). A possible reason for endogenous involvement here, despite unambiguous stimulus cuing of the appropriate task, might be that the experimental context as a whole promoted potential conflict between these two task sets, resulting in the development of mutually inhibitory links. In this experiment, the same individuals participated in both the crosstalk and no-crosstalk conditions. The competition between task sets experienced in the crosstalk condition, therefore, may have transferred to performance during the no-crosstalk condition. This, in turn, would have encouraged the deployment of a supervisory control mechanism to assist in

the reversal of task set activation and inhibition required when switching between competing task sets.

In contrast to the observed reduction in switch costs, increasing the RSI had no effect on the costs associated with inappropriate task set cuing from the competing foil of bivalent stimuli. As in earlier experiments, RTs on bivalent stimulus trials, where the stimulus cues both the currently relevant and irrelevant task set (e.g., 5E), were slower than on univalent stimulus trials (e.g., 5#), but this cost was *not* reduced by extending preparation time. Task set cuing costs from the competing foil, therefore, seem to arise from lower level competition factors that are not controlled in advance by an endogenous mechanism. On repeat trials, and on switch trials following endogenous switch preparation, this competition contributes to total reaction time but appears to be resolved with little, if any, further intervention of a discrete supervisory process.

The Rogers and Monsell (1995) experiments thus support the engagement of an endogenous control process during task switching between competing task sets, but less so or not at all in the control of inappropriate cuing from the competing foil. Moreover, results suggest that there are two distinct stages involved in attention switching -- an endogenously controlled preparatory stage, and an exogenously cued completion phase. However, given the presence of residual switch costs, the total magnitude of the switch cost clearly cannot be used alone as a measure of this endogenous control process. Nor can the reduction in switch cost be used as a measure of the duration of a preparatory supervisory attention process since, as pointed out by Allport and

colleagues (Allport & Wylie, 1999; Allport et al., 1994), the increase in RSI far exceeded the corresponding reduction in switch cost. Finally, the absence of a reduction in the task set cuing effect on switch trials suggests that the endogenous component of switching does not act through direct enhancement or inhibition of task sets. If endogenous preparation did involve partial reconfiguration of task set as argued by Rogers and Monsell, it would be difficult to explain why this partial reconfiguration would not lead to a reduced effect of task set cuing from the competing foil. Although the evidence is consistent with the idea that some form of endogenous bias can be introduced in advance to facilitate switching, exactly what form that bias takes is in need of further exploration.

Despite the difficulties inherent in measuring the duration of supervisory attention control in switching, corroborative evidence of endogenous intervention in switching comes from a number of other studies that have employed various paradigms and tasks. Meiran (1996), using either bivalent target location tasks or bivalent shape/colour object discrimination tasks, presented participants with an instructional cue prior to each trial that indicated which task should be performed on the upcoming bivalent stimulus. When the time between this instructional cue and the onset of the bivalent target stimulus (the cue-target interval) was increased from about 200 to 1500 ms, there was a significant reduction in switch cost. As with the long RSI interval in Rogers and Monsell, residual switch costs were still observed at the long cue-target interval. By independently varying the response-cue interval and the cue-target interval, Meiran was further able to conclude that the

reduction in switch cost was not due to simple dissipation of priming effects from the previous trial, but rather was attributable to advanced, endogenous preparation of task set. In yet another attention switching paradigm, Gopher (1996) as well found that the cost of switching between tasks (judging digit value vs. numerosity of displayed digits) and between performance strategies (speed vs. accuracy) was reduced by advanced cuing.

Using the pure versus alternating block paradigm, Rubinstein, Meyer, and Evans (in press) applied an additive factors approach (Sternberg, 1969; Sternberg, 1998) to the study of attention control during task switching by experimentally manipulating selected factors putatively associated with different components of either task execution (e.g., stimulus identification) or executive control (e.g., goal shifting). While stimulus discriminability, for example, affected overall RT but not switch costs, Rubinstein et al. found that both task set cuing and rule complexity did affect switch cost -- switch cost decreased with task set cuing and increased with rule complexity. Moreover, these effects were roughly additive, adding further support to a two-stage model of executive control: a goal-shifting stage (similar to Rogers and Monsell's endogenous preparation of task set reconfiguration); and a rule activation stage (similar to Rogers and Monsell's exogenously-cued completion of task set reconfiguration).

#### Lower-level Influences on Switch Costs

Research by Allport and colleagues (Allport & Wylie, 1999; Allport & Wylie, in press; Allport et al., 1994; Wylie & Allport, 1999) underlines the

potentially strong contribution of lower-level factors to switch costs. While acknowledging that switching between competing tasks must involve some type of endogenous control process to avoid an otherwise perseverative error, they argue that "involuntary priming (both positive and negative) of task-specific condition-action rules is the principal determinant of performance costs in switching between competing tasks" (Allport & Wylie, 1999, p. 274). As described below, this may be especially true of the Stroop-like stimuli used in their research, where one of two tasks is strongly dominant. In the traditional Stroop task, for example, when presented a colour word written in an incongruent ink colour (e.g., red written in green), reading the word dominates naming the colour of the ink.

Allport et al. (1994) employed the pure versus alternating block paradigm using traditional colour-word Stroop stimuli as well as other Stroop-like stimuli (e.g., digit arrays where the subject must make judgments regarding either the value of the digits or the number of elements in the array), and later extended their research to include the Rogers and Monsell (1995) alternating runs paradigm and other designs, again with Stroop and Stroop-like stimuli (Allport & Wylie, 1999; Allport & Wylie, in press; Wylie & Allport, 1999). The results of the Rogers and Monsell experiments and those of Allport and colleagues initially appear incompatible, but may overall represent complementary rather than conflicting views of the challenges and attention control processes implicated in task switching. That is, whereas Rogers and Monsell studied the moderating role of *current* trial activation/inhibition demands (e.g., competing-foil versus neutral-foil trials) using tasks of equal

difficulty, Allport and colleagues focused on the role of *preceding* trial activation/inhibition demands using Stroop-like stimuli.

In all of the Allport studies (Allport & Wylie, 1999; Allport & Wylie, in press; Allport et al., 1994; Wylie & Allport, 1999) task set activation and inhibition settings on *preceding* trials had a powerful influence on switch cost, an effect they called task-set inertia. This effect involved both positive priming of the now-competing task from its activation on the preceding trial, and negative priming of the now-target task from its inhibition on the preceding trial. For example, switching to a bivalent word-reading trial (e.g., the word "red" written in green ink) from a *univalent* colour-naming trial (a series of coloured Xs) yielded a small switch cost of only about 20 ms; in contrast, switching to a bivalent word-reading trial from a now *bivalent* colour-naming trial (e.g., the word "blue" written in brown ink -- name the colour of the ink), yielded a large switch cost of approximately 100 ms (Allport & Wylie, in press; Wylie & Allport, 1999). This difference is attributable not to the characteristics of the current word-naming switch trial -- since bivalent Stroop colour words were used in both cases, but rather to the nature of the preceding trial. Specifically, a large switch cost was incurred when the preceding trial was a Stroop word rather than a series of Xs because performance on the current switch trial required overcoming both activation of colour naming and inhibition of word reading from the preceding trial (and this despite an intertrial interval of over 1000 ms that maximised potential anticipatory switch preparation). On the basis of this and other experimental results (see Allport & Wylie, in press), they concluded that these (residual) switch costs reflect primarily

*disengagement* of prior task-set configuration when switching *from* a previous task, rather than *engagement* of upcoming task-sets when switching *to* the current trial.

It is perhaps worth noting here that Allport and colleagues further demonstrated that activation/inhibition patterns between competing tasks may persist over the long-term and also affect repeat trials (Allport & Wylie, in press). For this reason, they argue that performance on repeat trials in the alternating runs paradigm and indeed any trials following experience with bivalent stimulus tasks may not be representative of pure task performance. While this adds additional weight to caution in interpreting switch cost magnitudes, it does not negate the presence of additional challenges to the control of performance on switch trials and the need for supervisory attention control to ensure accurate responding. It is primarily because of the need to override automatic task-set priming patterns on switch trials that would otherwise lead to error that endogenous, supervisory attention processes are engaged. Their findings do, however, highlight the difficulties in attempting to infer and measure such executive processes through switch costs alone. More informative are selective effects of specific manipulations (e.g., length of the RSI, advanced cuing, differential practice, and task dominance) on various measures of performance (e.g., switch costs, stimulus ambiguity costs, and simple task execution).

### Asymmetric Switch Costs

In Rogers and Monsell (1995), alternating between letter and digit tasks produced roughly symmetric switch costs. That is, as assessed by the relative increase in RT, switching from the letter to digit task was no easier or harder than switching from the digit to letter task. Other researchers (e.g., Allport et al., 1994; Rubinstein et al., in press), however, have obtained asymmetric switch costs leading to questions concerning the nature and source of such asymmetric costs.

Allport and colleagues (Allport & Wylie, 1999; Allport & Wylie, in press; Allport et al., 1994; Wylie & Allport, 1999) consistently obtained 'paradoxical' asymmetric switch costs when switching between competing Stroop-like tasks. For example, when all stimuli were Stroop colour words, contrary to intuitive expectations a *small*, virtually negligible, switch cost obtained when switching to the non-dominant task (e.g., colour naming) whereas a large switch cost obtained when switching to the dominant task (e.g., word reading). Allport and colleagues attributed this counterintuitive effect to the differential inhibition required on the trial preceding colour-naming and word-reading switch trials. That is, because word reading is the overwhelmingly dominant task, little inhibition of colour naming is required on word reading trials. Consequently, there is little negative priming to be overcome when switching from a word-reading to a colour-naming trial. In contrast, strong inhibition of word reading is required on colour-naming trials; hence, the large switch costs obtained when switching from a colour-naming to a word-reading trial.

A study by Yeung (1997, reported in Allport & Wylie, in press), conducted in the Allport laboratory using the alternating runs paradigm, illustrated that these asymmetric task dominance effects in switching could be induced through differential practice of two initially equivalent tasks performed in response to single digit stimuli -- adding 3s and subtracting 2s. Before practice, switch costs were roughly equal (approximately 65 ms). After a short practice session with one of these tasks, designated A, the cost of switching to A (the now-dominant task) increased and the cost of switching to B (the now non-dominant task) was eliminated. After a subsequent practice session with task B, this asymmetric switch cost was reversed, again resulting in a large switch cost to the now-dominant task B, and a reduction in switch cost to the now non-dominant task A.

Rubinstein et al. (in press) also found asymmetric switch costs in two of their experiments. In Experiment 3, for example, participants were asked to classify shape stimuli according to one of four possible dimensions -- size, shading, shape, or numerosity -- in four pure blocks, within which only one sorting dimension was required, or in two alternating blocks. In one of the alternating blocks, participants switched between size and shading, and in the other, between shape and numerosity. In both alternating block conditions, asymmetric switch costs obtained; a smaller switch cost obtained when switching from shading to size than vice versa, and when switching from numerosity to shape than vice versa. Unlike with classic Stroop stimuli, determining task dominance here is less obvious. If defined by participants' relative speed of performance in the pure task blocks, dominance would be

assigned to shading over size, and numerosity over shape, and the results would conform to Allport and colleagues' findings of smaller switch costs when switching to the non-dominant task (i.e., switching to size; switching to numerosity).

Rubinstein et al., however, tested a different hypothesis based on subjective familiarity. With a new group of participants, they obtained subjective familiarity scores on a range from 1 to 4 that were based on a composite of paired familiarity comparisons between the four tasks (frequency of similar discriminations during daily activities) which were then averaged across participants. Familiarity scores for size, shading, shape, and numerosity were, respectively, 2.29, 1.86, 3.57, and 2.29. Thus, judging size was more familiar than shading, and judging shape was more familiar than numerosity. In a two-predictor multiple linear regression analysis with switch cost as criterion variable, subjective familiarity of the task preceding the switch correlated positively with switch cost, and subjective familiarity of the current task (to which the switch was made) correlated negatively with residualized switch cost (i.e., with the contribution of the first predictor, preceding-task familiarity, removed). In other words, it was both harder to switch *from* and easier to switch *to* a familiar task. Moreover, predicted switch costs conformed very closely to observed switch costs, adding further support to this familiarity hypothesis.

Thus, in Rubinstein et al's Experiment 3, if dominance is defined by RT in pure blocks (faster = dominant), the results support either the dominance or familiarity hypothesis since, in both competing task combinations, the faster

task had a lower familiarity score; however, if dominance is defined by subjective familiarity (more familiar = dominant), the results are consistent only with the familiarity hypothesis. The situation was different in the case of Experiment 4, in which participants performed either addition, subtraction, multiplication, or division operations, again in pure blocks and in blocks alternating between addition and subtraction, or multiplication and division. Here, addition was simply assumed to be more familiar than subtraction, and multiplication more familiar than division. Consistent with Rubinstein et al.'s hypothesis, switch costs were smaller when switching from subtraction to addition than vice versa, and from division to multiplication than vice versa. Unlike Experiment 3, however, if dominance here were based on mean RT in pure blocks, addition would be assigned as dominant over subtraction, and division as dominant over multiplication, leading to a rejection of Allport's dominance hypothesis in the case of addition/subtraction alternation, and support for the dominance hypothesis in the case of multiplication/division alternation.

Taken together, the asymmetric switch costs in Rubinstein et al.'s Experiments 3 and 4 are most consistent with their familiarity hypothesis. How then to explain Allport's results when surely reading a word would be considered more familiar than naming a colour, and switch costs are considerably larger in switching to word reading than to colour naming? Without going into the detail of their computational formulas and models, Rubinstein et al. claim that special processing considerations are implicated in asymmetric switching costs involving Stroop stimuli due to the highly

automatized activation of word reading. Using order-of-processing diagrams to map the overlapping of mental processes that may underlie the Stroop task, Rubinstein et al. argue that the executive control processes of goal shifting and rule activation are obscured by the extra time required to edit automatic word reading responses on colour naming trials. While this is a plausible explanation of the asymmetric switching patterns with Stroop stimuli, it is a less convincing explanation of the asymmetric switching patterns that arose after only brief practice with one or the other of two initially equivalent addition and subtraction tasks in the Yeung (cited in Allport & Wylie, in press) experiment described earlier. To conclude, Rubinstein et al. offer the intriguing possibility that subjective perceptions may in some situations influence switch costs; specifically, subjectively familiar tasks may be both easier to engage and more difficult to disengage than less familiar tasks. However, the evidence for this remains preliminary and inconclusive.

### Summary

In terms of the Norman-Shallice model, these studies provide evidence for a lower-level contention scheduling mechanism that controls competition between competing task schemata through the establishment of inhibitory links. The strength of both schema activation and inhibitory links to competing schemata is sensitive to how closely these task sets compete for control of action and how frequently and recently they have been engaged. The evidence also supports the existence of a supervisory attention system that biases contention scheduling to ensure appropriate, goal-directed schema selection

under conditions of conflict or uncertainty. As Norman and Shallice proposed, this top-down bias cannot bypass the influence of lower-level activation and inhibition patterns. Consequently, these patterns will continue to exert considerable influence on reaction times and switch costs. In situations of extreme inequality between competing task sets, the contribution of these lower level activation/inhibition patterns to reaction times and switch costs may be particularly large. When switching between more equal task sets, other factors such as advanced cuing, extended preparation time, and subjective task familiarity have been found to influence the efficiency of task switching.

#### Investigating Motivational Influences on On-Line Attention Control Processes

As exemplified by the research just reviewed on attention control processes in task switching, research on attention and performance is typically restricted to the consideration of cognitive factors and processes. Where motivation is considered, the research has tended to address global influences of motivation on attention, such as generalized arousal, effort and maintenance of attention, measured over relatively long time periods (e.g., Kanfer & Ackerman, 1996; Kanfer, Ackerman, Murtha, Dugdale, & Nelson, 1994; Reeve, 1989; Schiefele, 1991). Results from such studies say little about the moment-by-moment influences of motivation on component cognitive processes that occur on the order of milliseconds.

A notable exception is research conducted by Derryberry and colleagues (e.g., Derryberry, 1988; Derryberry, 1989; Derryberry, 1991; Derryberry,

1993; Derryberry & Reed, 1994; Derryberry & Reed, 1998), who applied motivational manipulations within traditional cognitive laboratory reaction time tasks. In these studies, participants performed speeded responses to target stimuli within a computer game format where the object was to accrue points through execution of fast and accurate responses. Motivational states were manipulated through current-trial point incentives and preceding-trial performance feedback signals. Using such point-incentive techniques, Derryberry has successfully studied motivational influences on a variety of on-line attention processes, including the arousal, focusing, and orienting of attention.

In one such study, Derryberry (1993) examined the effects of positive incentives (trials on which points could be gained), negative incentives (trials on which points could be lost), and neutral incentives (no points at stake), in conjunction with either high (five-point) or low (two-point) incentive size. Targets consisted of letter-digit pairs (e.g., M5, W3, 5V). Valuable targets always consisted of an M or W paired with either a 2 or 5. The letter indicated the valence of the incentive, either positive (e.g., M) or negative (e.g., W), and the digit indicated the potential number of points to be earned or lost (i.e., 2 or 5 points). Nonvaluable targets were created by replacing either the letter with V or A or the digit with 3 or 4. Participants were instructed to press a right button if the target was valuable (e.g., M5, 2M, W2, 2W) and a left button if it was nonvaluable (e.g., V5, 3M, W4). Fast and accurate responses were followed by a positive feedback signal (i.e., a smiling face), and slow or inaccurate responses by a negative feedback signal (i.e., a frowning face).

Reaction time patterns revealed a general bias in favour of positive and large incentives. On valuable trials, participants responded more quickly to positive than negative incentive targets and to large than small incentive targets. On nonvaluable trials, RT was fastest for targets with small incentive features (e.g., 2V, A2), followed by negative and large features (e.g., W3, 5A, V5), and slowest to targets containing positive incentive features (e.g., M3, 4M), indicating greater interference from positive and large incentive features than negative and small features. In addition, negative feedback led to a general focusing of attention on valuable targets, evidenced by faster RTs to valuable targets and slower RTs to nonvaluable targets (especially those that shared a large value feature, e.g., 5V, A5) following negative versus positive feedback. Derryberry interprets this result in terms of adaptive narrowing of attentional focus during anxiety, facilitating both attending to important information and inhibiting distraction (see also Derryberry & Reed, 1998).

In addition to these attentional focusing effects, the nature of the feedback also influenced the direction of attentional orienting. On valuable target trials, a congruent feedback effect obtained: performance was enhanced for positive targets following positive feedback, and negative targets following negative feedback. In contrast, an incongruent effect obtained on nonvaluable target trials: following negative feedback, RT was slowest for nonvaluable targets that contained a positive feature (e.g., 3M, M4). Derryberry argues that congruent and incongruent effects, by acting in opposition, may serve a motivationally-guided adaptive influence on attention. Following failure, for example, attention would be oriented toward additional threats (a congruent

effect favouring negative incentive targets), but once cues indicating possible relief were engaged (positive incentive features of nonvaluable targets), it would be difficult to then disengage attention from them (hence the incongruent effect).

To summarize, results from this and other studies by Derryberry and colleagues suggest that motivation can selectively orient attention toward positive and negative incentive stimuli and influence the breadth of attentional focus, thereby serving an adaptive *non-voluntary* regulatory role in attention. Their research, however, has not directly addressed the effect of motivation on the *voluntary* control of attention. By combining Derryberry's point incentive manipulations with the Rogers and Monsell (1995) paradigm, this thesis represents a first step in exploring the effect of motivation on attention control mechanisms.

## PARADIGM AND OVERVIEW OF THE EXPERIMENTS

Five experiments were conducted to investigate the influence of motivation on attention and performance. The basic paradigm and motivational manipulations are described below, followed by an outline of the experiments conducted and analytic procedures used.

### Task Switching Paradigm

The task switching paradigm employed throughout this thesis was based on the crosstalk condition of Experiment 1 of Rogers & Monsell (1995). In this paradigm, subjects respond to target-foil stimulus pairs (e.g., A3, 9E, G#, ?6) presented on a computer monitor. Targets are either letters (A, E, I, U; G, K, M, R) or digits (2, 4, 6, 8; 3, 5, 7, 9). Foils are letters, digits, or neutral symbols (% , #, ?, \*). Using a left/right button press, subjects perform vowel/consonant (letter task) or even/odd (digit task) judgments.

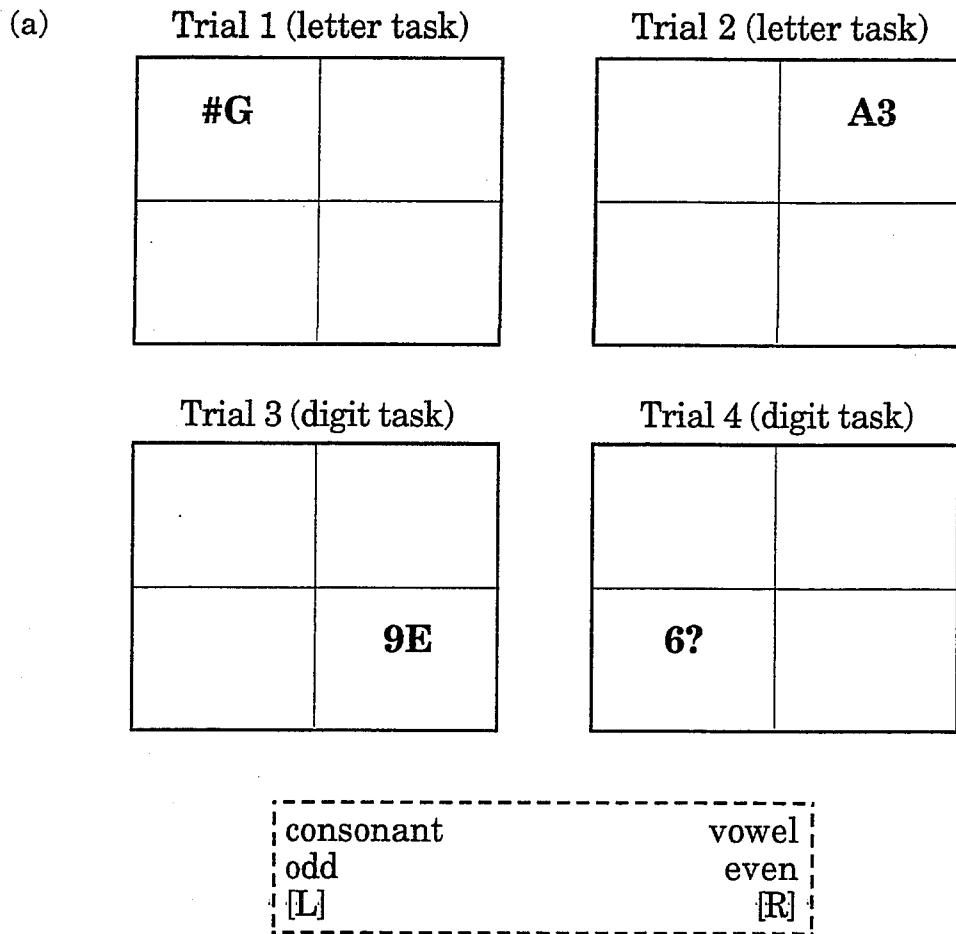
In an initial *training* phase, subjects receive extensive blocked training on the letter and digit tasks in order to learn the appropriate left/right button press mappings for the letter and digit judgments. During this training, the letter or digit target is always paired with a neutral foil and is presented in a single square in the centre of the monitor.

As briefly described earlier, during the subsequent *switch task* phase, stimulus pairs are presented in one of four quadrants. The quadrant position cues the subject to perform either the letter or digit task (e.g., letter task in the top two quadrants; digit task in the bottom two quadrants). Stimulus pairs are presented in clockwise rotation resulting in a regular alternation of *repeat*

trials, on which the subject performs the same task as on the previous trial, and *switch* trials, on which the subject has to switch attentional focus from the letter to the digit task or vice versa. On one third of the trials, the target is paired with a neutral foil, and on two thirds of the trials it is paired with a competing foil (e.g., a digit foil with a letter target). Figure 1 displays an illustrative sequence of trials, including left/right response mappings and task quadrant assignments.

Recall that participants are generally slower on switch trials than repeat trials (the switch effect) and on competing-foil trials than neutral-foil trials (the task-set cuing effect). This basic switch effect is typically computed as the difference in RT on switch versus repeat trials, collapsed across type of foil (competing, neutral). Similarly, this basic task-set cuing effect (referred to subsequently in this thesis as the *cue inhibition* effect) is computed as the difference in RT on competing-foil versus neutral-foil trials, collapsed across trial type (switch, repeat). All experiments in this thesis test for these two basic effects.

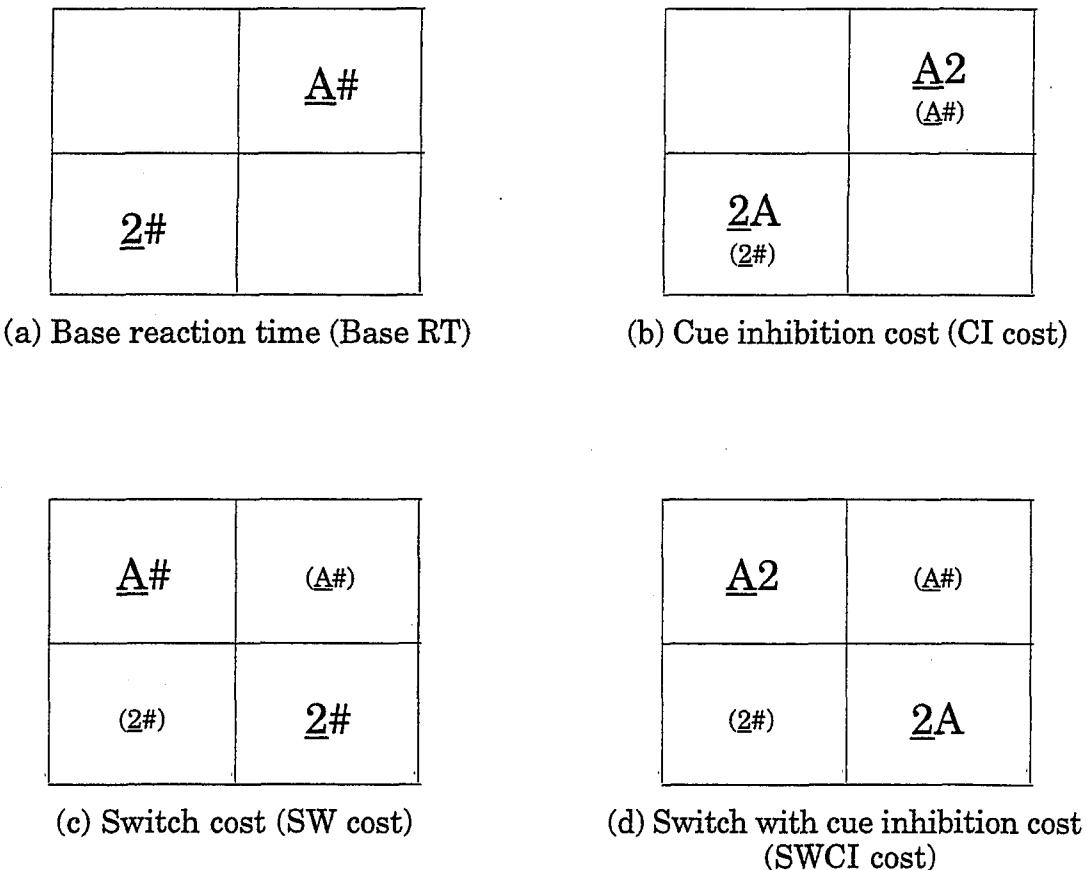
In addition, however, I computed four performance indices in order to assess task execution under varying on-line attention demands (see Figure 2 for a schematic representation): 1) task execution in the absence of any additional attentional demands, termed *base reaction time* (base RT) and operationally defined as mean RT on the repeat/neutral-foil trials; 2) task execution requiring inhibition of inappropriate task-set cuing from the competing foil, termed *cue inhibition cost* (CI Cost) and computed as the difference in mean RT on repeat/competing-foil versus repeat/neutral-foil trials;



(b)

letter task (SW)	letter task (R)
digit task (R)	digit task (SW)

Figure 1. (a) Illustrative sequence of trials and response mappings; (b) corresponding task-quadrant assignments and resultant alternation of switch (SW) and repeat (R) trials.



*Figure 2.* Schematic representation of the four computed performance indices used to assess on-line attention and task execution processes during performance of the switch task. Assume letter task assignment to top quadrants, digit task to bottom, as illustrated in Figure 1. Underlined characters represent targets, 'A' represents letter stimuli, '2' represents digit stimuli, and '#' represents neutral foils. Stimulus pairs in parentheses represent comparison trial types for the three cost computations. Each index is computed separately for letter and digit trials.

3) task execution requiring a switch of task set, termed *switch cost* (SW Cost) and computed as the difference in mean RT on switch/neutral-foil versus repeat/neutral-foil trials; and 4) task execution requiring both a switch of task set and inhibition of inappropriate task-set cuing, termed *switch with cue inhibition cost* (SWCI Cost) and computed as the difference in mean RT on switch/competing-foil versus repeat/neutral-foil trials. These computed indices allowed me to examine the effects of switching and cue inhibition, separately and in combination, against a common base reaction time (RT on repeat/neutral-foil trials). Thus, together with base RT, these measures offer four unique indices on which to assess the effects of differential letter and digit task incentive manipulations described below.

#### Motivational Manipulations

Motivational manipulations were modelled on those used by Derryberry and colleagues (Derryberry, 1993; Derryberry & Tucker, 1994). All motivational manipulations situate the participant in a computer game context where the object is to accrue as many points as possible. Participants are told they will gain points for fast and accurate responses (here termed *zaps*) and that the challenge level will increase across each block of the experiment. Task motivation is manipulated through the application of equal or differential point incentives for performance on letter and digit trials. When assigned equal incentives, participants earn four points per letter or digit zap; when assigned differential incentives, participants earn six points per letter zap and two points per digit zap, or vice-versa. Immediate auditory feedback following each zap is provided through a series of two, four or six beeps,

corresponding to the number of points earned on that trial. Summary feedback is given at the end of each block. Across Experiments 2, 4, and 5, task motivation is manipulated through the application of equal and/or differential incentives during training, during the switch task itself, or both. The incentive structures are summarized in Table 1 and are described in greater detail below.

Table 1

*Motivational incentive structure applied in Experiments 2, 4, and 5*

Experiment	Incentives	
	Training Phase	Switch Task Phase
<b>Experiment 2</b>		
Equal group (control)	equal	equal
Differential groups	differential	equal
<b>Experiment 4</b>		
	equal	differential
<b>Experiment 5</b>		
	differential	reverse differential

#### Overview of the Experiments

Experiment 1 is a replication of the Rogers and Monsell (1995) task switching paradigm that was used in all subsequent experiments. Experiments 2, 4, and 5 then combine this task switching paradigm with motivational

manipulations to investigate, respectively: a) the effect of *prior* motivational experience on attention and performance; b) the effect of *current* motivation on attention and performance; and c) the ability of current motivation to *overcome* the influence of prior motivational experience on attention and performance.

Experiment 3 was conducted to rule out a potential confound to the assessment of the motivational manipulations of Experiments 4 and 5.

#### Experiment 1: Partial Replication of Rogers and Monsell (1995, Experiment 1)

In Experiment 1, the Rogers and Monsell (1995) task switching paradigm was used without any motivational manipulations. Since the basic switch and cue inhibition effects of this paradigm underlie the attentional performance indices used in later experiments, it was important to verify their replicability before going on to examine the impact of motivational manipulations on these indices. It was also essential to verify that performance on letter- and digit-task trials was comparable and did not interact with either switching or cue inhibition effects. The absence of any initial task dominance permits, in later experiments, the contrast of letter and digit task performance as a function of motivational biases created through differential incentive structures.

#### Experiment 2: Effects of prior motivation

Experiment 2 investigated whether differential motivational experience can create an attentional bias in favour of the letter or digit task. To create high- and low-motivated task sets, participants were assigned differential incentives for letter and digit task zaps during the training phase of the

experiment. During the subsequent switch task, participants were assigned equal incentives for both letter and digit zaps. The influence of differential incentives was assessed on each of the four switch task performance indices described above. Since participants received equal incentives during the switch task itself, any motivational biases evidenced on the letter and digit performance indices could be attributed to their *prior* experience with differential incentives during training. For comparison, an additional group of participants received equal incentives throughout both training and switch task phases.

Experiment 3: Test of a potential confound to differential switch task incentives

Since Experiments 4 and 5 apply differential incentives during the switch task, it was essential to ensure that processing of the immediate auditory feedback from the preceding trial would not confound any obtained motivation effects. For example, if a participant were awarded six points per letter zap and two points per digit zap, digit switch trials that followed a letter zap would be preceded by six-beep feedback, whereas letter switch trials that followed a digit zap would be preceded by only two beeps. If processing of more feedback beeps from the preceding trial alone led to longer latencies on the current trial, it would be difficult to determine whether longer latencies on digit switch trials versus letter switch trials were due to the incentives manipulation itself, or simply to processing of feedback from the preceding trial. To verify that the number of feedback beeps in the absence of

motivational significance did not influence any of the performance indices of interest, participants in Experiment 3 consistently earned one point per letter or digit zap, regardless of the number of beeps that followed a zap. On half the trials of the switch task, letter zaps were followed by six beeps and digit zaps by two beeps, and on half the trials the reverse. Performance on basic switch and cue inhibition effects were then compared as a function of the number of beeps that preceded a given trial.

#### Experiment 4: Effects of current motivation

Whereas Experiment 2 concerned prior motivational experience, Experiment 4 explored the effects of *current* motivation on attention control. During training, participants received equal incentives for the letter and digit tasks followed by differential incentives during the switch task. In contrast to possible implicit motivational influences from prior experience, participants here might be expected to engage intentional incentive-based strategies during the switch task in order to maximise point earnings. The influence of differential incentives was again assessed on each of the four performance indices.

#### Experiment 5: Ability of current motivation to override prior motivational biases

Experiment 5, a more stringent test of the impact of current motivation, explored whether current motivation can actually *overcome* attentional biases developed through prior motivational experience. Participants received differential incentives for the letter and digit tasks during training (as in

Experiment 2) and *reverse* incentives during the switch task. For example, a participant receiving six points per letter zap and two points per digit zap during training, would receive two points per letter zap and six points per digit zap during the switch task. If current motivations are able to override prior motivational experience, reversing the motivation manipulation for the switch task should reverse the effects found in Experiment 2.

#### Participant Selection and Inclusion/Exclusion Criteria

For all experiments, participants were recruited from the Concordia University student population and were volunteers paid at a rate of \$6.00 per hour. All participants were required to have a language with an alphabetic script similar to English as their mother tongue, have vision corrected to normal, and no diagnosed reading, attentional, visual, or motoric impairments. None of the participants were involved in more than one of the present experiments and none had previously participated in any other attention switching studies in our laboratory.

Pilot testing for Experiment 2 revealed that the inclusion of performance incentives led to an increase in errors since point earnings depended upon speed of response as well as accuracy. Moreover, pilot participants with high error rates tended to exhibit attention and motivation effects in their pattern of errors, but not their reaction time data. This suggested that, when faced with performance challenges, these individuals rushed their responses at the risk of committing an error. Their response latencies, therefore, could not be assumed to reflect changes in performance demands and were deemed unsuitable for

inclusion. Consequently, for Experiments 2, 4, and 5, participants were excluded if they made more than 20 errors within any counterbalanced 4-block sequence of 192 trials (i.e., a maximum error rate of 10.4%).

#### General Analytic Procedures

All analyses were conducted on reaction time (RT) data only. Due to the requirement to maintain high accuracy during performance, too few errors were committed to permit meaningful analyses on the error data. Along with minor experiment-specific adjustments, analyses in all experiments (except Experiment 3) were conducted according to the common strategies and procedures described here.

Alpha was set at .05 for all statistical tests. Analyses involving within-subjects factors with more than two levels were corrected for positive bias if the sphericity assumption was violated. In such cases, the Greenhouse-Geisser Epsilon value is reported, along with the adjusted  $p$  value. Significant interactions were explored through simple effects analyses, with alpha adjusted for the number of levels across which simple effects were conducted.

#### Data Preparation

Data from practice blocks, warm-up trials, and trials on which participants committed errors were excluded. Following Rogers and Monsell (1995), trials immediately following an error were also excluded since their RTs may be affected by: 1) the extended response-stimulus interval that is provided following an error to allow the participant to recover; and 2) potential interference during this interval of normal preparation for the next trial by the

error recovery process. From a motivational perspective, removal of these trials also avoided any contamination due to possible differential facilitation of performance on high-incentive versus low-incentive trials following negative feedback, as obtained in Derryberry (1993).

Each participant's data was then winsorized (Wilcox, 1997) to stabilize participant RT means and reduce distortion from outliers. Since outliers were of concern only at the upper end of the RT distributions, winsorizing was applied only to the top 10% of each critical design cell. This consisted of rank ordering the data within each cell and replacing the top 10% of the data points of each cell with the next highest data value. If, for example, the cell contained 30 data points, the top three values would be replaced with the fourth highest value, thereby reducing the influence of extreme outliers. Winsorizing at 10% was considered sufficient to capture extreme outliers without replacing too large a proportion of the data. After winsorizing, data were aggregated by the relevant variables to obtain participant RT cell means for the subsequent group analyses.

#### Analysis of Basic Attention Effects

Before going on to explore the influence of motivation on attention, it was important to establish in each of the experiments that the basic switch and cue inhibition effects of this paradigm obtained. Switch task data were, therefore, first subjected to a within-subjects analysis of variance (ANOVA) examining the effects of trial type (switch, repeat) and foil (neutral, competing).

### Analysis of Motivation Effects

In Experiments 2, 4, and 5, the effects of motivation on basic task execution, attention switching and inhibition of task-set cuing by the competing foil were assessed in a series of planned comparisons. First, RT data from the training phase were analysed for the immediate influence, if any, of motivational manipulations on basic task execution. Latencies on the letter task and digit task trials were compared as a function of the high, low, or equal incentives applied to each task during training.

Next, and most central to this thesis, four planned comparisons were conducted to examine the influence of motivational manipulations on performance during the switch task. The four performance indices described above (base RT, CI Cost, SW Cost, and SWCI Cost) were first computed for each participant, for the letter and digit tasks separately. In four parallel analyses, performance on these indices was then assessed as a function of the incentive value associated with the letter and digit tasks.

## EXPERIMENT 1

Experiment 1 was conducted to verify the reliability of the attention switching paradigm later employed in conjunction with motivational incentive manipulations. I thus sought to replicate the basic findings from the crosstalk condition of Experiment 1 of Rogers and Monsell (1995) and establish a foundation for subsequent experiments of this thesis.

Of particular interest was replicability of their switch effect and task-set cuing effect (referred to here as *cue inhibition* effect). That is, participants should be slower to respond on trials that require a switch of attention from the letter to the digit task, or vice versa, than on trials that require the same task set as the previous trial. They should also evidence longer latencies on trials where the target is paired with a competing, rather than a neutral, foil. These two effects presumably reflect additional attention challenges present when an individual must perform an intentional switch of attention or selectively respond to one dimension of a bivalent stimulus while inhibiting task-set cuing from the competing dimension.

It was also important to verify that the letter and digit judgment tasks were roughly comparable in difficulty in order to attribute, with greater confidence, differences in performance in later studies to the differential incentives then applied to these tasks. I therefore sought to replicate -- in addition to the switch and cue inhibition effects mentioned above -- both the absence of a main effect of task (letter, digit) and the absence of any interaction effects involving task.

Finally, it should be noted that Experiment 1 constituted part of a larger study (see Segalowitz et al., 1999) conducted both as a replication and extension Rogers and Monsell's Experiment 1 (1995), and as a precursor to another programme of research in the Segalowitz laboratory. In the methods section below, I describe the complete design of this larger study since components pertinent to my thesis were intermixed with the full study. However, only the data and analyses of the crosstalk condition undertaken for this thesis are subsequently reported and discussed.

### Method

#### Participants

Eight paid volunteers (3 male, 5 female), aged 17 to 23 years ( $M = 20.5$  years) participated.

#### Materials

Stimuli consisted of target-foil pairs presented on a computer monitor. Targets were either letters or digits. Letters were drawn equally from the set {A, E, I, U, G, K, M, R} and digits from the set {2, 4, 6, 8, 3, 5, 7, 9}. Targets were paired with either a neutral foil or a competing foil. Neutral foils were nonalphanumeric symbols associated with neither the letter nor the digit task, and were drawn equally from the set {%, #, ?, \*}. Competing foils were characters drawn equally from the competing target set (i.e., a letter target paired with a digit foil, or a digit target paired with a letter foil). Stimuli were presented in uppercase 24-point Palatino font on a 14-inch computer monitor

set to 640 x 480 pixel resolution. For reasons unrelated to this thesis, the target and foil characters were presented as a vertically adjacent pair, rather than horizontally adjacent as in Rogers and Monsell (1995). Stimulus presentation and data collection was programmed in HyperCard, Version 2.3, software and run on a Macintosh Quadra 630 computer. Using a number key pad with the 4 key relabelled as a left arrow and the 6 key relabelled as a right arrow, participants categorized a letter target as a vowel or consonant (letter task), and a digit target as even or odd (digit task) by pressing the left arrow with their left index finger or the right arrow with their right index finger.

Training stimuli. Eight blocks of 24 letter trials and eight blocks of 24 digit trials were constructed, for a total of 192 training trials per letter and digit task. For training, targets were always paired with a neutral foil. Stimulus trials were counterbalanced across the training blocks such that each target occurred equally often with each foil and in each position (top, bottom). Target-foil pairs were sequenced in pseudo-random order, with the restriction that no target or foil be repeated on two successive trials.

Switch task stimuli. Four practice and 16 experimental blocks of 48 trials were created for the crosstalk and for the no-crosstalk conditions. For the crosstalk condition, targets were paired with a neutral foil on one third of the trials and with a competing foil on two thirds of the trials. On half of these competing-foil trials the foil was associated with a response that was *congruent* with the required target response (i.e., both the target and foil were associated with the same left or right button response), and on half the foil was associated with a response that was *incongruent* with the required target response (i.e.,

the target was associated with a left, and the foil with a right, button response, or vice versa). For the no-crosstalk condition, targets were always paired with a neutral foil.

Trials were sequenced throughout such that two consecutive letter-task trials alternated with two consecutive digit-task trials. This resulted in a regular alternation of *repeat* trials, on which participants performed the same task as on the previous trial, and *switch* trials, on which participants switched attentional focus from the letter to the digit task, or vice versa. The first 12 trials of each experimental block were considered warm-up trials and, along with the practice block trials, were excluded from all analyses. This left 36 experimental trials per block for a total of 576 experimental trials per condition.

Experimental trials were counterbalanced across each 4-block sequence of 144 experimental trials. In the crosstalk condition, there was one experimental trial for each combination of the following variables: task (letter or digit), trial type (switch or repeat), response (left or right), foil type (neutral, congruent, incongruent), response on the preceding trial (left or right), and foil type on the preceding trial (neutral, congruent, incongruent). In the no-crosstalk condition, there were nine experimental trials for each combination of the following variables: task (letter or digit), trial type (switch, repeat), response (left or right), and response on the preceding trial (left or right). Targets appeared randomly in the top or bottom positions (half the time in each). Finally, trials were sequenced such that there were never more than four successive left or right button press responses required. From the

resultant crosstalk and no-crosstalk counterbalanced trial sequence templates, unique stimulus sequences for the four practice and 16 experimental blocks per condition were created for each participant through pseudo-random sampling from the target and foil exemplar sets, with the restriction that each target and foil occur an equal number of times and no target or foil be repeated on two successive trials.

#### Procedure

All participants completed a standard consent form describing the general purpose and procedures of the experiment and detailing participant confidentiality and rights. Instructions were given in writing prior to each phase of the experiment, with oral clarifications provided upon request (see Appendix A for written instructions).

Throughout the experiment, participants sat at a comfortable viewing distance, approximately 60 centimetres, from the computer monitor. Each block of trials began with the message “Press any key to begin.” Approximately 450 ms later, the first stimulus pair appeared. Participants categorized a letter target as a vowel or consonant, and a digit target as even or odd. For half the participants, consonants and even digits required a left button press response, and vowels and odd digits required a right button press response. The digit response assignments were reversed for the remaining participants, with even digits requiring a right, and odd digits requiring a left, button response.

Stimuli remained on screen until the participant responded or until a deadline of 5000 ms. The interval between the participant's response and presentation of the next stimulus (the response stimulus interval, RSI) was approximately 450 ms, including computing overhead time. If the response was incorrect, a computer-generated "boing" sound was played and an extra 1500 ms were added to the RSI to allow the participant time to recover from the error. At the end of each block of trials, participants received summary feedback consisting of their mean reaction time and the total number of errors for that block. Participants were instructed to respond as quickly as possible without sacrificing accuracy.

Training. To learn the appropriate stimulus-response mappings, participants completed eight letter-task blocks in alternation with eight digit-task blocks. Target-foil stimulus pairs were presented in an 8 cm by 4.5 cm rectangle in the centre of the monitor. Throughout training, instructions for left and right button press assignments appeared as a reminder at the bottom of the screen.

Switch Task. Participants completed four practice blocks and four 4-block experimental sequences in both the crosstalk and no-crosstalk conditions of the switch task. Each target-foil stimulus pair was presented in one of four 8 cm by 4.5 cm quadrants on the monitor. The quadrant position cued participants to perform either the letter or digit task. The two quadrants (always contiguous) assigned to the letter and digit tasks were counterbalanced across participants to control for possible eye movement and position confounds. This resulted in four possible quadrant task assignments:

1) letter task in the top quadrants; digit task in the bottom; 2) letter task in the right quadrants, digit task in the left; 3) letter task in the bottom quadrants, digit task in the top; and 4) letter task in the left quadrants, digit task in the right. The four quadrant task assignments were crossed with the two button press response assignments across participants, resulting in a counterbalanced set of eight unique participant assignments. Stimulus blocks always began with two letter-task trials and proceeded in clockwise rotation. Left and right button press assignments appeared as a reminder at the bottom of the screen during practice blocks, but were removed for all experimental blocks.

Testing was conducted over two sessions on separate days. Following training in Session 1, participants completed two practice blocks followed by two 4-block sequences of the crosstalk condition and two practice blocks followed by two 4-block sequences of the no-crosstalk condition. Half the participants began with the crosstalk condition and half with the no-crosstalk condition. In Session 2, participants completed an additional two practice blocks followed by two 4-block sequences per condition, with the order of conditions reversed from that of Session 1 (i.e., participants beginning with the crosstalk blocks in Session 1 would begin with the no-crosstalk blocks in Session 2, and vice versa). Each session lasted approximately one hour.

### Results

The data presented below concern only the crosstalk condition of the switch task. As mentioned earlier, data for the no-crosstalk condition was

collected for purposes outside the scope of this thesis and will not be reported here (see Segalowitz et al., 1999).

Among the experimental trials, those trials on which participants made an error ( $M = 4.0\%$ ) and trials immediately following error trials were also excluded, resulting in a mean loss of 44 of the 576 experimental trials per participant (7.6%). Individual participant data were then winsorized at the top 10% of each cell of the following combination of variables: sequence (1, 2, 3, 4), trial type (switch, repeat), foil (neutral, congruent, incongruent), and task (letter, digit). While data were subsequently aggregated by session (thereby collapsing across sequences 1 and 2, and 3 and 4), they were winsorized by sequence in order to ensure that potential practice effects would not lead to the inappropriate adjustment of outliers. Finally, the data were aggregated to obtain the mean RTs per participant for each cell defined by the following combination of variables: Session x Trial Type x Foil x Task.

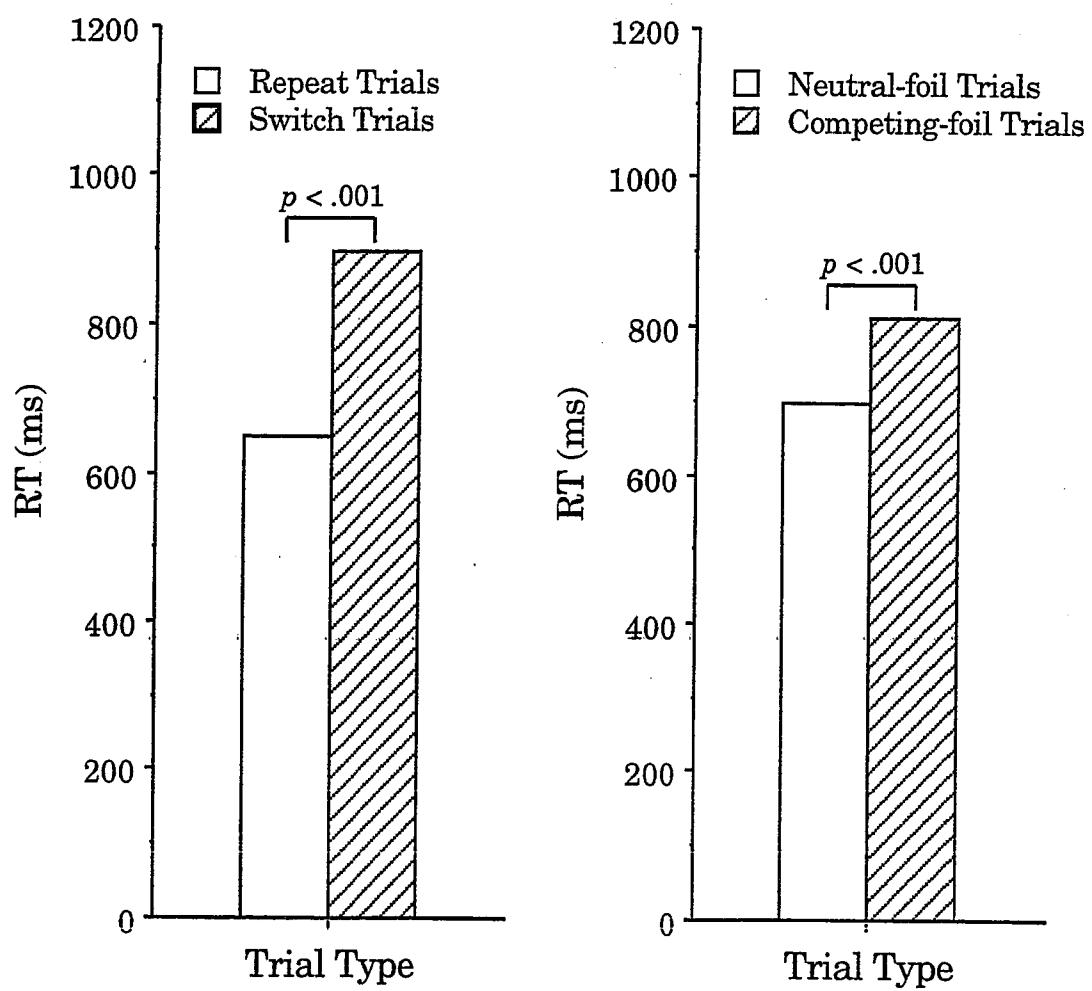
The individual participant aggregated means were entered into a within-subjects analysis of variance (ANOVA) with the following factors: session (Session 1, Session 2), trial type (switch, repeat), foil (neutral, congruent, incongruent), and task (letter, digit). Importantly, results revealed that both trial type and foil significantly affected RT, and no differences in performance between the letter and digit tasks obtained. Group mean RTs, and switch and cue inhibition costs for both tasks and sessions are presented in Appendix B, Table B1. As in the original Rogers and Monsell (1995) study, switch cost was computed by subtracting RT on repeat trials from RT on switch trials, collapsed across foil type. Similarly, cue inhibition cost was computed by

subtracting RT on neutral-foil trials from RT on competing-foil trials, collapsed across trial type.

Participants were slower to respond on switch trials ( $M = 898$  ms) than repeat trials ( $M = 647$  ms),  $F(1, 7) = 40.80, p < .0005, MSE = 74,504$ . This switch effect is illustrated on the left side of Figure 3. The difference between mean RT for switch trials and repeat trials yielded a switch cost of 251 ms. Trial type also interacted with session,  $F(1, 7) = 24.58, p = .002, MSE = 10,036$ , due to a smaller switch cost for Session 2 ( $M = 179$  ms) than Session 1 ( $M = 323$  ms). Despite this reduction, simple effects analysis indicated that the switch effect was still significant for Session 2,  $F(1, 7) = 37.36, p < .0005, MSE = 20,802$ .

The nature of the foil also significantly affected performance,  $F(2, 14) = 36.66, p < .0005, MSE = 8,051$ . This cue inhibition effect is illustrated on the right side of Figure 3. Two posthoc comparisons were conducted using  $t$ -tests and Bonferroni-adjusted alpha levels. Participants responded significantly more quickly to targets paired with a neutral foil ( $M = 695$  ms) than to targets paired with a foil from the competing task set ( $M = 811$  ms),  $t(7) = 7.13, p < .0005$ . Latencies on congruent ( $M = 821$  ms) and incongruent ( $M = 801$  ms) competing-foil trials did not differ significantly from each other,  $t(7) = 1.61, ns$ . The difference between mean RT on neutral-foil and competing-foil trials yielded a cue inhibition cost of 116 ms.

Finally, trial type did not interact with foil,  $F(2, 14) = .85, p = .448, MSE = 2,560$ . In addition, there was no main effect of task; nor did it enter into any interactions with other variables, all  $F$ s  $< 1$ .



*Figure 3.* Mean RT (ms) by trial type. The contrast on the left depicts the switch effect; the contrast on the right depicts the cue inhibition effect.

### Discussion

Experiment 1 successfully replicated the basic results of Rogers and Monsell's (1995) task switching paradigm. Of paramount importance was replication of the switch and cue inhibition main effects since subsequent experiments of this thesis will assess the influence of motivational manipulations on attention processing using performance indices based on these effects.

Both significant switch and cue inhibition effects obtained. Participants were significantly slower to respond on trials that required a switch of attention between task sets. The size of the switch cost, 251 ms (39% increase), was comparable to Rogers and Monsell's mean switch cost of 289 ms (40% increase). Since switch cost has been found to decrease with increasing RSI, the slightly smaller cost in this experiment was to be expected, since here the RSI was 450 ms as compared to a 150 ms RSI in Rogers and Monsell. Overall, the consistency in the switch effect between experiments suggests that this effect is large, robust, and highly reliable.

Participants were also slower to respond on trials where a competing, rather than neutral, foil was present. While Rogers and Monsell do not specify the magnitude of their cue inhibition cost, it can be estimated from the values graphed in their Figure 2 (Rogers & Monsell, 1995, p. 215) to be approximately 175 ms (23% increase). The cue inhibition effect of 116 ms found in this replication is somewhat smaller but still substantial, representing a RT increase of 17% over neutral-foil trials. This small reduction in cue inhibition cost may be due to participant sampling differences or to the fact that target-

foil pairs were presented vertically, rather than horizontally adjacent as in Rogers and Monsell, making them perceptually more separable and the competing foil easier to ignore. This latter factor may also have contributed to the absence of a Trial Type x Foil interaction in the present experiment.

Lastly, as in Rogers and Monsell, the congruency of response between the competing foil and target had no effect on reaction time; that is, RT on congruent trials did not differ significantly from RT on incongruent trials. This provides further support for Rogers and Monsell's argument that the increase on competing-foil trials is due primarily to inappropriate task-set cuing that must be inhibited, and not to crosstalk at the level of response selection.

A third concern was replication of the *absence* of any reliable differences in performance between the letter and digit judgment tasks. As in Rogers and Monsell (1995), no effects of task obtained, either globally or in interaction with trial or foil type. This provides further evidence of the initial comparability of the letter and digit tasks and their suitability for use in subsequent experiments to assess experimentally-manipulated motivational biases.

To conclude, this replication of the Rogers and Monsell (1995) paradigm provided a solid foundation for Experiments 2 through 5 of this thesis. Both the switch and cue inhibition effects obtained and, importantly, no differences between performance on the letter and digit tasks were found.

## EXPERIMENT 2

Following replication of the basic effects of the attention switching paradigm in Experiment 1, the purpose of Experiment 2 was to explore the impact of prior motivational experience on these on-line attention processes during performance of the switch task. The motivational significance of letter and digit task trials was manipulated through experience with either differential or equal incentives during the training phase. The application of differential incentives for the letter and digit tasks was counterbalanced across participants, with a letter-motivated (LM) group receiving six points per letter zap (a fast, correct response as operationally defined below) and two points per digit zap, and a digit-motivated (DM) group, the reverse. An equally-motivated (EM) group received four points per either letter or digit zap. During the switch task phase, all groups received equal four-point incentives for both letter and digit zaps. Consequently, any biases in letter and digit task performance by the differentially motivated participants during the switch task could be attributed to *prior* experience with training incentives. Letter and digit task performance was compared on each of the four switch task performance indices as described in *Paradigm and Overview of the Experiments*: base task execution (base RT), switch cost (SW cost), cue inhibition cost (CI cost) and switch with cue inhibition cost (SWCI cost).

I hypothesized that prior experience with differential incentives would create an enduring bias favouring the previously high-incentive task. Moreover, I predicted that this influence would extend beyond a global

energizing of performance, to actually modulate on-going cognitive processes engaged during performance. This experiment set out to explore the specificity of such influences. Because the Rogers and Monsell (1995) task switching paradigm affords assessment of basic task execution, attention switching and inhibition demands within a single task, it is particularly well suited for examining the nature of motivational effects on different forms of on-line attention control and execution processes.

Effects specific to attention processes would be revealed in differences on the CI, SW, and SWCI cost measures. Based on the view that motivation may serve to bias individuals to attend and respond to stimuli of perceived high value (e.g., Simon, 1994; Wise, 1987), I predicted that it would be easier to switch from a low-motivated task to a high-motivated task than vice versa, and easier to ignore a competing foil from the low-motivated than high-motivated task. For example, a LM participant would find it easier to switch from a digit trial to a letter trial, than vice versa, and harder to ignore a letter foil on a digit trial than a digit foil on a letter trial. An analogous, but of course reverse, pattern would be expected for a DM participant. Consequently, I predicted both a smaller SW cost and a smaller CI cost for the previously high-incentive than low-incentive task. This also led to the prediction of a smaller SWCI cost for the previously high-incentive than low-incentive task. The most recent work on asymmetric switch costs since conducted by Allport and colleagues (e.g., Allport & Wylie, 1999; Allport & Wylie, in press; Wylie & Allport, 1999) offers an interesting alternative prediction. If prior experience with differential task incentives affects schema activation levels analogously

to differential amounts of practice, one might expect to obtain *larger* SW costs for the high-motivated than low-motivated tasks -- the paradoxical asymmetry found in the Allport and colleagues studies.

While effects of motivation on attention processes were the major focus of this research, differential motivational experience may also directly affect the strength of stimulus-response set bonds, or what Norman and Shallice (1986) refer to as schemas. If motivation does have such an effect, it would be evidenced by faster responses on repeat/neutral foil trials of the previously high-incentive, as compared to the low-incentive, task. That is, a smaller base RT would be expected for the previously high-incentive task.

Finally, in contrast to the differentially-motivated participants, I predicted that no difference would obtain between the letter and digit tasks on any of the performance indices for the equally-motivated participants. This is consistent with the results of Experiment 1, which showed no general bias toward letter or digit task performance.

### Method

#### Participants

Participants were randomly assigned to each of the three motivation group conditions (LM, DM, and EM) until the eight positions (counterbalanced for task quadrant and left/right response mapping assignments as in Experiment 1) required for each group were filled. In order to meet counterbalancing and inclusion criteria (see *Paradigm and Overview of the Experiments*), a total of 44 participants were tested. Seventeen were

eliminated for exceeding the maximum error criterion and two for disruptions during testing. One participant was eliminated because his overall performance cast doubt as to whether the instructions had been understood.

A final set of 24 paid volunteers, all female and aged from 19 to 32 years ( $M = 23.2$  years), were retained for analyses.

### Materials

Visual stimuli were identical to the training and crosstalk condition of Experiment 1, except that the target-stimulus pairs were presented horizontally adjacent as in Rogers & Monsell's (1995) original study.

Immediate auditory feedback for earned points consisted of a series of beeps generated by the computer using the Hypercard 2.3 "play" feature with its built-in harpsichord sound generator. This and all subsequent experiments were run on a Power Macintosh 4400 computer and presented on a 15-inch rather than 14-inch monitor, again set to 640 x 480 pixel resolution. Written instructions were modified to include specification of the task incentives (see Appendix C for a sample set of instructions).

### Procedure

General experimental set up, procedures for administration of the consent form and instructions, participant counterbalancing, and stimulus presentation and response parameters were identical to Experiment 1. The major procedural changes involved the elimination of the no-crosstalk condition and the inclusion of motivational incentives and feedback as described below.

All participants were instructed that they were to play a computer game involving simple letter and digit judgments where the object was to win as many points as possible by responding quickly and accurately. They were further informed that it was a difficult task and that the challenge level would be adjusted at the end of each block. The speed criterion was defined operationally as an RT faster than the 75th percentile RT of comparable trials of the previous block (this operational definition was not communicated to the participant). Thus, participants earned points for every correct response faster than the criterion RT. These responses were referred to as *zaps*.

To ensure that the probability of receiving a reward remained constant across the different trial types, the criterion was calculated separately for letter and digit task trials during training, and for trials in each of the four quadrants during the switch task (letter switch and repeat trials, and digit switch and repeat trials). Had this not been done -- for example, had switch and repeat trials been assigned the same criterion -- participants would have been rewarded more frequently on repeat than switch trials, since switch-trial RTs are generally longer than repeat-trial RTs. Similarly, if motivation were to affect switch costs as hypothesized, participants would have been rewarded more frequently on trials associated with the high-valued task than on trials associated with the low-valued task. By using separate criteria, however, the incentive value manipulation was not confounded with frequency of reward.

During training, the letter-motivated (LM) group received six points per letter trial zap as compared to two points per digit trial zap; the digit-motivated (DM) group received six points per digit trial zap as compared to two points per

letter trial zap; and the equally-motivated (EM) group received four points per letter or digit trial zap. During the switch task, all groups received equal, four-point rewards for both letter and digit trial zaps. Thus, the differential incentives for the LM and DM groups were applied only during the training task. Participants were informed of the point value of zaps in written instructions prior to both training and the switch task, and were reminded on-screen of the point value of letter and digit zaps at the beginning of each block of trials. To encourage participants to treat both training and the switch task as equally important in terms of point earnings and performance, training was always referred to as Part 1, and the switch task as Part 2, of the experiment when interacting with participants.

For all groups, the 75th percentile RT criteria corresponded to an expected earning of 144 points per block, given a comparable level of performance as the previous block (i.e., 36 zaps per 48-trial block at an average of 4 points per zap). However, to maintain motivation and minimize commission of errors through rushed responses, participants were told that a good player typically scores from 100 to 120 points per block. Participants were asked to make as few errors as possible and were given a 10-point bonus if they made fewer than five errors per block.

Participants received both immediate auditory feedback and end-of-block summary feedback. Following each zap, a series of computer-generated beeps sounded, the number of beeps corresponding to the number of points earned on that trial (2, 4, or 6). If the response was correct, but too slow to earn points, no beeps were played. As in Experiment 1, if a participant

responded incorrectly, an alerting 'boing' was sounded and 1500 ms were added to the RSI to facilitate recovery before onset of the next trial. At the end of each block, on-screen performance feedback indicated the total number of zaps and corresponding points earned for each the 24 letter and 24 digit trials, the number of errors made and whether a bonus was earned, and the total score for that block. In addition, qualitative descriptors were placed next to the total score as follows: fewer than 80 points, "DON'T GIVE UP!"; 80-99 points, "NOT BAD!"; 100-119 points, "GOOD!"; 120-129 points, "GREAT!"; 130-139 points, "SUPER!"; 140-149 points, "EXCEPTIONAL!"; more than 150 points, "UNBELIEVABLE!!!". To allow participants to track their progress and to ensure that they fully processed the feedback, participants recorded their feedback at the end of each block on a "Performance Record" chart and handed it in at the end of the experiment.

Testing lasted approximately 90 minutes, and was divided into two sessions separated by an obligatory 10-minute break. Following training in Session 1, participants completed the first half of the switch task. They returned after the break for Session 2, during which time they completed the second half of the switch task, responded to two brief questionnaires on their experience, and were debriefed. (The questionnaire data were collected for purposes beyond the purview of this thesis and will not be presented here.)

Training. The training phase served both to train participants on the appropriate stimulus-response mappings and to expose participants to either differential (LM and DM groups) or equal (EM group) motivational experience with the letter and digit tasks. As in Experiment 1, participants completed

eight blocks of 24 letter-task trials and eight blocks of 24 digit-task trials. However, in Experiment 2 these blocks were combined into eight double blocks of 48 trials consisting of 24 letter-task trials followed by 24 digit-task trials, or vice-versa. An on-screen message informing the participant of the upcoming task and the point value per zap preceded each sequence of 24 trials. The task for the first 24 trials of each block was counterbalanced across participants and alternated for each participant across the eight double blocks.

Participants were told that the first of these 48-trial blocks was for practice only and, therefore, no points were awarded and only immediate error feedback was given. Letter and digit task performance on this practice block was then used to establish the RT criteria for earning points during the first of the game blocks. Immediate and summary reward feedback was provided for the seven remaining 48-trial blocks as described above, with RT criteria recalculated after each successive block.

Switch Task. The switch task consisted of the four practice blocks (here divided into two double blocks of 96 trials each) and 16 experimental blocks of the crosstalk condition only of Experiment 1. Quadrant task assignments were counterbalanced across participants as before. Throughout the switch task phase of the experiment, letter and digit zaps were of equal, 4-point value for all motivation groups (LM, DM, and EM).

During Session 1 of the switch task, participants completed one double practice block, during which no points were awarded and only immediate error feedback was provided, followed by eight experimental blocks (two counterbalanced four-block sequences). Performance on the last 48 trials of

the practice block were used to set the RT criteria for earning points on the first experimental block, after which the RT criteria were reset after each successive block. In Session 2 after the 10-minute break, participants again warmed up with a double practice block, followed by the final eight experimental blocks. The RT criteria for the first of these eight experimental blocks was again based on the final 48 trials of the preceding practice block, after which the RT criteria were reset after each successive block.

### Results

Among the experimental trials of the switch task data, 11.2% of the differentially-motivated subjects' data were lost through elimination of trials on which errors were committed ( $M = 5.8\%$ ) and trials immediately following errors; similarly, 9.5% of the equally-motivated group trials were lost through elimination of trials on which errors were committed ( $M = 4.9\%$ ) and trials immediately following errors. The remaining data for each participant were winsorized at the upper 10% of each data cell of the following combination of variables: sequence (1, 2, 3, 4), trial type (switch, repeat), foil (neutral, competing), and task (letter, digit). The RT data were then aggregated to obtain mean RTs per participant according to the following break variables: session (1, 2), trial type, foil, and task. Since the congruency of the competing foil had no effect on RT in either Experiment 1 of this thesis or in Rogers & Monsell's (1995) original experiment, in analyses of this and all remaining experiments I collapsed congruent and incongruent foil trials into a single cell. Thus, the foil variable now had just two levels: neutral and competing. Lastly, the LM and

DM group means were combined into a single data file by recoding the letter and digit tasks as high-motivated or low-motivated tasks. For example, the letter task was recoded as the high-motivated task for the LM participants and as the low-motivated task for the DM participants. Note that, in this experiment, task motivation is defined throughout both the training and switch task data analyses as a function of the differential incentives applied during the *training* phase since it the effect of this prior motivational experience on switch task performance that is of interest.

The training data were also prepared prior to analysis. After first excluding practice block trials, 10.7% of training data of the differentially-motivated subjects was eliminated due to errors ( $M = 5.5\%$ ) and removal of trials immediately following errors; similarly, 12.6% of training data of the equally-motivated participants was eliminated due to errors ( $M = 6.5\%$ ) and removal of trials immediately following errors. The remaining training data of each participant were winsorized at the upper 10% of each the letter and digit trial data cells and then aggregated by task (letter, digit). Again, the LM and DM group means were combined into a single data file by recoding the letter and digit tasks as high-motivated and low-motivated tasks.

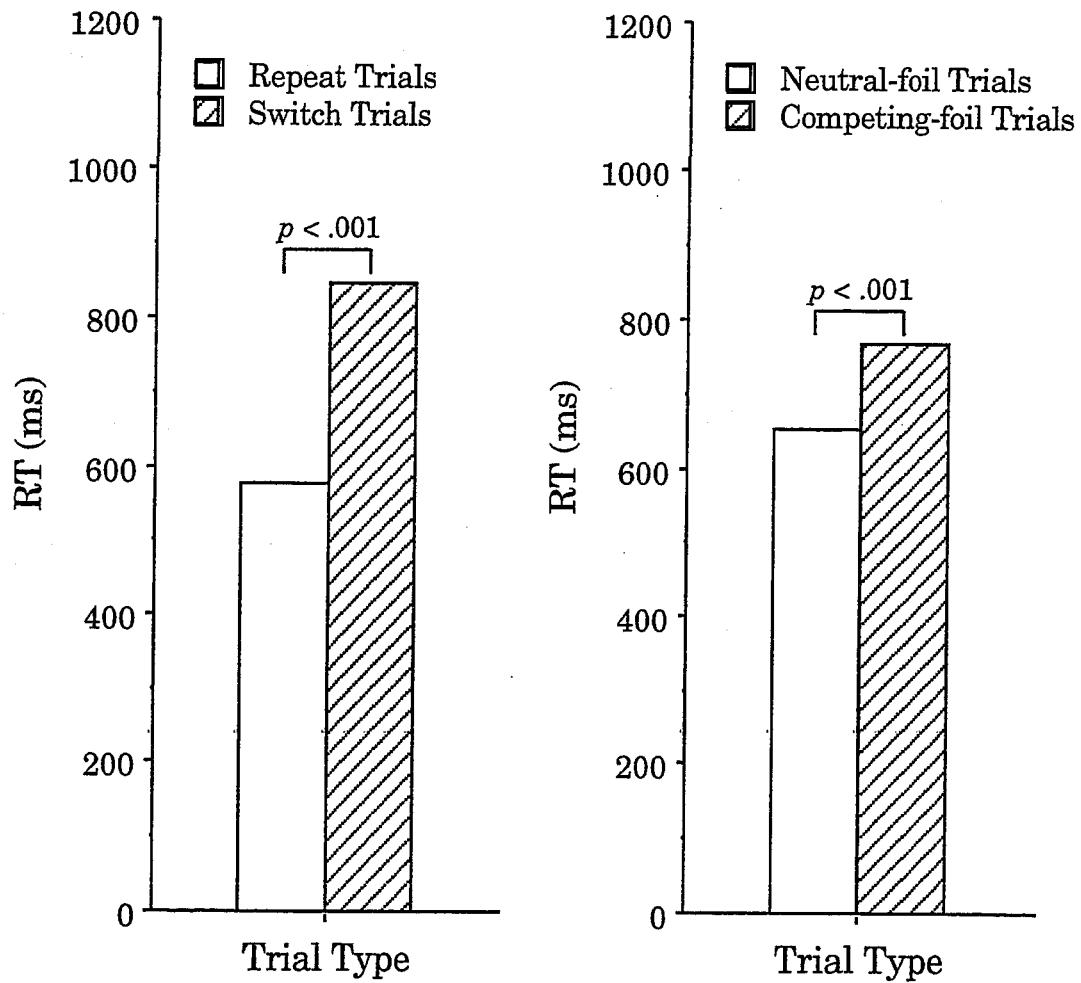
Separate, but parallel, analyses of the basic attention and motivation effects were conducted for the differentially-motivated participants (LM and DM groups) and the equally-motivated participants (EM group).

### Basic Attention Effects (LM & DM Groups)

To test for the presence of the basic switch and cue inhibition effects for the differentially-motivated participants, a mixed-design ANOVA was performed on the LM and DM groups' switch task data with three within-subjects variables of session (Session 1, Session 2), trial type (switch, repeat), and foil (neutral, competing), and one between-subjects variable of group (LM, DM). Results revealed that both switch and cue inhibition effects obtained.

First, there was a significant main effect of trial type. Participants were slower to respond on switch ( $M = 846$  ms) than repeat trials ( $M = 575$  ms),  $F(1, 14) = 38.15, p < .0005, MSE = 61,602$ , yielding a global switch cost of 271 ms. This switch effect is shown on the left side of Figure 4. As in Experiment 1, however, trial type interacted with session,  $F(1, 14) = 17.03, p = .001, MSE = 5,802$ , due to a smaller switch cost for Session 2 ( $M = 215$  ms) than Session 1 ( $M = 323$  ms). Nevertheless, the simple main effect of trial type was still significant for Session 2 despite this reduction,  $F(1, 14) = 29.93, p = .001, MSE = 24,805$ .

Second, there was a significant main effect of foil,  $F(1, 14) = 69.71, p < .0005, MSE = 5,774$ . Participants responded more slowly on competing-foil trials ( $M = 766$  ms) than neutral-foil trials ( $M = 654$  ms), yielding a global cue inhibition cost of 112 ms. This cue inhibition effect is shown on the right side of Figure 4. While this effect did not interact with session,  $F(1, 14) = .11, p = .747, MSE = 1,679$ , there was a three-way interaction involving foil, session, and the between-subjects factor of group,  $F(1, 14) = 4.98, p = .042; MSE = 1,679$ , due to a small decrease in cue inhibition cost from Session 1 ( $M$  cost = 138 ms) to



*Figure 4.* Mean RT (ms) by trial type for the differentially motivated participants in Experiment 2. Switch and cue inhibition effects are depicted on the left and right, respectively.

Session 2 ( $M$  cost = 110 ms) for the DM group, coupled with a small *increase* in cue inhibition cost from Session 1 ( $M$  cost = 82 ms) to Session 2 ( $M$  cost = 119 ms) for the LM group. Simple interaction analyses revealed, however, that the Session x Foil interaction was not significant for either the DM group,  $F(1, 14) = 1.81, p = .200, MSE = 1,679$ , or the LM group,  $F(1, 14) = 3.28, p = .092, MSE = 1,679$ .

Finally, there was an interaction between trial type and foil,  $F(1, 14) = 6.23, p = .026, MSE = 3,144$ . Switch cost was greater on competing-foil trials ( $M = 296$  ms) than neutral-foil trials ( $M = 246$  ms). Simple effects, however, revealed that the effect of trial type was still significant for neutral foil trials,  $F(1, 14) = 29.86, p = .001, MSE = 32,492$ . Similarly, cue inhibition cost was greater for switch trials ( $M = 137$  ms) than repeat trials ( $M = 87$  ms), but again, the simple effect for foil was still found to be significant for repeat trials,  $F(1, 14) = 45.45, p = .001, MSE = 2,689$ .

#### Basic Attention Effects (EM Group)

To test for the presence of the basic switch and cue inhibition effects for the equally-motivated participants, a within-subjects ANOVA was performed on the EM group's switch task data with the following variables: session (Session 1, Session 2), trial type (switch, repeat), and foil (neutral, competing). As in the differentially-motivated subjects' analysis, both significant switch and cue inhibition effects obtained.

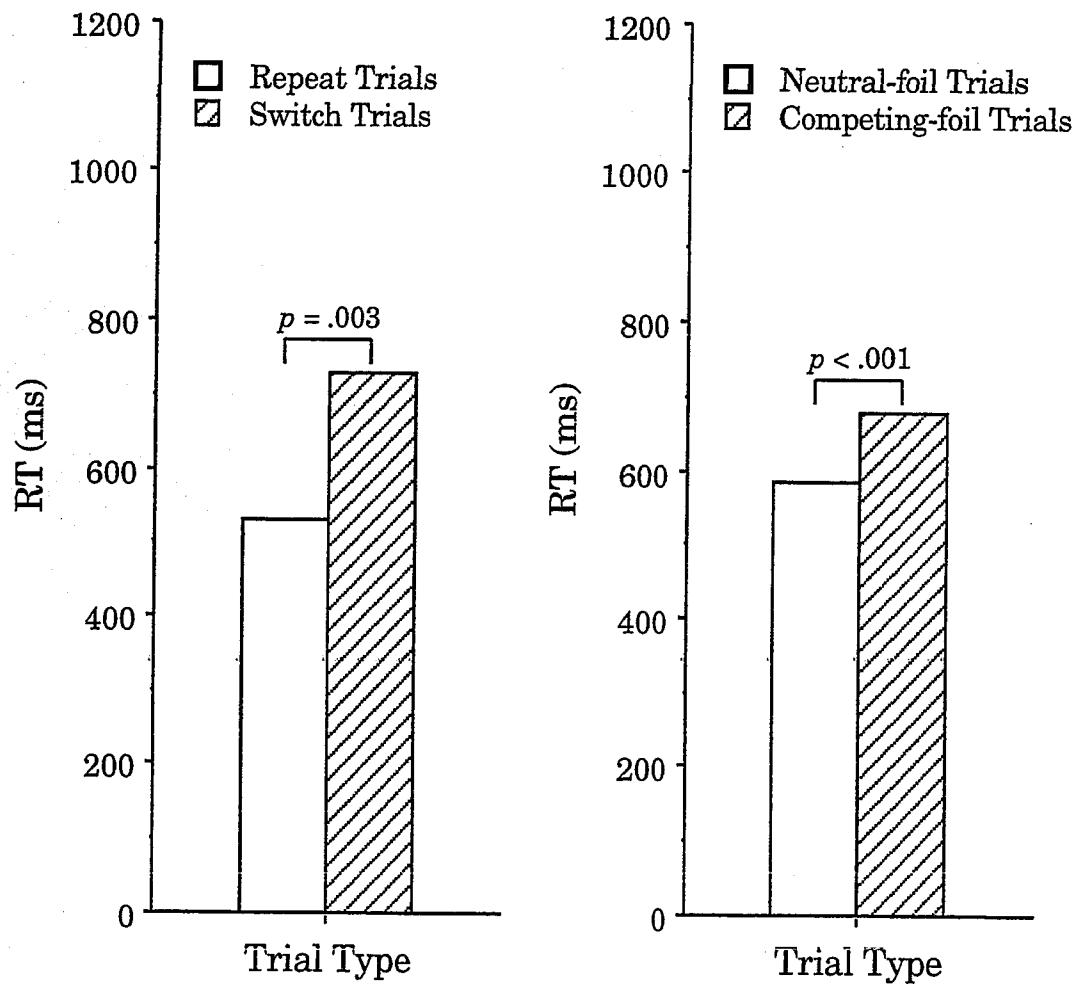
Participants were slower to respond on switch ( $M = 729$  ms) than repeat trials ( $M = 531$  ms),  $F(1, 7) = 20.38, p = .003, MSE = 30,963$ , yielding a global

switch cost of 198 ms. This switch effect is shown on the left side of Figure 5. Again, switching improved with practice, from 251 ms in Session 1 to 146 ms in Session 2, as revealed by a significant Trial Type x Session interaction,  $F(1, 7) = 29.83, p = .001, MSE = 1,476$ . The simple effect of trial type for Session 2, however, remained significant despite this reduction,  $F(1, 7) = 15.55, p = .006, MSE = 10,986$ .

The main effect of foil was also significant. Participants were slower to respond on competing-foil ( $M = 676$  ms) than neutral-foil trials ( $M = 584$  ms),  $F(1, 7) = 132.45, p < .0005, MSE = 1,038$ , a global cue inhibition cost of 92 ms. This cue inhibition effect is shown on the right side of Figure 5. There were no interactions between foil and either trial type or session.

#### Motivation Effects (LM & DM Groups)

First, in order to test for any immediate motivational bias on basic response execution, the training data of the differentially-motivated participants were submitted to a 2 x 2 mixed-design ANOVA with the within-subjects variable of task motivation (high, low) and the between-subjects variable of group (LM, DM). No main effect of task motivation obtained,  $F(1, 14) = .46, p = .506, MSE = 515$ . However, task motivation did interact significantly with group,  $F(1, 14) = 24.54, p < .0005, MSE = 515$ , due to reverse effects of task motivation for the LM and DM groups. Simple effects analyses revealed that the LM group responded significantly more slowly on low-motivated ( $M = 504$  ms) than high-motivated ( $M = 470$  ms) task trials,  $F(1, 14) = 9.13, p = .009, MSE = 515$ , whereas the DM group responded significantly



*Figure 5.* Mean RT (ms) by trial type for the equally motivated participants in Experiment 2. Switch and cue inhibition effects are depicted on the left and right, respectively.

more slowly on high-motivated ( $M = 498$  ms) than low-motivated ( $M = 452$  ms) task trials,  $F(1, 14) = 15.88, p = .001, MSE = 515$ . In effect, during training both groups performed faster on the letter than the digit task, irrespective of task incentives.

Next, to address the central question of whether experience with differential incentives during training affects subsequent equal-incentive switch task performance, a series of four planned analyses were conducted on the switch task data. Base RT, CI cost, SW cost, and SWCI cost were first computed for each participant for the high-motivated and low-motivated tasks separately, and then entered into four separate  $2 \times 2 \times 2$  mixed-design ANOVAs with two within-subjects variables of session (Session 1, Session 2) and task motivation (high, low), and one between-subjects variable of group (LM, DM). Table B2 of Appendix B presents the group means of the four performance indices for the high- and low-motivated tasks and for both sessions of the switch task. Mean RT for the four trial types used to compute the cost indices are presented in Table B3 of Appendix B.

The contrasts between the high- and low-motivated tasks for base RT and the three attention cost indices are displayed on the left and right sides of Figure 6, respectively. Only the SW and SWCI cost analyses yielded significant main effects of task motivation: SW cost was smaller for the high-motivated (212 ms) than low-motivated task (280 ms),  $F(1, 14) = 15.03, p = .002, MSE = 4,965$ ; SWCI cost was also smaller for the high-motivated (346 ms) than low-motivated task (421 ms),  $F(1, 14) = 10.19, p = .007, MSE = 8,821$ . In addition, task motivation did not interact with session in either the SW or the SWCI

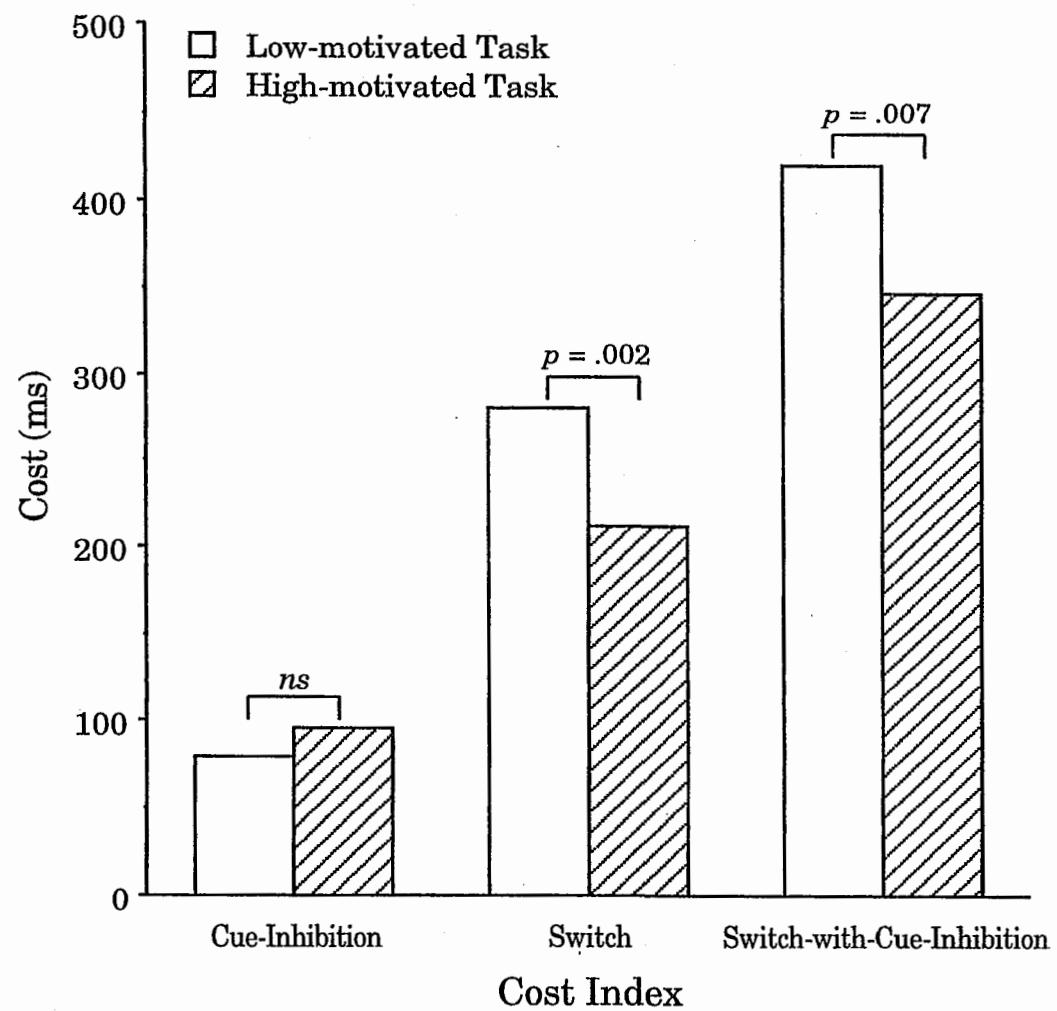
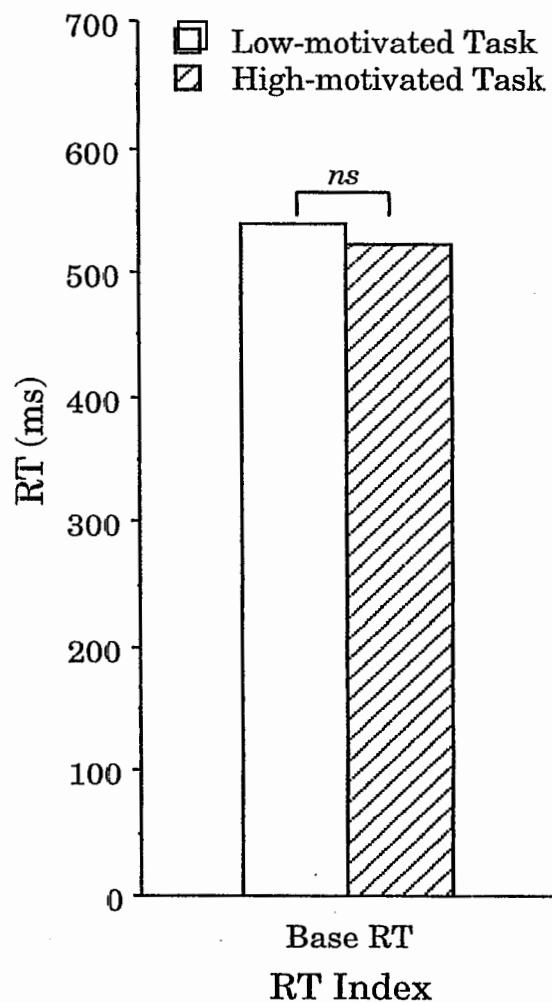


Figure 6. Mean base RT (ms) and costs (ms) by current task motivation for differentially motivated participants in Experiment 2.

cost analyses, indicating that this task motivation effect persisted through both sessions of the switch task.

Task motivation did not affect base RT,  $F(1, 14) = 2.17, p = .162, MSE = 1,887$ ; nor was there a main effect of task motivation in the CI cost analysis,  $F(1, 14) = .87, p = .366, MSE = 5,194$ . There was a Task Motivation x Group interaction in the CI cost analysis due to a *smaller* CI cost for the high-motivated task ( $M = 72$  ms) than the low-motivated task ( $M = 100$  ms) for the DM group, but a *larger* CI cost for the high-motivated task ( $M = 119$  ms) than the low-motivated task ( $M = 58$  ms) for the LM group,  $F(1, 14) = 6.04, p = .028, MSE = 5,194$ . Simple effects analyses revealed that the task motivation effect was not significant for the DM group,  $F(1, 14) = 1.16, p = .299, MSE = 5,194$ , or the LM group,  $F(1, 14) = 5.75, p = .031, MSE = 5,194$ . None of the other analyses yielded a significant Task Motivation x Group interaction.

Finally, it is worth noting that there was no significant main effect of group in any of the performance index analyses, all  $F$ 's  $< 2.1$ , indicating that the letter- and digit-motivated groups performed comparably overall.

#### Motivation Effects (EM Group)

For comparison with the differentially-motivated group results, a comparable set of training and switch task analyses were run on the participants who received equal incentives during training. First, a *t*-test comparing letter and digit task performance during training was conducted. Despite receiving equal incentives for both letter and digit zaps, participants responded more quickly on letter task ( $M = 443$  ms) than digit task ( $M = 469$

ms) trials, thus showing a small ( $M_{\text{diff}} = 25.28 \text{ ms}$ ,  $SE = 10.16 \text{ ms}$ ), but significant, advantage for the letter task during training,  $t(7) = 2.49$ ,  $p = .042$ .

The performance of the EM group during the switch task was examined next in a series of four planned analyses of the switch task data. Base RT, CI cost, SW cost, and SWCI cost were computed for each participant for the letter and digit tasks separately. Table B4 of Appendix B presents the group means of the four performance indices for the high- and low-motivated tasks and for both sessions of the switch task. Mean RT for the four trial types used to compute the cost indices are presented in Table B5 of Appendix B. Each of these performance indices were subjected to a  $2 \times 2$  within-subjects ANOVA with the variables of session (Session 1, Session 2) and task (letter, digit).

The contrasts between letter and digit task performance indexed by base RT and the three attention costs are shown on the left and right sides of Figure 7, respectively. In contrast to the differentially-motivated group analyses, no significant effects of task obtained in the base RT or any of the attention cost analyses, all  $F$ s  $< 1.5$ . Nor were any of the Task  $\times$  Session interactions significant, all  $F$ s  $< 1.5$ .

### Discussion

In addition to again replicating the basic switch and cue inhibition effects of this paradigm, Experiment 2 more importantly revealed that motivational experience could have a longlasting impact on on-line cognitive processes during performance. Moreover, this effect was highly specific, selectively affecting attentional set switching, but not inhibition of task-set

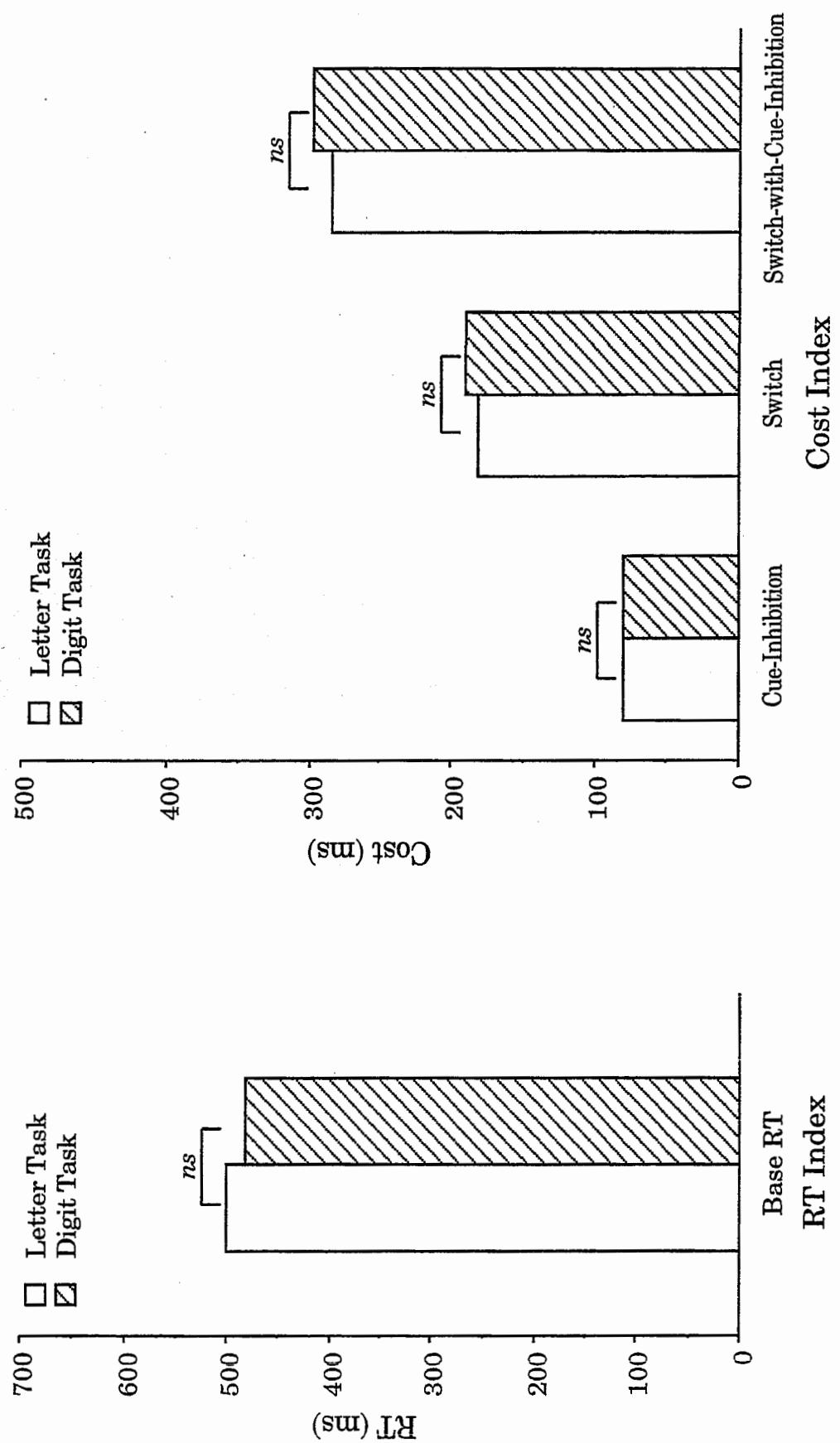


Figure 7. Mean base RT (ms) and costs (ms) by current task motivation for equally motivated participants in Experiment 2.

cuing from the competing foil or basic task execution. These effects cannot be attributed to current incentive-based strategies since all groups received equal incentives during the switch task itself; rather, it suggests that an implicit bias was created and persisted in influencing attention switching during subsequent performance.

As in Experiment 1, large and significant switch and cue inhibition effects obtained for both the differentially and equally motivated participants. The magnitudes of these effects for both groups were comparable, and similar to those of previous experiments. Collapsed across letter and digit task trials, differentially-motivated participants yielded a mean global switch cost of 271 ms (47% increase) and a mean global cue inhibition cost of 112 ms (17% increase). Equally motivated participants performed somewhat better, with a mean global switch cost of 198 ms (37% increase) and a mean global cue inhibition cost of 92 ms (16% increase). Although these effects generally diminished with practice, they remained quite large and significant through both sessions of the switch task. Having established the presence of these basic attention effects, of particular interest was the influence of prior incentive experience.

As predicted, when participants were trained on the letter and digit tasks under differential incentives, they showed a persistent bias favouring the previously high-incentive task. However, this effect was even more selective than predicted, having a large impact on both SW and SWCI cost indices, and no effect on CI cost or base RT. In addition to the large magnitude and statistical reliability of these selective effects, the overall pattern of results is

also internally consistent. First, the magnitude of the motivational effects on SW and SWCI costs are remarkably similar. Participants were, on average, 68 ms faster on high- than low-motivated switch trials with neutral foils, and 75 ms faster on high- than low-motivated switch trials accompanied by competing foils. Thus, similar motivational effects obtained on two indices that implicate switching, each based on a unique set of switch trials. This finding is also consistent with the absence of an effect on CI cost and suggests that the motivational effect on SWCI costs is due predominantly to modulation of attentional switching between tasks. This influence of prior motivational experience on switching was also persistent. Although the magnitude of motivational differences for SW cost decreased from Session 1 to Session 2, whereas the magnitude of SWCI cost increased somewhat, neither of these changes was significant. Thus, the impact of prior incentives on set switching did not appear to diminish over time.

An interesting issue concerns whether these motivational effects on switching are due to differential difficulty in disengaging *from* the high-motivated versus low-motivated task, or differential facility in switching *to* the high-motivated task versus the low motivated task. The design of the present study cannot resolve this question since switching from and switching to always involved both a high- and low-motivated task set and so confounded independent assessment of these two aspects of switching. I return to this issue in the general discussion and suggest another paradigm that could be used in combination with motivational incentives to better address this question.

The absence of an effect on base RT suggests that prior motivational experience with differential task incentives did not differentially strengthen corresponding task sets. Rather, performance of the high- and low-valued tasks appeared to be equally triggered by the target on repeat/neutral foil trials and comparably executed. The absence of a motivational effect on CI cost further indicates that participants found it no more challenging to inhibit inappropriate task set activation triggered by a competing foil from the previously high-incentive task than from the previously low-incentive task. This again is indicative of comparable stimulus triggering of task set for the high- and low-motivated tasks. Together, these results suggest that task set activation, triggered either appropriately by the target on repeat/neutral foil trials or inappropriately by the foil on repeat/competing foil trials, was not influenced by prior motivational experience.

Focusing of attention likewise appeared to be unaffected by prior motivational experience in this experiment. Enhanced target focusing on competing-foil trials might be expected both to facilitate target activation and inhibit foil activation, resulting in smaller CI costs on previously high-incentive than low-incentive task trials. This did not obtain. Rather, as described above, participants were equally slowed by the presence of competing foils regardless of the acquired motivational significance of the target and foil.

The finding of a selective impact on attention switching for participants who experienced differential task incentives during training is reinforced by the counterbalancing of incentive assignments since, for motivational effects to obtain, the letter-motivated and digit-motivated participants had to show

opposite performance on letter and digit tasks. Furthermore, an equally motivated group, who received the same task incentives throughout, was included as an additional comparison group. Like the participants in Experiment 1, who performed the switch task without any experimentally-manipulated incentives, the equal-incentive group here performed comparably on all indices of letter and digit task performance. Specifically, no differences between letter and digit task performance obtained on base RT or any of the attentional cost indices for this group. Although both the differentially and equally motivated groups did evidence a small, significant bias in favour of the letter task during training, there is no evidence that this difference carried over into performance during the switch task phase or otherwise contributed to the prior motivation effect on switching obtained here.

Finally, given that letter and digit task incentives during the switch task phase were equal for all participants, it is highly unlikely that an incentive-based strategy could account for this prior-motivation effect on set switching. Instead, the results of this study appear to reveal a selective and *implicit* influence of motivational experience on an *intentional* supervisory attention control mechanism. The theoretical implications of this intriguing result and possible underlying mechanisms will be explored later, within the *General Discussion* section of this thesis.

### EXPERIMENT 3

Before proceeding with Experiments 4 and 5, in which differential incentives for letter and digit task trials are applied during the switch task itself, it was important to verify that current trial reaction times would not be affected simply by perceptual processing differences in the immediate feedback signal of the preceding trial. Such an effect would introduce a confound in interpreting RT differences in terms of the *motivational* value of the incentives.

Since all participants are, on average, rewarded on 75% of the trials due to an adaptive speed criterion for zaps, letter and digit trials in Experiments 4 and 5 will differ not only in terms of their incentive value, but also in terms of the positive feedback signal (two versus six beeps) that is processed during the preparatory interval (the RSI leading up to the current trial). For example, for participants receiving six points per letter trial zap and two points per digit trial zap, many digit switch trials would be preceded by a six-beep feedback signal from the preceding letter trial, whereas many digit switch trials would be preceded by only a two-beep feedback signal from the preceding digit trial. If perceptual processing of the six- and two-beep feedback signals differentially affected current trial preparation and reaction time, it would be impossible to determine whether larger digit switch trial RTs were due to increased processing demands of the preceding six-beep letter trial feedback or to the lower motivational value of digit trials as compared to letter trials.

In the first instance, it was important to equate the playing time of six and two beeps since a participant may wait to begin preparation for the next trial until after feedback has finished playing. However even with time equated, by virtue of their number, six beeps may be either more demanding or take longer to process than two beeps, and thereby interfere more with concurrent preparation for the upcoming trial. Consequently, after first equating the play time of all positive feedback signals, Experiment 3 further explored whether the number of feedback beeps, *in the absence of differential motivational significance*, would influence reaction times.

Both letter and digit zaps throughout Experiment 3 were assigned a value of one point, regardless of the number of beeps in the feedback signal. During training, all zaps were followed by four-beep feedback. During the switch task, half of all letter and all digit trial zaps were followed by six-beep feedback and half by two-beep feedback. As in previous experiments, I expected to obtain significant switch and cue inhibition effects. Most importantly, however, I hoped to obtain *no* main effect for number of preceding beeps and no significant interactions of this variable with either trial type or foil type.

### Method

#### Participants

Eight paid volunteers (1 male), aged 20 to 33 ( $M = 24.4$  years) participated.

### Materials

Visual stimuli were identical to Experiment 2. Immediate auditory feedback again consisted of a series of beeps generated by the computer using the Hypercard 2.3 "play" feature with its built-in harpsichord sound. The duration of beeps was adjusted so that a sequence of two, four, or six beeps required approximately the same play time, about 350 ms. Since the RSI was 450 ms, this allowed a full 100 ms between the offset of the auditory feedback and the onset of the next stimulus.

### Procedure

General experimental set up, administration of consent form and instructions, subject counterbalancing, and stimulus presentation and response parameters were identical to Experiments 1 and 2. As in Experiment 2, participants completed the experiment in the context of a computer game during which they earned points for fast and accurate responses. However, in both the training and switch task phases of Experiment 3, all participants earned just one point per letter or digit zap, and the number of beeps following each zap was no longer related to the number of points earned.

During training, a series of four beeps always sounded after each letter or digit zap. During the switch task, either two or six beeps sounded after a zap. For half the participants, letter zaps were followed by six beeps and digit zaps by two beeps during the first and third counterbalanced sequences of four 48-trial blocks, whereas digit zaps were followed by six beeps and letter zaps by two beeps during the second and fourth four-block sequences. This assignment

was reversed for the remaining participants. Thus, each participant completed two counterbalanced sequences of 144 experimental trials in which letter trials were preceded by two beeps and digit trials by six beeps, and two sequences in which the reverse was true. Since both letter and digit zaps were worth one point each throughout, this afforded analysis of RTs as a function of the number of beeps that preceded each trial type when number of beeps held no motivational significance for the participant. Scheduling and completion of blocks during the training and switch task phases were otherwise identical to Experiment 2.

Lastly, to further minimize errors due to rushed responses and to maximize the number of trials preceded by positive feedback signals, the RT criterion for zaps in this experiment was relaxed to an RT faster than the 90th percentile, rather than 75th percentile, of comparable trials of the previous block. This corresponded to an expected gain of 43 points per block, given a similar level of performance as the previous block (43 one-point zaps per 48-trial block). A bonus of two points was added if fewer than five errors were committed. Participants were told that a good player typically scores in the 36-38 point range on each block.

### Results

Following elimination of trials on which errors were committed ( $M = 8.0\%$ ), and trials immediately following error trials (a total mean loss of 15.4% of experimental trials), individual data files were winsorized at the upper 10% of

each data cell defined by the variables: trial type (switch, repeat), foil (competing, neutral), and preceding beeps (0 beeps, 2 beeps, 6 beeps).

To examine the effect of the number of preceding beeps on RT performance, a  $2 \times 2 \times 3$  (Trial Type x Foil Type x Preceding Beeps) within-subjects ANOVA was conducted. Only the main effects of trial type and foil type were significant. Participants responded more quickly on repeat trials ( $M = 556$  ms) than switch trials ( $M = 776$  ms),  $F(1, 7) = 33.66, p = .001, MSE = 34,412$ . They also responded more quickly on neutral-foil trials ( $M = 611$  ms) than competing-foil trials ( $M = 721$  ms),  $F(1, 7) = 19.46, p = .003, MSE = 14,754$ . Importantly, however, the number of preceding beeps did not significantly affect reaction time,  $F(2, 14) = 1.55, p = .247, MSE = 1,821$ . Indeed, the mean RTs of trials following 0, 2, and 6 beeps were very similar in magnitude: 676, 658, and 664 ms, respectively. Moreover, preceding beeps did not enter into any two-way or three-way interactions with trial type or foil, all  $F$ s  $< 1$ . Switch and cue inhibition effects as a function of the number of preceding beeps is shown in Figure 8. Table B6 in Appendix B displays the mean RTs for each of the four types of trials (trial type x foil) as a function of the number of preceding-trial feedback beeps.

### Discussion

By eliminating the motivational significance of the number of beeps played, Experiment 3 tested whether the mere perceptual processing of two-versus six-beep feedback on the preceding trial would affect reaction times of the current trial. Results revealed that, when total feedback play time is held

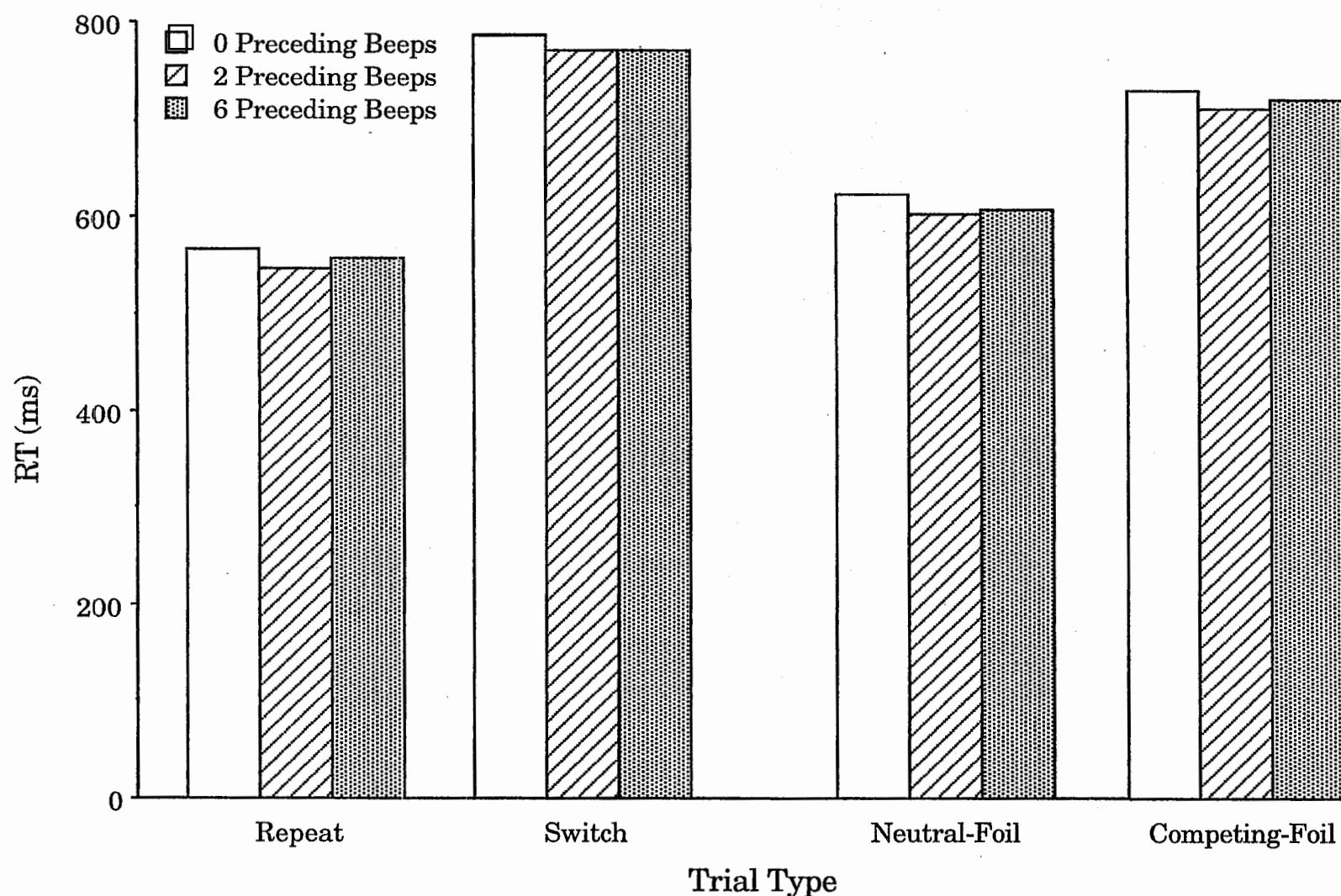


Figure 8. Mean RT (ms) by trial type as a function of the number of feedback beeps played on the preceding trial in Experiment 3. Switch and cue inhibition effects are also evident in the comparisons on the left and right, respectively. L8

constant, the number of feedback beeps on the preceding trial does not affect the reaction time of the current trial.

While the main effects of switch and cue inhibition previously found with this paradigm again obtained here, the number of preceding beeps did not in any way moderate these effects. This suggests that the number of preceding beeps processed during the interval preceding a switch or competing foil trial does not interfere with preparation for that upcoming trial or add to any working memory load associated with that trial.

These results indicated that it was appropriate to proceed with the differential feedback manipulations during the switch task phase of Experiments 4 and 5. Interpretation of any effects of task incentives obtained in these upcoming experiments could now safely discount the likelihood of contamination by non-motivational processing effects of differential preceding trial feedback.

## EXPERIMENT 4

In contrast to Experiment 2, which addressed the impact of prior incentive experience on subsequent performance, Experiment 4 examined the influence of *current* incentives. Current motivation was manipulated by applying differential incentives during the switch task itself, again counterbalancing the high- and low-motivated task assignment across participants. Thus during the switch task, a letter-motivated (LM) group received six points per letter zap and two points per digit zap, and a digit-motivated (DM) group, the reverse. To equate prior motivational experience, all participants received equal four-point incentives for both the letter and digit tasks during training. It was not necessary to include a group receiving equal incentives throughout both training and the switch task here, since this was already done in Experiment 2. The influence of current differential incentives was assessed by comparing performance between the high- and low-motivated tasks on each of the four performance indices: base RT, SW cost, CI cost, and SWCI cost.

Given that participants are receiving differential incentives during performance of the switch task itself, they may be expected to engage explicit, incentive-based strategies in an attempt to maximise their point earnings. Such an explicit strategy may create a stronger effort-driven influence than the implicit bias assumed to operate in Experiment 2. Increased effort, for example, on high-incentive task trials may lead to enhanced performance across all performance indices for the high-motivated task, but would likely

have the greatest impact on trials making the highest demand on cognitive resources (Kahneman, 1973).

I predicted, therefore, a smaller SWCI cost, SW cost and CI cost for the high-incentive than low-incentive task. Since the basic attention costs previously obtained in this paradigm have revealed that attention challenge is greatest on switch/competing-foil trials, followed by switch/neutral-foil trials, and repeat/competing-foil trials, I further predicted that the greatest current-incentive effects would obtain for SWCI cost, followed by SW cost, and lastly by CI cost. Despite the selective effect of prior motivational incentives on attention switching obtained in Experiment 2, given the different process hypothesized to underlie current incentive influences, I did not predict a similar selective effect here. Finally, I expected that current incentives would have the smallest effect, if any, on base RT since performance on these very simple trials is likely to be relatively automatic and benefit little from enhanced effort.

### Method

#### Participants

Participants were randomly assigned to each of two motivation group conditions (LM and DM) until the eight counterbalanced positions required for each group were filled. Any participant who exceeded the maximum error criterion was eliminated from the study and another participant was tested to fill his/her place. For this reason, a total of 24 paid volunteers were tested, from which a final set of 16 participants (4 male, 12 female), aged from 19 to 24 years ( $M = 21.5$  years), were retained for analyses.

### Materials

Visual stimuli were identical to Experiments 2 and 3. The immediate auditory reward signal was identical to that used in Experiment 3, with the play time of two, four, and six beep feedback again all equal to approximately 350 ms. Written instructions were modified to reflect the change in incentive structure described below.

### Procedure

General experimental set up, administration of the consent form and instructions, subject counterbalancing, and stimulus presentation and response parameters were the same as in Experiments 1 to 3. As in Experiment 2, participants completed the tasks in the context of a computer game during which they earned points for fast and accurate responses. The speed criterion for zaps was also defined and applied in an identical fashion to Experiment 2.

In contrast to Experiment 2, however, differential incentives were applied during the *switch task* phase of Experiment 4, instead of the training phase. During training, all participants earned four points for each letter or digit zap. Throughout the switch task, half the participants earned six points per letter zap and two points per digit zap (letter-motivated, LM group), and half the participants earned the reverse (digit-motivated, DM group). All other procedures concerning expected point earnings per block, immediate and end-of-block error and reward feedback, scheduling and completion of blocks during the training and switch task phases, and so on, were otherwise identical to

Experiment 2. As in Experiment 2, participants concluded testing with the completion of three brief questionnaires on their experience, and were debriefed.

### Results

In the switch task data, exclusion of trials on which errors were committed ( $M = 5.6\%$ ), and trials immediately following errors resulted in a loss of 11.1% of experimental trials. As in Experiment 2, the remaining switch task data for each participant were winsorized at the top 10% of data cells defined by the following variables: sequence (1, 2, 3, 4), trial type (switch, repeat), foil (neutral, competing), and task (letter, digit). Data were then aggregated by session (1, 2), trial type, foil, and task. Finally, the LM and DM data were combined into a single data file by recoding the letter and digit tasks as high-motivated or low-motivated tasks. In contrast to Experiment 2, however, task motivation here is defined by the differential incentives applied during the switch task itself.

In the training data, after first excluding the practice block, 10.6% of trials were eliminated due to errors ( $M = 5.4\%$ ), and trials immediately following errors. The remaining training data of each participant were winsorized at the upper 10% of letter and digit trial data cells and aggregated by task (letter, digit).

### Basic Attention Effects

As in Experiment 2, the basic switch and cue inhibition effects of this paradigm obtained. The switch task data were subjected to a mixed-design ANOVA with three within-subjects variables of session (Session 1, Session 2),

trial type (switch, repeat), and foil (neutral, competing), and one between-subjects variable of group (LM, DM).

There was a main effect of trial type,  $F(1, 14) = 24.03, p < .0005, MSE = 47,972$ , and a significant Trial Type x Session interaction,  $F(1, 14) = 13.14, p = .003, MSE = 4,088$ . Overall, participants responded more slowly on switch ( $M = 754$  ms) than repeat trials ( $M = 564$  ms), yielding a global switch cost of 190 ms. In addition, this global switch cost decreased with practice from 231 ms in Session 1 to 149 ms in Session 2. Despite this decrease, the simple effect of trial type for Session 2 remained significant,  $F(1, 14) = 15.66, p = .001, MSE = 22,636$ . The switch main effect is shown on left side of Figure 9.

There was also a main effect of foil,  $F(1, 14) = 59.22, p < .0005, MSE = 8,599$ , and a significant Foil x Session interaction,  $F(1, 14) = 14.23, p = .002, MSE = 1,935$ . Participants responded more slowly on competing-foil ( $M = 722$  ms) than neutral-foil ( $M = 596$  ms) trials, yielding a global cue inhibition cost of 126 ms. This global cue inhibition cost decreased with practice, from 156 ms in Session 1 to 97 ms in Session 2. Despite this decrease, the simple effect of foil for Session 2 remained significant,  $F(1, 14) = 61.05, p = .001, MSE = 2,457$ . The main effect of cue inhibition is shown on right side of Figure 9.

There was no main effect of group, nor did group enter into interaction with any other variables, all  $F$ s  $< 1.2$ , indicating that, in terms of the basic attention effects, the LM and DM groups performed in a similar fashion throughout.

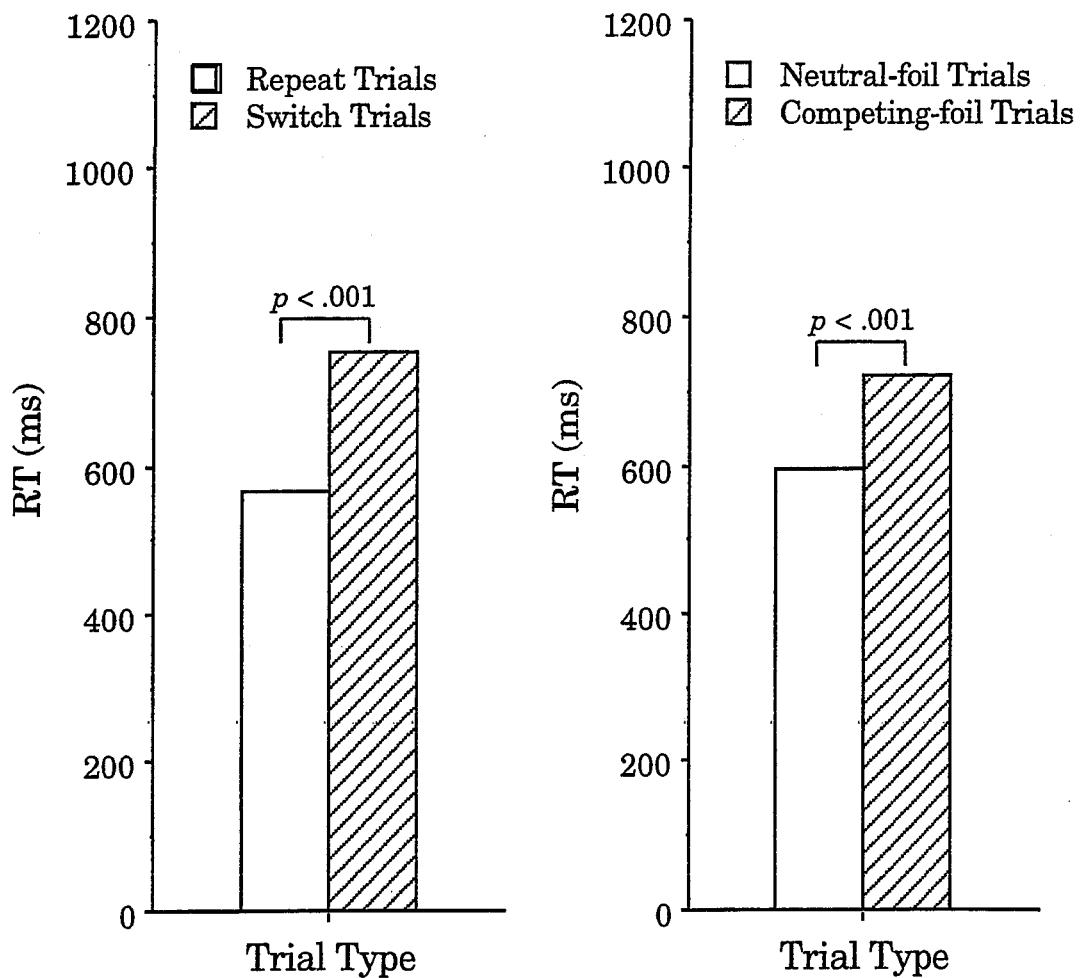


Figure 9. Mean RT (ms) by trial type in Experiment 4. Switch and cue inhibition effects are depicted on the left and right, respectively.

### Motivation Effects

Analysis of the training data, during which participants received equal incentives for performance on the letter and digit tasks, revealed a small, but significant, advantage for the letter task in both groups. A mixed-design ANOVA was conducted on the training data with the within-subjects variable of task (letter, digit) and the between-subjects variable of group (LM, DM). A significant main effect of task obtained,  $F(1, 14) = 22.71, p < .0005, MSE = 954$ , due to faster responding on letter ( $M = 444$  ms) than digit trials ( $M = 496$ ). The Group x Task interaction was not significant,  $F < .1$ .

The central question concerning the impact of current differential incentives for letter and digit task performance in effect during the switch task itself was examined in four planned analyses of the switch task data. After computing base RT, CI cost, SW cost, and SWCI cost for each participant for the high-motivated and low-motivated tasks, the means for each index were subjected to a  $2 \times 2 \times 2$  mixed-design ANOVA with two within-subjects variables of session (Session 1, Session 2) and task motivation (high, low), and the between-subjects variable of group (LM, DM). Table B7 of Appendix B presents the group means of the four performance indices for the high- and low-motivated tasks and for both sessions of the switch task. Mean RT for the four trial types used to compute the cost indices are presented in Table B8 of Appendix B.

Inspection of the means reveals several trends in the data. Mean differences between performance on the high- and low-motivated tasks were negligible in magnitude for both base RT ( $M_{diff} = 11$  ms) and CI cost ( $M_{diff} = 4$

ms), but were relatively large for both SW cost ( $M_{\text{diff}} = 39$  ms) and SWCI cost ( $M_{\text{diff}} = 57$  ms). Furthermore, these two costs increased across switch task sessions, during which differential incentives had been applied (SW cost:  $M_{\text{Session 1}} = 19$  ms,  $M_{\text{Session 2}} = 59$  ms; SWCI cost:  $M_{\text{Session 1}} = 38$  ms,  $M_{\text{Session 2}} = 76$  ms).

However, despite these trends in the means, the four planned ANOVAs revealed that these task motivation differences were not significant for any of the four indices. There was no main effect of task motivation in the analysis of base RT,  $F(1, 14) = 1.06, p = .320, MSE = 2,033$ ; CI cost,  $F(1, 14) = .05, p = .826, MSE = 6,239$ ; SW cost,  $F(1, 14) = .86, p = .369, MSE = 28,274$ ; or SWCI cost,  $F(1, 14) = 1.18, p = .269, MSE = 44,240$ . Nor was the Task Motivation x Session interaction significant in either the SW cost analysis,  $F(1, 14) = 1.21, p = .290, MSE = 5,499$ , or the SWCI cost analysis,  $F(1, 14) = .87, p = .365, MSE = 6513$ . Although these differences were not significant, in order to facilitate comparison with Experiment 2, the mean base RTs for the high- and low-motivated tasks collapsed across session are shown on the left side of Figure 10. Similarly, the right side of Figure 10 shows the mean CI, SW, and SWCI costs for the high- and low-motivated tasks, also collapsed across session.

There was only one significant interaction with group, that of Group x Task Motivation in the base RT analysis,  $F(1, 14) = 13.34, p = .003, MSE = 2,033$ . Base RT was *faster* for the high-motivated task ( $M = 481$  ms) than the low-motivated task ( $M = 533$  ms) for the LM group, but was *slower* for the high-

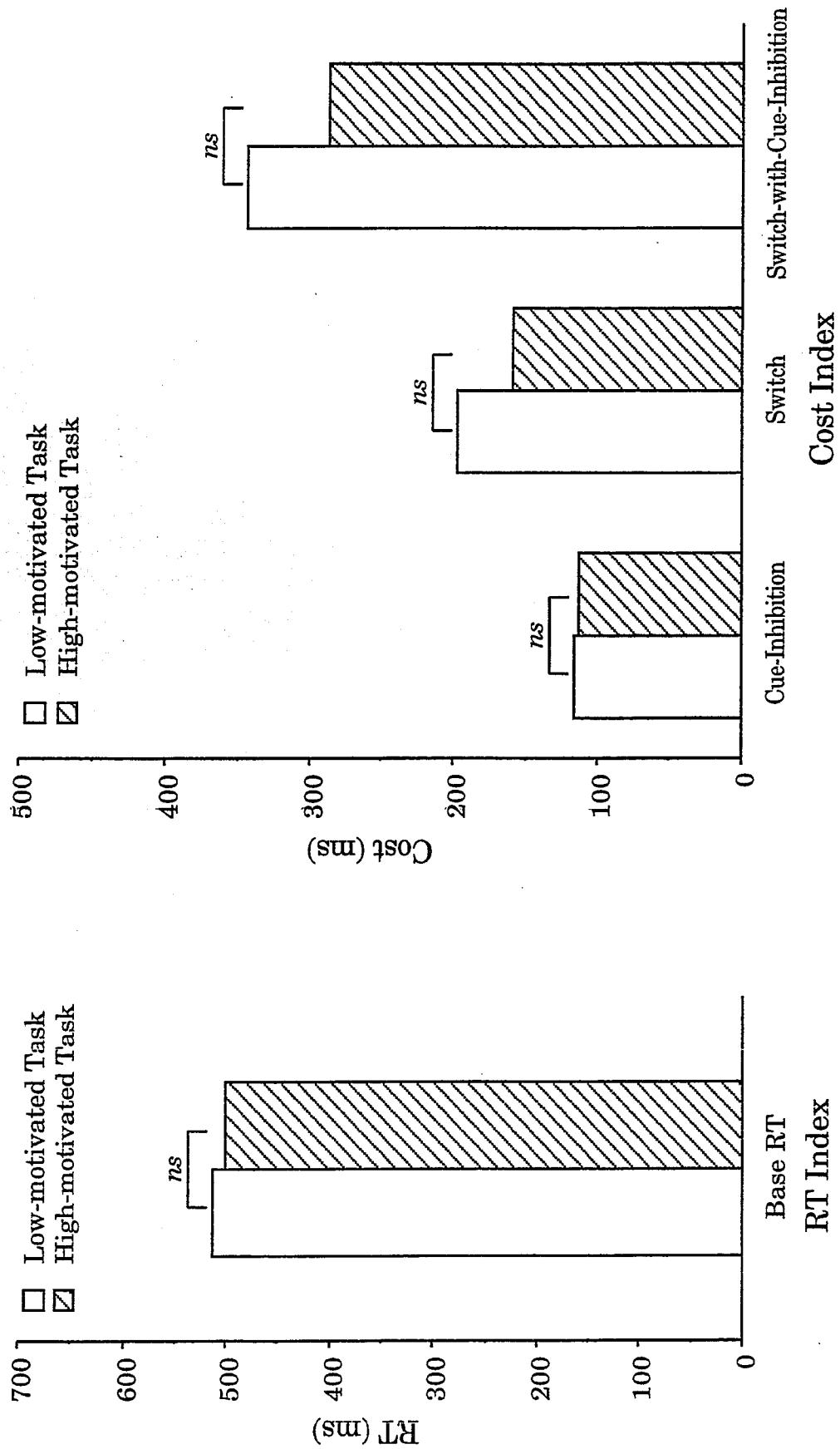


Figure 10. Mean base RT (ms) and costs (ms) by current task motivation in Experiment 4.

motivated task ( $M = 521$  ms) than the low-motivated task ( $M = 491$  ms) for the DM group. Simple effects analyses revealed that the task motivation effect was significant for the LM group,  $F(1, 7) = 10.96, p = .005, MSE = 2,033$ , but not the DM group,  $F(1, 7) = 3.43, p = .085, MSE = 2,033$ . Finally, there was no main effect of group in any of the performance index analyses, all  $F$ s  $< .1$ , indicating that the LM and DM groups performed comparably overall.

### Discussion

Experiment 4 again replicated the basic attention effects of this paradigm. However, current incentives evidenced only a nonsignificant trend toward faster switching from the low to the high-motivated task and no trend at all for cue inhibition. Finally, as expected, current motivation did not affect basic performance on repeat/neutral-foil trials.

As in all previous experiments, participants evidenced both significant switch and cue inhibition effects. The magnitude of the switch cost (190 ms, a 34% increase) and the cue inhibition cost (126 ms, a 21% increase) were both large and roughly comparable to previous results.

Examination of current differential incentives on these attention effects yielded no significant differences. The magnitude of the differences for the high- and low-motivated groups on SW cost (39 ms) and SWCI cost (57 ms) were 43% and 24% smaller, respectively, than the magnitude of these costs in Experiment 2, where differential incentives were applied during training and incentives were equal during the switch task itself. In addition, the effect of task motivation on SW cost and SWCI cost was also much more variable in

the present experiment where the *MSEs* were 28,274 and 44,240, respectively, than in Experiment 2 where the corresponding *MSEs* were 4,965 and 8,821, respectively. Thus rather than having a greater effect than prior incentives on performance, current incentives had a smaller and less reliable influence, even on difficult trials where voluntary enhancement of effort would be expected to have the greatest impact.

Despite the failure to reach statistical significance, the motivational trend on switch costs was, importantly, present in both SW and SWCI costs and in both cases increased from Session 1 to Session 2. This provides some evidence of consistency since these two costs are based on separate switch trials, those with and without a competing foil, respectively. Second, these results are in striking contrast to the equally motivated group of Experiment 2, whose SW and SWCI costs were virtually identical for both tasks across both sessions.

As in Experiment 2, there was no evidence of any influence at all on CI cost, again suggesting a somewhat greater sensitivity to motivational biasing in attentional set shifting than inhibition of task set cuing. Again as in Experiment 2, there was no influence of motivation on basic task execution, with participants performing equally well on high- and low-motivated base RT trials.

Two possible influences may have contributed to the absence of a significant motivational effect of current incentives on attention control processes. First, compatible with the notion of a voluntary incentive-based strategy, participants may have been inconsistent in its application. Rather

than an implicit motivational bias developed over multiple experiences with differential letter and digit task values, the effect of motivation here would likely rely much more heavily on explicit control strategies. If participants failed to maintain this strategy across trials, its potential effect would overall be diminished. In addition, increased variability in its application across participants could also have led to less reliable results and a failure to find statistical significance (as indicated by the large *MSEs* for the effect of task motivation on these two indices) despite a relatively large trend for the switch cost indices. Second, because participants received equal task incentives during training, they may have learned to discount the importance of incentive values. This, in turn, may have resulted in reduced attention to the differential incentive values subsequently applied during the switch task, and, therefore, reduced effects on performance. The consistent increase in the magnitude of both SW and SWCI costs from Session 1 to Session 2 suggests that participants may have increased their attention to current incentives and/or their use of an explicit incentive-based strategy over time. These two issues are further explored in the *General Discussion*.

## EXPERIMENT 5

Experiment 5 explored the ability of current differential incentives to override the influence of prior incentives. Results of Experiment 2 already indicated that prior experience with differential incentives can have a persistent effect on attentional set shifting despite the presence of equal incentives during the switch task. The shift to equal incentives, however, may not have been strong enough to engage an incentive-based performance strategy during the switch task. Consequently, in Experiment 5, the differential task incentives during training were *reversed* during the switch task. For example, a participant receiving 6 points per letter zap and 2 points per digit zap during training, would receive 2 points per letter zap and 6 points per digit zap during the switch task. Again, task incentives were counterbalanced across participants, and the influence of now *reversed* differential incentives on switch task performance was assessed by comparing performance between the current high-incentive and low-incentive tasks on base RT, SW cost, CI cost, and SWCI cost indices.

As in Experiment 4, I predicted that an intentional incentive-based strategy would be engaged to bias performance in favour of current incentives. Based on the observed increase in the motivational trend observed in SW cost and SWCI cost from Session 1 to Session 2 of Experiment 4, I hypothesized that a voluntary incentive strategy would be applied immediately by participants to override prior incentive influences, but that its effect would increase in consistency and efficiency over time as participants learn the basic performance requirements of the switch task and accrue increasing experience

with the reversed differential incentives. The switch task was extended by two additional sessions in order to test this hypothesis. Finally, I again hypothesized that a voluntary strategy would be most effective on trials requiring the greatest degree of attentional control, and be least influential on relatively automatic performance components.

More specifically, I predicted the greatest influence of current incentives on SWCI cost and SW cost. These two costs were expected to show immediate and increasing biases in favour of current incentives across switch task sessions; that is, smaller costs for the *current* high-incentive than low-incentive task. Given that neither base RT nor CI cost was previously affected by prior or current incentives, I predicted less or no influence on CI cost, and no effect on base RT. Participants were, therefore, expected to have roughly equal CI cost and base RT values for the current high-incentive and low-incentive tasks.

### Method

#### Participants

Participants were randomly assigned to each of two motivation group conditions (LD and DL) until the eight counterbalanced positions required for each group were filled. Any participant who exceeded the maximum error criterion was eliminated from the study and another participant was tested to fill his/her place. For this reason, a total of 21 paid volunteers were tested, from which a final set of 16 participants (4 male, 12 female), aged from 19 to 32 years ( $M = 23.3$  years), were retained for analyses.

### Materials

Visual stimuli were again the same as used in Experiments 2 through 4, with the following minor modifications to the creation of the training and switch task blocks. In order to examine motivational influences from early to late in training as experience with differential incentives accrued, an additional block of 48 trials (24 letter and 24 digit) was added to the beginning of training as practice (later discarded in analyses) and the remaining 384 training trials were counterbalanced within each of three sets of 128 trials (rather than across the entire 384 trials as in previous experiments). Within each set, each target occurred equally often with each foil, and in each position (left, right). Because a set of 128 trials does not divide evenly into blocks of 48 trials (24 letter and 24 digit), it was necessary to insert some trials from Set 2 towards the end of Set 1 and just after the beginning of Set 3. However, there was no overlap between Set 1 and Set 3, thereby permitting comparison of motivational influences on performance early and late in training through the analysis of data exclusively from these two sets. As before, target-foil pairs were sequenced in pseudo-random order, with the restriction that no target or foil be repeated on two successive trials.

For the switch task, an additional 16 experimental blocks of 48 trials were created to permit examination of the effects of the now reversed differential incentives extended across two additional switch task sessions. All other aspects, including counterbalancing within each four-block sequence of trials, remained the same as before.

The immediate auditory reward signal was identical to that used in Experiments 3 and 4, with the play time of two, four, and six beep feedback again all equal to approximately 350 ms. Written instructions were modified to reflect the additional blocks and change in incentive structure.

### Procedure

General experimental set up, administration of the consent form and instructions, subject counterbalancing, and stimulus presentation and response parameters were the same as in the previous experiments. As in Experiments 2 and 4, participants completed the tasks in the context of a computer game during which they earned points for fast and accurate responses. The speed criterion for zaps was also defined and applied in an identical fashion to Experiments 2 and 4. This time, however, differential incentives were applied during training and then reversed for the switch task.

During training, the LD group received six points per letter zap and two points per digit zap, whereas the DL group received six points per digit zap and two points per letter zap. Throughout the switch task these differential incentives were reversed; thus, what was previously the high-incentive task during training, now became the low-incentive task during the switch task, and vice versa. Specifically, during the switch task, the LD group received six points per digit zap and two points per letter zap, and the DL group received six points per letter zap and two points per digit zap. All other procedures concerning expected point earnings per block, immediate and end-of-block error and reward feedback were otherwise identical to Experiments 2 and 4.

With the additional training block and switch task blocks, testing now lasted approximately one hour and 45 minutes, and was divided into the training phase and four sessions of the switch task. In the training phase, participants completed the practice block followed by eight game blocks, during which the differential incentives were applied. As before, the practice block (during which no rewards were given) was used to establish the RT criteria for earning points during the first of the game blocks, with RT criteria then recalculated after each successive game block.

Participants proceeded immediately to the switch task phase, beginning with the first 96-trial practice block followed by two 4-block experimental sequences of the switch task (Session 1). After a two-minute break, this was followed by another two 4-block sequences (Session 2). After a 10-minute break, participants completed the second 96-trial practice block and another two 4-block sequences (Session 3), again followed by a two-minute break and then the final two 4-block sequences of the switch task (Session 4). As before, the last 48 trials of each of the practice blocks were used to calculate the RT criteria for earning points during the subsequent experimental block, after which the RT criteria were recalculated after each successive experimental block. Finally, as before, participants concluded testing with the completion of three brief questionnaires on their experience, and were debriefed.

### Results

In the switch task data, exclusion of trials on which errors were committed ( $M = 4.9\%$ ), and trials immediately following errors resulted in a loss of 9.6% of experimental trials. The remaining switch task data for each participant were winsorized at the top 10% of data cells defined by the following variables: sequence (1 through 8), trial type (switch, repeat), foil (neutral, competing), and task (letter, digit). Data were then aggregated by session (1, 2, 3, 4), trial type, foil, and task. Finally, the LD and DL groups' switch data were combined into a single data file by recoding the letter and digit tasks as high-motivated or low-motivated tasks, where task motivation was defined by the current differential incentives applied during the switch task itself.

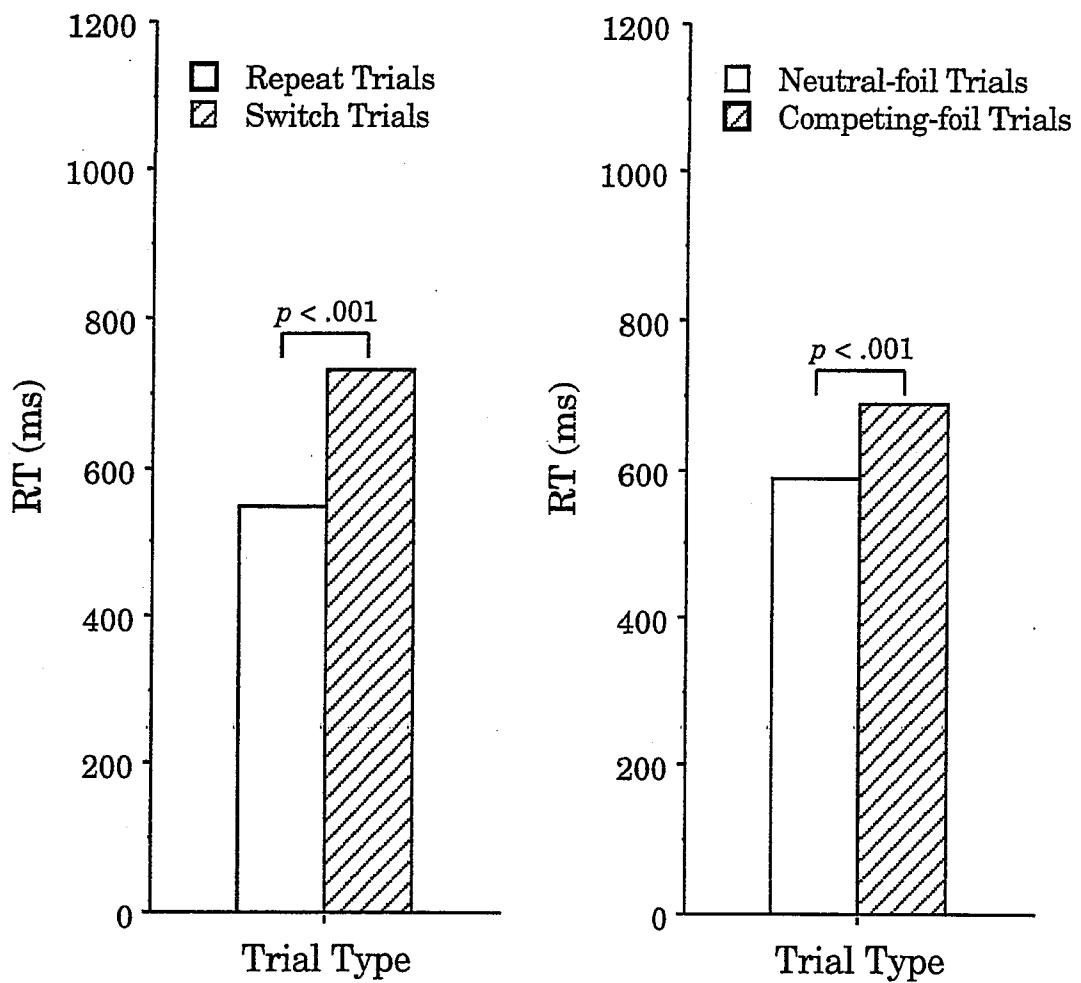
To examine the early and late influence of differential incentives applied during training, only the RT data of trials from Sets 1 and 3 were retained for analysis. Of these, exclusion of trials on which errors were committed ( $M = 5.2\%$ ), and trials immediately following errors resulted in a loss of 9.9% of trials. The remaining training data for each participant were winsorized at the top 10% of data cells defined by set (1, 3) and task (letter, digit), and then aggregated by set and task. Finally, the LD and DL groups' training data were again combined into a single data file by recoding the letter and digit tasks as high-motivated or low-motivated tasks, but defined here by the differential incentives in place during training. Thus, in analyses of both the training and switch task phases, it is the effect of the incentives currently in place that determines the designation of high- and low-motivated tasks.

### Basic Attention Effects

The switch task data were subjected to a mixed-design ANOVA with three within-subjects variables of session (1, 2, 3, 4), trial type (switch, repeat), and foil (neutral, competing), and one between-subjects variable of group (LD, DL). Again, the basic switch and cue inhibition effects of this paradigm obtained.

There was a main effect of trial type,  $F(1, 14) = 72.51, p < .0005, MSE = 29,937$ . Overall, participants responded more slowly on switch ( $M = 730$  ms) than repeat trials ( $M = 546$  ms), yielding a global switch cost of 184 ms. This switch main effect is shown on the left side of Figure 11. In addition, a significant Trial Type x Session interaction obtained,  $F(3, 42) = 12.90$ , Greenhouse-Geisser Epsilon = .68653,  $p < .0005, MSE = 4,119$ , due to a decrease in global switch cost across sessions (259, 196, 152, and 129 ms for Sessions 1 to 4, respectively). Despite this decrease, the simple effect of trial type was significant for all sessions, all  $F$ s  $> 40, p < .0005$ .

There was also a main effect of foil,  $F(1, 14) = 75.10, p < .0005, MSE = 8,293$ . Participants responded more slowly on competing-foil ( $M = 688$  ms) than neutral-foil ( $M = 589$  ms) trials, yielding a global cue inhibition cost of 99 ms. This cue inhibition effect is shown on the right side of Figure 11. The Foil x Session interaction not significant,  $F(1, 14) = 2.41, p = .081, MSE = 932$ , indicating that cue inhibition costs remained roughly constant across sessions.



*Figure 11.* Mean RT (ms) by trial type in Experiment 5. Switch and cue inhibition effects are depicted on the left and right, respectively.

The Trial Type x Foil interaction also was significant,  $F(1, 14) = 21.36, p < .0005, MSE = 2,373$ . Switch cost was greater on competing-foil trials ( $M = 213$ ) than neutral-foil trials ( $M = 156$ ), but the simple effect of trial type was still significant for neutral-foil trials,  $F(1, 14) = 51.96, p < .0005, MSE = 14,993$ . Similarly, cue inhibition cost was greater on switch trials ( $M = 127$ ) than repeat trials ( $M = 70$ ), but the simple effect of foil was still significant for repeat trials,  $F(1, 14) = 80.40, p < .0005, MSE = 1,988$ .

Finally, as in Experiments 2 and 4, there was no main effect of group, nor did group enter into interaction with any other variables, all  $F$ s  $< 2.2$ . This indicates that, in terms of the basic attention effects, the LD and DL groups performed in a similar fashion throughout.

#### Motivation Effects

To examine the effects of differential incentives in place during training, a  $2 \times 2 \times 2$  mixed-design ANOVA was conducted on the training data with two within-subjects variables of set (Set 1, Set 2) and task motivation (high, low), and one between-subjects variable of group (LD, DL). Although no main effect of task motivation obtained, there was a significant Task Motivation x Group interaction,  $F(1, 14) = 19.61, p = .001, MSE = 969$ , due to opposite effects of task motivation for LD and DL groups. The LD group responded more *slowly* on low-motivated ( $M = 510$  ms) than high-motivated ( $M = 492$  ms) task trials, but simple effects analysis revealed that this difference was not significant,  $F(1, 14) = 2.68, p = .124, MSE = 969$ . In contrast, the DL group responded significantly more *quickly* on low-motivated ( $M = 493$  ms) than high-motivated

( $M = 544$  ms) task trials,  $F(1, 14) = 21.40, p < .0005, MSE = 969$ . In effect, during training there was a general advantage for the letter task across both groups, although this advantage was not significant for the LD group. Finally, although there was, not surprisingly, an overall reduction in RT with practice from Set 1 ( $M = 548$  ms) to Set 3 ( $M = 471$  ms),  $F(1, 14) = 47.29, p < .0005, MSE = 2,050$ , this set effect did not interact with either task motivation or group, all  $F$ s  $< 2$ .

To examine the effects of the now reversed differential incentives on performance during the switch task, four planned analyses on the switch task performance indices were conducted. Base RT, CI cost, SW cost, and SWCI cost were first computed for each participant for the high-motivated and low-motivated tasks separately, and then entered into four separate  $4 \times 2 \times 2$  mixed-design ANOVAs with two within-subjects variables of session (1, 2, 3, 4) and task motivation (high, low), and one between-subjects variable of group (LD, DL). Table B9 of Appendix B presents the group means of the four performance indices for the high- and low-motivated tasks and for both sessions of the switch task. Mean RT for the four trial types used to compute the cost indices are presented in Table B10 of Appendix B.

Inspection of the means reveals a trend toward faster base RTs and smaller SW and SWCI costs for the currently high-motivated than low-motivated task. However, the four planned ANOVAs revealed that these differences were not significant for any of the four indices. There was no main effect of task motivation in the analysis of base RT,  $F(1, 14) = 1.42, p = .253, MSE = 63,244$ ; CI cost,  $F(1, 14) = 2.63, p = .127, MSE = 3,675$ ; SW cost,  $F(1,$

$F(1, 14) = 2.58, p = .130, MSE = 33,595$ ; or SWCI cost,  $F(1, 14) = 2.20, p = .161, MSE = 45,346$ . Also, the Task Motivation x Session interaction was not significant in any of the analyses despite observed changes in the magnitude of mean differences across sessions -- particularly for the SWCI cost. To facilitate comparison with Experiments 2 and 4, the mean base RTs for the high- and low-motivated tasks collapsed across session are shown on the left side of Figure 12. Similarly, the right side of Figure 12 shows the mean CI, SW, and SWCI costs for the high- and low-motivated tasks, also collapsed across session. Finally, it is worth noting that there was no main effect of group in any of the performance index analyses, all  $Fs < .5$ , nor did group interact with task motivation, all  $Fs < 3.3$ , indicating that the LD and DL groups performed comparably.

### Discussion

In addition to again replicating the basic switch and cue inhibition effects of this paradigm, Experiment 5 revealed that reversing the differential incentive values for letter and digit tasks during the switch task could counter, but not reliably reverse the motivational bias of prior task incentive experience. The trend in favour of current incentives was evident immediately on SW cost and SWCI cost indices, but contrary to predictions, it was strongest in Session 2 and then declined in Sessions 3 and 4.

As previously, the robust switch and cue inhibition effects obtained. There was a global switch cost of 184 ms (a 34% increase) and a global cue inhibition cost of 99 ms (a 17% increase), both relatively large and significant.

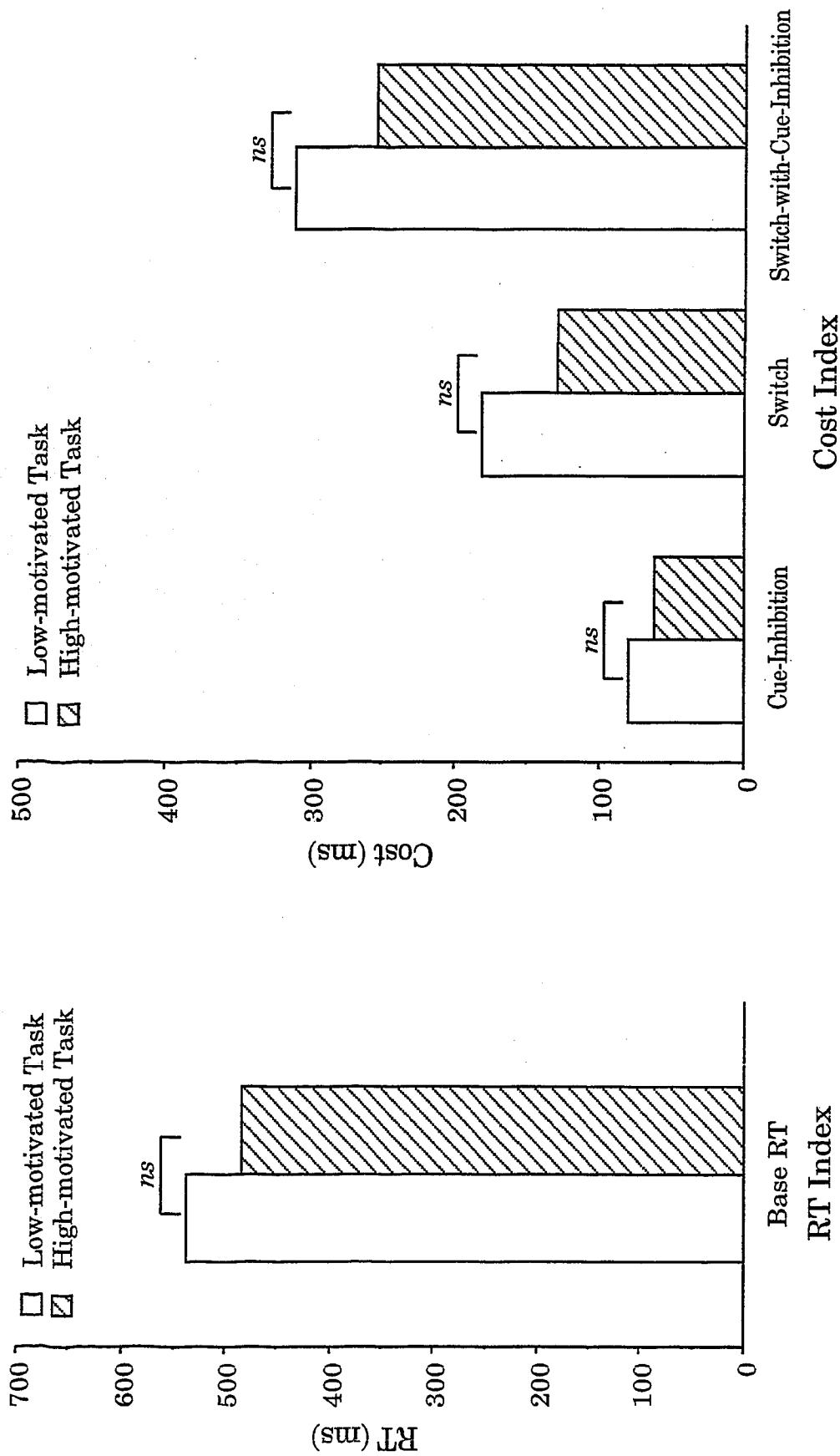


Figure 12. Mean base RT (ms) and costs (ms) by current task motivation in Experiment 5.

Results of the motivational analyses, however, only weakly supported predictions. Current reversed incentives were clearly able to overcome the large and highly reliable effects of prior incentives on SW and SWCI cost obtained in Experiment 2. Moreover, this shift away from prior incentive value biases was evident from the first session of the switch task where the direction of task incentive differences for both SW and SWCI cost favoured the *current* high-incentive task. This suggests that a voluntary strategy based on current incentives could be immediately engaged, in order to at least neutralize the influence of prior incentive experience. Also in line with predictions, the largest magnitude of task incentive differences was observed for SW and SWCI costs, representing the high-demand switch trials.

Contrary to predictions, this current motivation trend for SW and SWCI costs never reached statistical significance and did not consistently increase over time. The largest differences between the current high- and low-incentive tasks on these indices obtained in Session 2, where the differences were 94 ms and 102 ms for SW and SWCI costs, respectively. In contrast to the large and highly significant *prior* motivational effects on SW and SWCI costs in Experiment 2, the large but nonsignificant differences obtained here for *current* incentives are again suggestive of a voluntary incentive-based strategy that was inconsistently applied across participants. This inconsistency across participants is evidenced, as in Experiment 4, by very large *MSEs* for the task motivation effect on SW and SWCI costs -- 33,595 and 45,346, respectively -- as compared to Experiment 2, where the corresponding *MSEs* were only 4,965 and 8,821, respectively.

Somewhat puzzling is the apparent decrease in the magnitude of the current incentives trend for SW and SWCI costs after Session 2. This decrease could in part be accounted for by the corresponding linear decrease in basic switch cost across sessions. However, another factor may have been the adaptive speed criterion for zaps. Recall that this criterion was defined as a RT faster than the 75th percentile RT of comparable trials of the preceding block and was designed to hold the frequency of reward constant across tasks and trial types by computing separate criteria for letter and digit switch and repeat trials. Consequently, participants may have learned after a time that increased effort on the high-incentive task would not result in a consistently greater number of zaps earned, leading to a reduced engagement of this strategy and the maintenance of a small but much diminished benefit on switching performance.

## GENERAL DISCUSSION

Three major findings emerged from the present studies. First, it was revealed that motivation can exert a considerable influence on the efficiency of on-line attention control processes. This effect was most clearly illustrated by the results of Experiment 2, where voluntary switching of task set was faster when switching from the low- to high-valued task than vice versa. This finding is particularly noteworthy given the relatively subtle manipulation of motivational value applied in this research. Both tasks were associated with a positive incentive value that differed in magnitude by only four reward points per trial. Moreover, the motivational manipulation was confined solely to the experimental context, involved no monetary reward, and bore no relation to participants' prior experience or future activity outside the laboratory.

Second, task motivation did not simply have a global facilitating influence on performance. Motivational incentives selectively impacted indices of task switching, affecting neither simple task execution nor the resolution of attentional challenge arising from the presence of a competing foil. This selective effect was highly reliable in Experiment 2 for both switch cost (SW cost) and switch-with-cue-inhibition cost (SWCI cost). While the selective effect of differential task motivation on switching was less reliable under the conditions of Experiments 4 and 5 and therefore failed to reach statistical significance, the direction and magnitude of the mean SW cost and SWCI cost differences for the low- and high-motivated tasks are indicative of a consistent trend favouring attention switching from the low- to the high-motivated task.

This is in distinct contrast to the magnitude of the differences between the low- and high-motivated tasks for both base RT and cue inhibition cost, which were negligible in Experiments 2 and 4, and generally quite small in Experiment 5. In addition to providing further support for the distinction between different components of attention, this outcome suggests that motivation can modulate cognitive and attentional processes in a highly selective fashion through specific mechanisms.

Third, motivational experience with the tasks during the initial training phase seemed particularly influential. In Experiment 2, initial experience with differential task incentives introduced a persistent bias during subsequent set switching, during which equal task incentives were in effect. In Experiment 4, following initial experience with equal incentives, the influence of subsequent differential incentives on set switching was limited to a non-significant trend. Finally, differential incentives applied during the switch task in Experiment 5 were able to neutralize, but not reliably overturn participants' prior experience with reversed differential incentive values experienced during the training phase.

I argue, below, that these results do not support the view that prior or current motivational experience directly influenced stimulus-response bonds or task set activation levels. Rather, the findings suggest that *prior* motivational experience acts primarily by adding a bias to endogenous intervention by the supervisory attention system, and that *current* motivational experience may directly influence the supervisory system through adoption of a voluntary strategy that explicitly incorporates incentive values. In neither case did the

motivational manipulations affect the processes implicated in basic task execution or task set cuing by the competing foil since both these processes operate through exogenous triggering, without the intervention of supervisory control.

#### Motivation Effect as Strengthening of S-R Bonds

From a behavioural reinforcement perspective, motivational incentives may be expected to enhance performance by differentially strengthening the associations between stimuli and their required responses (here, the letter and digit stimuli and their left and right hand responses). Such an explanation, however, is inconsistent with the pattern of results of this research. First, in neither Experiment 2 nor 5 did the differential incentives applied during training affect reaction times on letter and digit task training trials. It is unlikely that this absence of a motivational effect during training was due to insufficient experience with the differential incentives. In Experiment 5, where performance early and late in training was contrasted, motivational incentives did not affect performance even late in training. In fact, across all incentive experiments participants tended to respond during the training phase more quickly on letter task than digit task trials, regardless of whether the letter task incentives were greater, smaller, or equal to digit task incentives. Second, performance during the switch task on repeat/neutral-foil trials (base RT) was similarly unaffected by either prior or current task incentive manipulations. Performance here was approximately equal on letter and digit task trials, regardless of incentives. This again indicated the absence of a direct

motivational effect on simple task processes since these trials involved only basic task execution upon presentation of the stimulus, without any additional attention challenges. Lastly, the pattern of asymmetry in the switch costs here is different from the asymmetry that arises from task dominance or simple strengthening of one task set over the other, suggesting that the motivational bias introduced through incentive manipulations operates via a different mechanism (see below, *Asymmetric Switch Costs and Motivation*).

#### Motivation Effect as an Intentional Incentive-driven Strategy

From a cognitive strategy perspective, motivational incentives may be expected to enhance performance through the adoption of a rational and explicit, or even implicit, strategy devised to maximise reward gains (Erev & Gopher, 1999). Again, such an explanation cannot account for the entire pattern of current findings. In Experiments 4 and 5, where differential incentives were applied during the switch task itself, intentional strategies may have come into play. Consistent with the notion of *voluntary engagement* of supervisory attention control, following completion of the experiment roughly one third of participants reported that the differential value of letter and digit zaps had affected their strategy, whereas two thirds of participants claimed to have adopted no strategy based on the differential incentive structure and approximately half said they hadn't even paid attention to the difference. Thus, the degree to which an optional, intentional strategy is engaged may be influenced by the perceived importance of incentive value differences. This could account for the increased variability across participants that resulted in

non-significant effects of motivation on task switching in these two experiments, despite rather large differences in the magnitude of SW cost and SWCI cost for the low- and high-incentive tasks.

In Experiment 2, differential incentives were applied during the training phase only, and all participants received equal incentives for the letter and digit tasks during performance of the switch task itself. Consequently, it is highly unlikely that an endogenous strategy favouring one task over the other would have been adopted during the switch task. Interestingly, upon debriefing all participants claimed to have paid no attention to the differential point values during training and cared only about getting as many 'zaps' as possible, regardless of the point-value of the zaps. Indeed, some participants needed to be reminded during debriefing that letter and digit zaps had been differentially rewarded in the training phase. Although these incentive manipulations did go on to have a powerful influence over performance during the subsequent switch task, the evidence points to a non-strategic mechanism.

#### Motivation Effect as Modulation of SAS Intervention

As discussed above, neither a traditional behavioural reinforcement nor cognitive strategy account can adequately explain the motivational effects obtained in this thesis, especially the highly selective influence of prior motivation on attention switching in Experiment 2. I propose that the motivational bias arising from *prior* differential incentives affected attention switching through modulation of input from the supervisory attentional system (SAS). Such modulation either facilitated or inhibited SAS intervention

during switching, depending on the relative motivational significance of the task sets. In contrast, prior experience with differential task incentives did not influence either base RT or cue inhibition cost since performance in these instances involved exogenous, stimulus-triggered activation of task set, not endogenous control. *Current* motivational incentives (Experiments 4 and 5), however, may have operated through an explicit strategy adopted by the SAS to enhance overall point earnings. When engaged, this additional SAS intervention facilitated switching to the currently more valuable task set and was able to overcome prior incentive biases. The rationale underlying this interpretation follows.

Results from Rogers and Monsell (1995) suggest that the letter and digit task sets acquired during training are triggered automatically upon presentation of a corresponding stimulus. On repeat/neutral-foil trials, only the appropriate task set is triggered and performance proceeds unimpeded since there is little, if any, task set competition (the appropriate task set is already primed and no foil is present to trigger the competing task set). On repeat/competing-foil trials, however, the inappropriate task set is automatically triggered by the foil, causing interference and requiring the resolution of task set competition before the response can be carried out. This competition, or interference, is thought to be responsible for the increase in reaction time observed on competing-foil trials, the cue inhibition cost. Rogers and Monsell argue that this is the same stimulus-triggered activation of task set exhibited by capture errors in normal individuals, and by utilization behaviour observed in patients with frontal lobe damage. In these cases, an

involuntary habitual action is triggered by an environmental stimulus and performed unintentionally due to a momentary lapse of control in normal individuals, and a pathological loss of executive control in patients with frontal lobe damage.

In both capture errors and utilization behaviour, the action undertaken is *not* goal-directed or motivated, and so arguably may well bypass processes that assess the value of an action. Similarly, both performance on repeat/neutral-foil trials and exogenous triggering by a competing foil may automatically engage corresponding task sets. Accordingly, one would expect to obtain a cost due to inappropriate exogenous cuing by the competing foil, but the *magnitude* of the exogenous cuing to be resolved would be identical for both the high-motivated and low-motivated task foils since this exogenous cuing would not be influenced by motivational assessment. This is what obtained in the present series of experiments. As in the traditional Rogers and Monsell paradigm, the presence of a competing foil brought about an increase in reaction time as compared to neutral-foil trials for both the high- and low-motivated tasks. However, motivational manipulations did not affect the magnitude of this difference (the cue inhibition cost) because, I contend, the foil automatically and *equally* triggered the competing task set, irrespective of whether it was associated with the high- or low-motivated task. This argument would also apply to competing foils on switch trials. In Experiment 2, differential incentives led to faster switching to the high-motivated than low-motivated task, but the difference in switch costs was not affected by the motivational value of the competing foil. That is, although switching was

slower overall when a competing foil was present (i.e., SWCI costs were larger than SW costs), the RT increase was roughly identical for both the high- and low-motivated tasks, 134 ms and 141 ms respectively. This provides further evidence of the motivational neutrality of task set triggering by the competing foil.

In contrast to the automatic, stimulus-triggering of task set implicated in both base RT and CI cost indices, most evidence to date (see Introduction) suggests that switching between competing task sets requires context-appropriate, goal-directed control of attention. In addition, there is considerable evidence that this switching process occurs in two stages, an endogenous preparatory stage and a stimulus-triggered implementation stage. According to the Norman and Shallice (1986) model, endogenous preparation would involve the intervention of a supervisory attention system (SAS) that actively raises or lowers schema activation levels in order to bias contention scheduling of task set selection toward meeting current goals. The highly selective impact of motivation only on indices of attention switching suggests that motivational incentives are having a direct modulatory influence either on the operation of the SAS itself, or on the input of the SAS to the lower-level contention scheduling system. One obvious possibility is the incorporation of the incentive value of the goal into explicit performance strategies mediated by the SAS. As argued above, this may well occur in Experiments 4 and 5, where differential incentives during performance of the switch task itself are in effect. However, results of Experiment 2, where differential incentives during training are followed by equal incentives during the switch task, point to an implicit

modulation of the input signal from the supervisory control system to lower-level task set selection processes. The strength of this modulation would depend on motivational outcomes of prior task performance experiences. A possible physiological mechanism for such modulation is presented below in the section *Speculations Regarding Underlying Neural Mechanisms*.

In summary, the present results suggest that acquired motivational biases operate primarily to guide voluntary, context-specific, goal-directed behaviours, and have little, if any, direct influence on habitual, automatized actions. If one views habitual responses, or automaticity, as a form of acquired modularity, it is interesting to note that Fodor (1983) made a similar proposal within a very different theoretical context. He argued that modularized processes enable fast responses because they are encapsulated and hence shielded from top-down influence. Only a limited amount of information needs to be considered and one does not need to decide whether that information is worth processing; one merely computes set transformations on *triggering* data. In contrast, unencapsulated, controlled behaviours such as voluntary attention switching would be open to, and in many situations may benefit from, input regarding the motivational value of a given action choice.

#### Possible Methodological Influences

##### Predictability of Switching

An additional factor which could have further influenced the selectivity of motivational effects is predictability of attentional challenge. Specifically, in this paradigm switching is predictable, but the presence of a competing foil is

not. If motivational influences are engaged through expectancies prior to stimulus onset, predictable switching of task set may have enhanced the effect of differential incentive biases. Conversely, the unpredictability of competing-foil trials may have made it difficult for motivational expectancies to come into play. While the present data cannot speak directly to this possibility, the absence of a motivational effect on repeat/neutral-foil trials makes an explanation based purely on predictability less plausible. In Experiment 2, for example, although both switch and repeat trials were equally predictable, a motivational bias obtained for switch trials (819 vs. 735 ms) but not repeat trials (539 vs. 523 ms). At the least, therefore, such an explanation would need to consider the issue of predictability in the context of endogenous intervention processes.

The importance of predictability could be assessed through two different experimental modifications to the present design. First, trials could be structured to make both switching and the presence of a competing foil predictable. This could be accomplished by superimposing upon the current double alternation of letter and digit task trials alternation between a four-trial cycle of neutral-foil trials and a four-trial cycle of competing-foil trials. This would permit investigation of the influence of prior and current incentives on the inhibition of *predictable* task cuing from the competing foil. If, as argued above, motivational biases act primarily through modulation of endogenous control processes, one would predict a motivational effect to the extent that endogenous preparation can facilitate inhibition of a competing foil. However, given that competing-foil trials were always unpredictable in the original

Rogers and Monsell design, the extent to which inhibition of such cuing can be endogenously prepared for has yet to be examined. If task cuing is entirely stimulus-triggered and cannot be prepared for in advance, no effect of motivational incentives would be predicted, even for predictable competing-foil trials.

A second way to investigate the issue of predictability would be to apply differential prior and/or current task incentives within an *unpredictable* switching version of this paradigm. For example, one could cue the required task set by coloured background (see, for example, Rogers et al., 1998) rather than quadrant location (thereby avoiding the introduction of variability due to location unpredictability), and pseudo-randomly vary the occurrence of repeat and switch trials, making the occurrence of a switch trial unpredictable. If, under these conditions, an endogenous preparatory control process is not engaged during task switching, an effect of motivational incentives on switch cost should no longer obtain.

#### Strength of Motivational Manipulations

The motivational manipulations in the current series of experiments were relatively subtle. The point-based incentives had no impact outside the laboratory and payment for participation was in no way related to the participant's performance or total score. Therefore, it could be argued that stimulus-triggered processes such as those indexed by base RT and CI cost are not immune, but are simply less sensitive, to motivational modulation than are goal-directed processes such as endogenous attention switching. Results from

these experiments clearly cannot rule out the possibility that had more powerful motivational incentives been used, effects on basic task execution and control of inappropriate task-set cuing would have obtained. Such a finding would support a weaker version of the strong interpretation proposed earlier and require a modification of, or addition to, the proposed mechanism(s) by which motivational signals modulate cognitive activity in this task. In particular, it would suggest a potential direct influence of motivation on the lower-level schema activation and selection processes.

#### Asymmetric Switch Costs and Motivation

Further evidence of the distinct nature of motivational influences on the control of switching comes from comparison of the pattern of asymmetric switch costs in the present studies versus those obtained by Allport and colleagues (Allport & Wylie, 1999; Allport & Wylie, in press; Allport et al., 1994; Wylie & Allport, 1999). In the Allport studies, where task dominance has developed through differential amount or recency of practice with alternative task sets, participants are faster overall and experience less interference from the irrelevant stimulus dimension when performing the dominant task than the nondominant task. They are nevertheless *slower* in switching to the dominant task than in switching to the nondominant task. Allport and colleagues account for this paradoxical asymmetry in switch costs in terms of the strength of the underlying schemata, or stimulus-response set bonds. Thus, for example, switching from the nondominant to the dominant task is slower due to negative priming that results from strong inhibition of this

dominant task schema on the preceding nondominant task trial. Switching to the nondominant task is faster since relatively little inhibition of the nondominant task schema is required on the preceding dominant task trial.

In the present experiments, where experience with differential task incentives could be characterized as producing dominance of the high-motivated task over the low-motivated task, the results are very different from those of Allport and colleagues. Here, participants perform *equally* well in both tasks on the repeat trials and are *equally* slowed in both tasks by the presence of a competing foil. Furthermore, they are *faster* in switching to the dominant (high-motivated) task than in switching to the nondominant (low-motivated) task -- the reverse pattern of asymmetry to that of Allport and colleagues. The type of task dominance created by differential motivational experience therefore appears to operate through different mechanisms than the processes affected by increased practice.

Interestingly, subjective familiarity of alternative task sets was a better predictor of speed of switching in Rubinstein et al. (in press) than was dominance as defined by mean RT in pure task blocks. Similar to the present study, participants were faster to switch from the less familiar to the more familiar task than vice versa. Given the potential influence of motivational or affective factors on subjective ratings, it is possible that similar motivational mechanisms underlie both the Rubinstein et al. findings and those obtained here.

### Switching to versus Switching from

A related issue that arises when considering the source of asymmetric switch costs is whether the asymmetry arises from differential ease in switching *from* the previous trial task set or differential ease in switching *to* the current trial task set. For example, in Experiment 2 subjects may have been faster when switching from the low-motivated task to the high-motivated task than vice versa because it was easier to disengage attention from the low-motivated than high-motivated task set, because it was harder to engage the low-motivated than high-motivated task set, or both.

In the case of task dominance due to differential practice, Allport and Wylie (Allport & Wylie, 1999; Wylie & Allport, 1999) convincingly illustrate through clever experimentation that the pattern of task set activation and inhibition engaged on preceding trials has a very strong impact on current trial performance, particularly in the case of switch trials. Thus, they reason, it is primarily the need to overcome inhibition of the competing task set on the trial *from* which the switch is made that is responsible for asymmetric switch costs. However, as argued above, it is unlikely that differential task schema strength, which presumably underlies the Allport et al. asymmetry effect, would also underlie the motivation-based asymmetry effect obtained in the present research since a reverse pattern of asymmetry, and equal performance in both tasks on repeat neutral-foil and on repeat competing-foil trials was found here. Consequently, disengagement from the preceding-trial task set may or may not play as important a role in the motivation-based effect on switching

obtained here. If indeed disengagement does contribute to motivation-based switch costs, it is probably due to a different process than negative priming.

Rubinstein et al. (in press) found that the task familiarity of both the preceding and current trials contributed independently to the statistical prediction of switch costs. Specifically, it was both easier to switch *from* a less familiar task and to switch *to* a more familiar one. While this analysis may be tapping more subjective influences on attention that are akin to motivation, it remains to be determined whether distinctly motivational influences modulate primarily the disengagement or engagement operations of task set selection.

Employing the Posner cuing paradigm (Posner, 1980; Posner, Snyder, & Davidson, 1980) along with positive and negative incentive and feedback signals, Derryberry (1989) examined the impact of motivation on the engage and disengage components of attention in the visuospatial domain. In the basic version of this paradigm, a target stimulus appears in one of two spatial locations and the subject must press a key as soon as the target is detected. Presentation of the target is preceded by either a valid, invalid, or neutral cue. On neutral trials, the cue provides no information regarding the location of the upcoming target. Performance on these trials serves as a baseline. On valid trials, the target appears at the cued location. The RT difference between valid and neutral trials indexes the benefits of advanced engagement of attention at the cued location. On invalid trials, the target appears at the uncued location. The RT difference between invalid and neutral trials indexes the costs of disengaging attention from the cued location before moving to the actual target location.

In Derryberry (1989), changes in the motivational significance of positive and negative target locations (where points could be gained or lost, respectively) as a function of the need state arising from positive or negative feedback on the previous trial selectively affected cuing costs, but not cuing benefits. For example, following negative feedback participants were slower to disengage from positive than negative locations on invalid cuing trials, but were no faster to engage positive than negative locations on valid cuing trials. If one interprets the effect of negative feedback as increasing the incentive value of potential point gains at positive locations, a similar process may have operated in the present study, where incentive value was instead manipulated by actual incentive magnitude with feedback kept roughly constant for the high- and low-motivated tasks. However, in addition to the obvious differences in motivational manipulations between these two studies, it is important to recognize the difference in attentional mechanisms involved. The Posner cuing paradigm employed by Derryberry is primarily designed to assess visuospatial attention shifting associated with the posterior attention network. In contrast, the paradigm used in this research is designed to assess voluntary attention switching between cognitive task sets associated with the anterior attention network.

Given the proposed differences in neural mechanisms implicated most strongly in each of these paradigms, it would be of great interest to adapt the Posner cuing paradigm to examine directly the effect of motivation on disengage and engage components of switching between task sets. Rather than cuing location, advance cues would validly or invalidly cue the upcoming task

set. The costs and benefits as a function of the differential motivational significance of the task sets could be used as a measure of motivational influences on engage and disengage operations. Such an adaptation without motivational manipulations has already been employed to examine the control of task set switching in Parkinson's patients (Hsieh, Hwang, Tsai, & Tsai, 1996) and shows promise for use with incentive applications.

#### Prior versus Current Incentive Effects on Performance

As previously discussed, results of this thesis revealed that prior incentive experience during training had a relatively large, reliable, and persistent effect on subsequent performance. In Experiment 2, following 384 trials of training with differential point incentives for letter and digit task performance, a motivational bias on task switching favouring the previously high-incentive task persisted throughout an additional 768 trials in which equal incentives for the letter and digit task were in effect. Moreover, this motivational effect did not reliably decline as a function of exposure to equal incentives. Thus, the change in incentive structure to equal task incentives during the switch task seemed unable to modify the initial bias created by differential task values. This seemingly implicit influence of prior motivational experience selectively and persistently affected the efficiency of voluntary attention switching by speeding switching to the previously high-incentive task or slowing switching to the previously low-incentive task. In contrast, when participants received equal task incentives throughout both the training and

switch task phases, there was no difference between switching performance on the letter and digit tasks.

In Experiment 4, where prior experience during training with equal task incentives was followed by differential task incentives during the switch task, there was an immediate trend favouring switching to the now high-incentive task and the magnitude of that trend grew from Session 1 to Session 2 of the switch task. However, in contrast to the reliable influence of prior motivational experience in Experiment 2, current motivational incentives failed to produce a reliable effect on performance in Experiment 4. As argued earlier, this suggests that a different motivational mechanism was underlying the trend observed in this experiment, specifically, an explicit, voluntary, and optional strategy that can be immediately deployed, rather than an implicit motivational influence accrued through extended experience. As a result of initial exposure to equal incentives, the default pattern of equal switching between tasks would dominate performance unless an endogenous strategy were engaged to favour the now high-incentive task. If this optional strategy were applied inconsistently, current motivational effects on attention switching between tasks would then fail to reach significance.

A similar effect obtained in Experiment 5, where following prior experience with differential incentives during training, an immediate trend in favour of current incentives was observed. Again, the immediate and highly unreliable influence of current incentives may be explained by the engagement of an explicit, endogenous strategy that was inconsistently applied leading to variability both within and across subjects.

While the engagement of an optional endogenous strategy may be a plausible explanation of the differential reliability of prior and current motivational incentives on performance, it cannot account for why the presumably more reliable implicit motivational mechanism failed to adjust to the change in task values applied during the 768 trials of the switch task in Experiments 2 and 4 and the 1536 trials of the extended switch task in Experiment 5. One possibility consistent with results across all three experiments is that initial task incentive exposure is particularly resistant to revision, but without an underlying theoretical rationale this is hardly more than a restatement of the results. Rather, it could be argued that the overall attentional demands of the training and switch task phases of these experiments may have contributed to the persistence of the initial motivational values associated with the letter and digit tasks. Research on latent inhibition, the slowing of associative learning following nonreinforced stimulus preexposure, suggests that attention processes may mediate the learning of reward contingencies (Redgrave, Prescott, & Gurney, 1999b; Weiner, 1990). In terms of the present experiments, the additional attention demands of the switch task, in contrast to the relatively easy performance demands during training, may have reduced the allocation of attentional resources to the relative point values of letter and digit zaps. As a consequence, greater tuning of the motivational significance of the letter and digit tasks would take place during the training phase and tend to persist through performance of the switch task. In contrast to the implicit motivational mechanism, the incorporation of current motivational incentives

into an explicit strategy may not be similarly affected. Here, incentive influences would be mediated by cognitive strategies, as another source of information to guide performance, rather than by an implicit mechanism that acquires task value through experience.

The effect of differential attention demands of training and switch task phases on *implicit* learning of motivational significance would apply equally to all three incentive-manipulation experiments, but may have been additionally amplified in Experiments 2 and 4. In Experiment 2, the equal value of incentives during the switch task may have further reduced the salience of these current task values, thereby resulting in still slower learning and influence of current incentives on the proposed implicit motivational mechanism, and continued influence of prior motivational experience on task switching. In Experiment 4, attentional allocation to current differential incentives may also have been further damped through a process akin to latent inhibition or learned irrelevance. In both these phenomena, learning of new reinforcement contingencies is slowed due to preexposure during which an animal learns to ignore a stimulus required in the later learning environment. During training, participants may have learned to attend to the occurrence of immediate auditory feedback following zaps (responses for which points were earned), while ignoring the number of beeps making up that signal since both letter and digit zaps were equally signalled by a series of four beeps. Thus, the mechanism underlying implicit motivational influences may have been resistant to revision not only due to increased attentional demands of the switch task itself, but also because they had learned to ignore the relative

value of letter and digit zaps since this was largely irrelevant during the initial training phase.

To summarize, this interpretation is based on several assumptions, notably: 1) motivational effects on attention switching can be mediated by either an implicit motivational mechanism or an explicit strategy; 2) motivational significance is acquired by the implicit motivational mechanism through extended experience, whereas an explicit strategy to maximize point gains can be immediately formulated and engaged; 3) some attentional resources need to be allocated to the value of letter and digit zaps during performance in order for the implicit motivational mechanism to benefit from experience; 4) the influence of an explicit strategy is highly variable since it requires controlled, explicit engagement; and 5) the disposition of the implicit motivational mechanism will act as a default unless overridden by an explicit strategy that incorporates the current task incentive values.

At present, this interpretation is clearly speculative, but suggests a number of follow-up experiments. For example, the need to allocate attentional resources to processing of auditory reward feedback in order for the postulated implicit mechanism to acquire task values could be tested in a modification of Experiment 2. Participants would first undergo training and the switch task as currently designed, with differential incentives during training and equal incentives during the switch task. Following this, participants would receive a second round of "training" (i.e., blocked task trials) in which incentive manipulations are reversed, again followed by a switch task phase with equal incentives. Presumably, experience under the relatively simple task demands

of the blocked training task would leave sufficient attentional resources for processing the differential task feedback and permit new learning by the mechanism mediating implicit influences of motivational value on performance. This, in turn, would lead to the opposite pattern of incentive values on subsequent task switching from that obtained following initial training. Second, the influence of learned irrelevance of task point values could be examined by assigning another group of participants to equal incentives during both the initial training and switch task phases, followed by the same second round of differential training and equal switch task incentive described above. If initial exposure to equal incentives leads participants to ignore subsequent differential task values, the effect of the second round of training with differential incentives on subsequent task switching should be attenuated. Importantly, in both these experiments the application of explicit incentive-based strategies during the switch task would be minimized since both the letter and digit tasks would at that time be assigned equal incentives.

#### Speculations Regarding Underlying Neural Mechanisms

Converging evidence from studies of neuropsychological patients (e.g., Hayes, Davidson, Keele, & Rafal, 1998; Rogers et al., 1998) and animal-based neurophysiological research (e.g., Masterman & Cummings, 1997; Mink, 1996; Redgrave, Prescott, & Gurney, 1999a; Watanabe, 1998) suggests that both the frontal cortex and the basal ganglia are implicated in task switching and the integration of the behavioural and motivational significance of tasks. More specifically, the planning and preparation phase of task switching appears

most closely associated with the executive control functions of the frontal cortex and is impaired in patients with frontal lobe damage, whereas the implementation phase appears to be related to competitive striatal action control and is impaired in patients with Parkinson's disease (PD), a progressive neurological disease associated with striatal dopamine depletion (Hayes et al., 1998).

#### Proposed Mechanisms Underlying Task Set Switching

In a modified version of the Rogers and Monsell (1995) predictable switching paradigm used in the present research, Rogers et al. (1998) found impaired switching early in performance in both left and right frontal lobe patients. Persistent switching deficits on switch trials with a competing foil present in left frontal lobe patients indicated that the left frontal cortex continued to play a role in the control of set switching, even late in performance. In contrast, Parkinson's patients were unimpaired early in switching, but showed increasing errors on switch trials over time, leading Rogers et al. to propose that striatal dopamine depletion results in progressive behavioural inflexibility and the inability to implement task set reconfiguration signals initiated by the frontal cortex.

Stablim, Leonardi, Mazzoldi, Umiltà, and Morra (1994) compared performance of patients with severe closed head injury (CHI) affecting the frontal cortex on both predictable and unpredictable switching with unidimensional stimuli. In the predictable condition, where advanced preparation was possible, switch costs were three times greater in CHI

patients than normal controls. However in the unpredictable condition, where switching could be completely stimulus-triggered, the mean switch cost of CHI patients was equal to that of normal controls. This again suggested that the executive, preparatory component of attention switching is impaired in frontal lobe patients, whereas automatic, stimulus-triggered switching is spared.

Finally, Hayes, Davidson, Keele, and Rafal (1998), in a study of unpredictable task set switching with univalent and bivalent stimuli found that Parkinson patients were slower both in switching between tasks and in inhibiting task set cuing from the currently irrelevant task dimension of bivalent stimuli. Interestingly, Parkinson patients have been found to perform normally in Posner's spatial cuing paradigm (Rafal, Posner, Walker, & Friedrich, 1984), providing further evidence of the distinction between the mechanisms underlying visuospatial shifting of attention (posterior network) and those underlying task set switching (frontal cortex and basal ganglia).

Importantly, the frontal lobes and the basal ganglia are densely interconnected via highly structured, parallel circuits (Alexander & Crutcher, 1990; Alexander, Crutcher, & DeLong, 1990; Chow & Cummings, 1999; Masterman & Cummings, 1997) that project from specific areas of the frontal cortex to the striatum, to the globus pallidus and substantia nigra, to the thalamus, and then back to the same originating regions of the frontal cortex. Five such circuits have been identified (each named for the area of the frontal cortex from which it projects). These circuits subserve specific functions and remaining largely segregated throughout cortical and subcortical regions. Three of these circuits, projecting from areas of the prefrontal cortex, may play an

essential role in coordinating activity between preparatory and implementation phases of attentional set switching, and in mediating motivational influences on performance.

The dorsolateral circuit is closely implicated in the executive control of behaviour. Dorsolateral regions of the prefrontal cortex are associated, in part, with working memory functions that permit the integration and manipulation of information in the service of goal-directed behaviour. Damage to this circuit is characterized by impairments in planning, memory search strategies and task set switching, and by increased dependency on environmentally-triggered behaviour. The anterior cingulate circuit, with its converging projections from the 'limbic' regions, is closely associated with motivational and emotional behaviour, and lesions within this system are marked by apathy and impaired initiation of behaviour (either motor or cognitive). The orbitofrontal circuit, in addition to mediating the inhibition of socially inappropriate behaviour, is implicated in the recognition of reinforcing stimuli and modulation of behaviour as a function of changing reinforcement contingencies. Dysfunction in this circuit can also lead to difficulty in set switching and is believed to underlie obsessive-compulsive disorder (Chow & Cummings, 1999).

An important feature within each of these circuits is their further subdivision into direct and indirect pathways from the striatum to the globus pallidus. The direct pathway has a net excitatory effect on behavioural output, whereas the indirect pathway has a net inhibitory effect on behaviour. It is the opposition of these two pathways that is hypothesized to permit striatal gating of competing motor and cognitive programs (Mink, 1996), and thus may serve

a contention scheduling function in the coordination of excitatory and inhibitory links between competing schemata (Norman & Shallice, 1986). The frontostriatal projections may further provide the physiological mechanism by which the supervisory attention system exerts an endogenous bias on the selection of action schemata. More direct physiological evidence comes from single cell recording within the basal ganglia-thalamic circuits of Parkinson's patients by Kropotov and Etlinger (1999), who observed selective neuronal firing patterns consistent with the involvement of the basal ganglia in coordinating task set selection and attention switching. In addition, basal ganglia activity increased in amplitude when a stimulus was actively attended and during voluntary control of behaviour, providing further evidence of the involvement of these circuits during goal-directed action.

#### The Role of Dopamine in Behavioural Switching and Motivation

Dopaminergic neurotransmission is broadly associated with the activation of cognitive or motor behaviour and has been closely implicated in both attention switching and motivation, as well as working memory. Originating in the ventral tegmental and substantia nigra cell bodies located in the brain stem, dopaminergic cells project widely, via three subsystems, to the frontal cortex (mesocortical), the limbic regions (mesolimbic), and the basal ganglia (mesostriatal), and are integral to the normal functioning of frontostriatal circuits. Redgrave, Prescott, and Gurney (1999a) recently proposed that tonic changes in dopamine (DA) transmission may be associated with a general increase or decrease in the responsiveness of striatal-mediated

behavioural switching, and phasic changes with triggering the interruption and switching of on-going behaviour in response to behaviourally or motivationally salient stimuli.

Consistent with this proposal, an increase in tonic levels of DA has been found to facilitate behavioural switching, whereas depletion of DA suppresses both initiation and switching of behaviour (Dunnett & Robbins, 1992). It is a decrease in tonic striatal DA levels that is believed to underlie the set switching deficits in Parkinson's disease patients, as demonstrated, for example, by Hayes et al. (1998) through comparison of set switching performance in patients both on and off L-Dopa medication.

Single cell recordings in awake monkeys (Schultz, 1998; Schultz, Tremblay, & Hollerman, 1998) have revealed that a brief phasic increase in the firing rate of dopaminergic cells immediately follows delivery of unpredicted rewards. After learning, these phasic responses transfer to the earliest reward-predicting stimulus, and no change in the rate of firing occurs upon actual presentation of the reward unless it is better than predicted (phasic increase) or worse than predicted (phasic decrease). These findings led Shultz and colleagues to conclude that phasic dopamine responses act as a global error signal in the prediction of reward. However, given that DA neurons also fire in response to novel stimuli and respond before foveal identification of the stimulus can take place, Redgrave et al. (1999b) argued that phasic DA bursts may instead act as an imperative signal to switch attentional and behavioural responses to stimuli of potential significance.

Of particular relevance here, dopaminergic projections from the substantia nigra pars compacta terminate on the same striatal neurons that receive prefrontal cortical input in such a fashion as to permit highly selective modulation of incoming cortical signals (Masterman & Cummings, 1997; Mink, 1996). In addition, descending projections from the anterior cingulate and limbic regions to the substantia nigra pars compacta (SNpc) may further allow motivational information mediated by the anterior cingulate circuit to influence, through its modulation of SNpc DA activity, the cognitive and motor inputs of the other largely segregated frontal-subcortical circuits (Masterman & Cummings, 1997).

Returning now to the results of this thesis, these dopaminergic inputs to the striatum may be one mechanism by which the acquired motivational value of letter and digit task sets could modulate supervisory control system input to lower-level task set selection processes during attentional set switching. This mechanism would not require that the motivational significance of letter and digit task sets be explicitly represented in working memory, but rather would afford an implicit influence of motivation acquired through prior experience with differential task incentives. The implication of dopamine in both behavioural switching and motivation may also relate to the observed sensitivity of switching processes to the motivational manipulations applied in the current paradigm.

Finally, it should be noted that dopaminergic cells are not the only neurons that selectively respond to reward-related information. For example, Kimura (1997) found that during the course of conditional learning, an

increasing proportion of tonically active striatal neurons develop a pause in their tonic firing upon presentation of reward-predictive stimuli, a response he argues is initially conditioned by dopaminergic inputs to the striatum. It is not clear, however, what selective role these neurons might play in task switching and why such a conditioned response would not also have affected both basic task execution and the strength of inappropriately-triggered task set cuing in the present study.

Watanabe (1998; 2000) has identified reward- and reinforcement-related neurons in both the orbital and lateral regions of the prefrontal cortex. However, only neurons in the lateral prefrontal cortex also coded the behavioural demands associated with reward (for example whether a reward is associated with a go or no-go response) and the correctness of the response regardless of the receipt of a reward. Given that the lateral prefrontal cortex receives projections from both the orbitofrontal and posterior cortex and has numerous neurons related to sustained cognitive representations (working memory-related neurons), Watanabe suggested that this region may play a critical role in integrating both motivational and cognitive information in the service of goal-directed behaviour. Perhaps it is this motivation-related activity in the lateral prefrontal cortex that mediated the explicit representation and influence of motivational incentives on task switching in Experiments 4 and 5 of the present thesis.

These proposed underlying neurophysiological mechanisms are obviously highly speculative at this point, but could be explored through single cell recording in a primate version of the present paradigm. One important

difference between such a study and the present human study would be the more central role of motivational reinforcement in the primate acquisition of the basic response pairings and switch task. In the present study, participants received detailed verbal instructions explaining both the task to be performed and the incentive values of the competing task sets. Therefore, reward feedback following zaps served as an additional incentive in the performance of the task, but was not essential in mediating the learning of the task *per se*.

While it is ethically impossible to explore these proposed underlying mechanisms through single cell recording in humans, advances in noninvasive brain imaging techniques have greatly enhanced the ability to study ongoing human brain activity. One such method, dense array (e.g., 128-channel) recording of event-related brain electrical potentials (ERP), now affords millisecond temporal resolution along with much improved source localization (Gevins, 1998; Gevins, Leong, Smith, Le, & Du, 1995; Tucker, Liotti, Potts, Russell, & Posner, 1994). Using dense array ERP methods along with filtering techniques, Luu and Tucker (1999) recently recorded the presence of oscillating electrical brain activity in centromedial and frontal cortex most suggestive of reverberant activation of frontal-subcortical circuits from striatal gating of response set competition. If, as proposed here, task incentives modulate striatal task set selection processes, then these motivational effects should be revealed in changes to this oscillatory activity. This methodology would not permit the detailed analysis afforded by single cell recordings and would be limited to inferred subcortical activity based on cortical recordings, but may present an initial strategy for investigating motivational modulation of

frontal-subcortical circuit activity in normally-functioning humans. In addition, one might look for changes in unfiltered, non-oscillatory prefrontal cortex activity correlated with current differential task incentive values reflective of explicit coding of motivational significance.

Another approach would be to investigate the performance of various neuropsychological patients on this motivational adaptation of the task switching paradigm. For example, would Parkinson's patients, who suffer from tonic depletion of striatal dopamine levels, also evidence reduced sensitivity to motivational signals mediated by phasic dopaminergic activity? One might also explore whether patients with damage to the ventromedial prefrontal cortex, who were unable to develop biasing signals based on prior rewards and penalties in the gambling task developed by Bechara and colleagues (Bechara et al., 1995; Bechara et al., 1997; Bechara et al., 1996), would also show reduced effects of differential incentives on task switching in the present paradigm.

#### Implications for Skill Development and Performance

The experiments conducted here begin to address basic issues related to the motivational modulation of attention control processes during performance of a complex task. As stated in the introduction, one of the long-term objectives of this programme of research is to develop better approaches to enhancing learning and performance. While further research is clearly required, preliminary consideration of at least some potential implications of the present findings for skill development will be briefly explored in this section.

First, the strong impact of initial motivational experience on attention switching obtained in this study indicates that early skill learning experiences may be particularly important in determining not only the likelihood of future engagement in a task, but also the *quality* of attentional processing during that future engagement. Findings revealed that the ease of attention switching between component tasks can be affected by differential task incentive values developed by the individual through prior performance outcomes. Thus, early patterns of success on various subcomponents of complex tasks may help shape a learner's attention during subsequent engagement. This suggests that, in addition to providing cognitive instruction during training, it may be important to enhance a learner's perceived value of key task components.

The persistence of early experience evidenced in the present research also points to the limitations of attention control mechanisms in overriding acquired motivational biases. On the whole, results suggest that voluntary attention control mechanisms can prevail over prior motivational dispositions, but only at a cost in efficiency and reliability of performance. In Experiment 1, participants were slower to intentionally switch to a previously low-incentive task, and in Experiments 4 and 5, participants appeared inconsistent in their ability to overcome prior motivational experience through voluntary strategies. Such findings may be related to the experience of performance blocks which prove resistant to revision by control strategies.

Finally, the experiential dynamics of skill acquisition and performance studied by Csikszentmihalyi and colleagues (Csikszentmihalyi & Rathunde, 1993; Csikszentmihalyi et al., 1993) fit well with the interpretation forwarded

in this thesis; namely, that acquired motivational biases serve primarily to guide voluntary, goal-directed behaviour and have little or no effect on automatized behaviour. Initial learning and performance is typically directed by explicit goals and instructions with few motivational cues to guide attention and action. Not surprisingly, such performance is often choppy and unsatisfying. Csikszentmihalyi and colleagues have found that once acquired skills are able to meet the challenges of the task, performers may begin to experience "flow" -- a phenomenological state characterized by feelings of intense involvement, effortless control of attention and action, intrinsic motivation, and positive affect. The underlying mechanisms linking these descriptive features of flow states have yet to be elucidated, but the results of this thesis suggest an intriguing possibility. It may be during such a flow state that performance is accompanied by acquired motivational signals that appropriately guide and reinforce attentional switching among component actions and their corresponding stimuli. Such signals would enhance both the fluidity of performance and the perception of a state of flow. Importantly, it is the fluidity of *control* processing during goal-directed performance that appears to be essential to the experience of flow. The fluidity of automatized action, present when an individual's skills surpass the challenge level of the task, instead engenders feelings of boredom or apathy. Thus, consistent with the present study, motivational and affective signals appear to accompany goal-directed activity, but not lower-level, automatized action.

Csikszentmihalyi and colleagues (1993) argue that it is the desire to continue experiencing flow and avoid boredom that drives learners to seek increasingly

complex challenges and skills and advance to ever higher levels of achievement. Thus, motivational and affective modulation of attention and performance may play an important role in facilitating both the quality and progress of skill acquisition.

#### Future Directions

The results of the present set of experiments raise numerous issues and avenues for further investigation, some of which were explored in greater detail earlier in this section. Perhaps the most intriguing outcome of this study was the dissociation between motivational influences on control of attentional set switching versus basic task execution and inhibition of task set cuing. It was proposed that this may represent a broader underlying sensitivity of executive attention control processes to motivational signals, which presumably serve to guide the direction of attention during goal-directed behaviour. Automatic, stimulus-triggered behaviours, in contrast, appear relatively insensitive to motivational input. In the paradigm employed here, the primary goal toward which control processes were engaged was task-set switching. Future research could explore whether other attention control functions show similar sensitivity to motivational biases by employing paradigms whose behavioural goals emphasize different control processes. Also of great interest, and now facilitated by recent advances in cognitive neuroscience and neuroimaging techniques, would be the exploration of the underlying neural mechanisms speculatively proposed above.

Another major question that arises from these findings concerns the source of the reaction time difference between high- and low-motivated task switches. As discussed earlier, it would be useful to determine whether the motivationally-based differences in switch costs are due to difficulty in switching away from a high-valued task or to ease of switching to a high-valued task. In other words, is it the holding power or the attracting power of the high-motivated task that is primarily responsible for differential ease of switching? Such detailed analysis should shed further light on the mechanisms by which motivation affects attention processes.

Finally, the present experiments were limited to the study of positive incentives on performance. Given the important role also played by negative incentives in guiding behaviour, this research should be extended to investigate the influence of negative motivational stimuli on attention control, and the impact of both positive and negative feedback on motivation and attention.

To conclude, cognitive psychologists, through carefully controlled experimentation, have revealed many insights into the operation of attention control processes during performance. As illustrated by the present research, these paradigms can be fruitfully employed to examine on-line modulation of attentional processes by motivational and affective factors. Continued exploration into the close interaction between both cognitive and non-cognitive determinants of performance holds considerable promise for further advancements in our understanding of human learning.

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## APPENDIX A

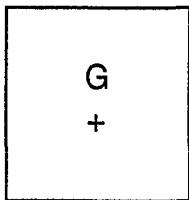
*Sample of Instructions from Experiment 1*

### Training Instructions

In a moment you will be shown a pair of characters in the centre of a square on the computer screen. Each character pair will be made up of either a symbol (#, +, &, %) and a letter, or a symbol and a digit:

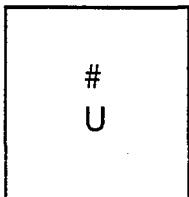
For the **letter task**, you are to indicate if the letter is a consonant (G, K, M, R) or a vowel (A, E, I, U) while ignoring the other character. If the letter is a consonant, press the "<--" key with your left index finger. If the letter is a vowel, press the "-->" key with your right index finger.

Example 1:



consonant  
↓  
left index

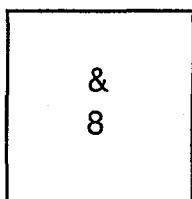
Example 2:



vowel  
↓  
right index

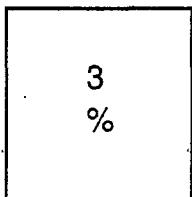
For the **digit task**, you are to indicate if the digit is even (2, 4, 6, 8) or odd (3, 5, 7, 9) while ignoring the other character. If the digit is even, press the “<--” key with your left index finger. If the digit is odd, press the “-->” key with your right index finger.

**Example 1:**



even  
↓  
left index

**Example 2:**



odd  
↓  
right index

You will alternate between 8 blocks of trials of the letter task and 8 blocks of trials of the digit task, with each block lasting about 2 minutes, for an approximate total of 30 minutes.

Please respond as quickly as possible without sacrificing accuracy. To ensure that you can respond quickly, please keep your fingers resting lightly on the keys at all times.

Do you have any questions?

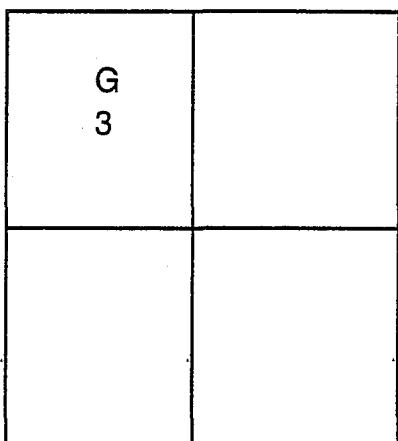
You may press any key to begin.

### Instructions

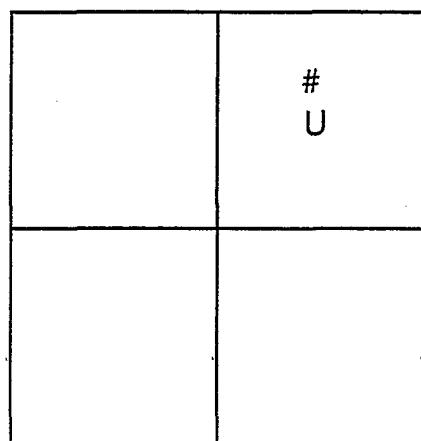
In this part of the experiment, you will be shown a pair of characters in one of four quadrants on the computer screen. Each character pair will be made up of one of the following combinations: either a symbol (#, +, &, %) and a letter, OR a symbol and a digit, OR a letter and a digit. On successive trials, the position of the character pair will move clockwise to the next quadrant.

When the character pair is in either of the **two top quadrants**, you are to perform the **letter task**. As in training, you are to indicate if the letter is a consonant (G, K, M, R) or a vowel (A, E, I, U) while ignoring the other character. If the letter is a consonant, press the "<--" key with your **left index finger**. If the letter is a vowel, press the "-->" key with your **right index finger**.

**Example1:**



**Example2:**

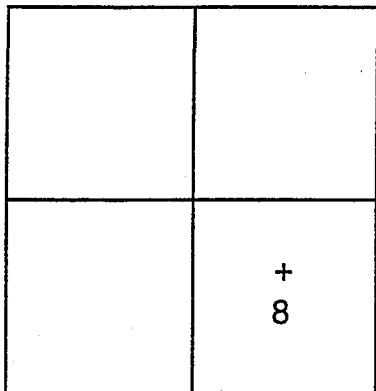


consonant  
↓  
left index

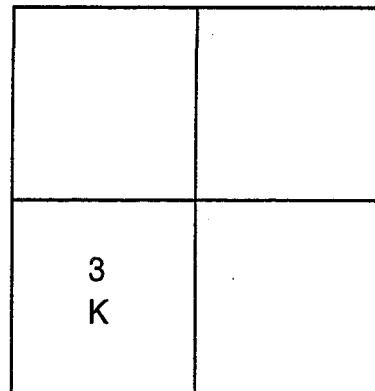
vowel  
↓  
right index

When the character pair is in either of the **two bottom quadrants**, you are to perform the **digit task**. As in training, you are to indicate if the digit is even (2, 4, 6, 8) or odd (3, 5, 7, 9) while ignoring the other character. If the digit is even, press the “<–” key with your **left index finger**. If the digit is odd, press the “->” key with your **right index finger**.

Example 1:



Example 2:



even  
↓  
left index

odd  
↓  
right index

Please respond as quickly as possible without sacrificing accuracy. To ensure that you can respond quickly, please keep your fingers resting lightly on the keys at all times.

Do you have any questions?

You may press any key to begin.

## APPENDIX B

*Tables of Mean RTs and Cost Indices for Experiments 1 through 5*

Table B1

*Mean RT (ms) and Costs (ms) by Tasks and Switch Task Session in Experiment 1 ( $N = 8$ )*

Trial Type/Cost	Session 1			Session 2			Average		
	Letter task	Digit task	$M$	Letter task	Digit task	$M$	Letter task	Digit task	$M$
Switch	1011	1021	1016	782	779	780	897	900	898
Repeat	714	671	693	609	592	601	662	632	647
Switch Cost	297	350	323	173	187	179	235	268	251
Competing-foil	900	886	893	740	721	730	820	803	811
Congruent	921	878	899	761	725	743	841	801	821
Incongruent	879	893	886	718	716	717	799	804	801
Neutral-foil	789	767	778	608	615	612	699	691	695
Cue Inhibition Cost	111	119	115	132	106	118	121	112	116

*Note.* Apparent minor discrepancies in mean values are due to rounding.

Table B2

*Mean Base RT (ms) and Costs (ms) by Prior Task Motivation and Switch Task Session for Differentially Motivated Participants in Experiment 2 (N = 16)*

Index	Session 1			Session 2			Average		
	Low <sup>a</sup>	High <sup>b</sup>	L - H <sup>c</sup>	Low	High	L - H	Low	High	L - H
Base RT	574	546	28	504	500	4	539	523	16
CI Cost	77	112	-35	80	79	1	79	96	-17
SW Cost	358	265	93	203	159	44	280	212	68
SWCI Cost	469	404	65	372	287	85	421	346	75

*Note.* Apparent minor discrepancies in mean values are due to rounding.

<sup>a</sup> Low-motivated task trials (2 points/zap during training). <sup>b</sup> High-motivated task trials (6 points/zap during training).

<sup>c</sup> Difference between low-motivated and high-motivated task trials.

Table B3

*Mean RT (ms) by Trial Type, Prior Task Motivation and Switch Task Session for Differentially Motivated Participants in Experiment 2 (N = 16)*

Trial Type <sup>a</sup>	Session 1				Session 2				Average	
	Low <sup>b</sup>	High <sup>c</sup>	L - H <sup>d</sup>	Low	High	L - H	Low	High	L - H	
Rep/NeutF	574	546	28	504	500	4	539	523	16	
Rep/CompF	652	658	-6	584	658	-74	618	658	-40	
Sw/NeutF	932	811	122	706	659	47	819	735	84	
SW/CompF	1043	949	94	876	788	88	960	869	91	

*Note.* Apparent minor discrepancies in mean values are due to rounding.

<sup>a</sup> Rep = Repeat; Sw = Switch; NeutF = Neutral Foil; CompF = Competing Foil. <sup>b</sup> Low-motivated task trials (2 points/zap during training). <sup>c</sup> High-motivated task trials (6 points/zap during training). <sup>d</sup> Difference between low-motivated and high-motivated task trials.

Table B4

*Mean Base RT (ms) and Costs (ms) by Task and Switch Task Session for Equally Motivated Participants in Experiment 2 (N = 8)*

Index	Session 1				Session 2				Average		
	Letter task	Digit task	L - D <sup>a</sup>	task	Letter task	Digit task	L - D	task	Letter task	Digit task	L - D
Base RT	535	500	35		466	461	5		501	481	20
CI Cost	91	104	-13		70	55	15		80	79	1
SW Cost	239	238	1		124	141	-17		182	190	-8
SWCI Cost	369	352	17		201	243	-42		285	298	-13

*Note.* Apparent minor discrepancies in mean values are due to rounding.

<sup>a</sup> Difference between letter and digit task trials.

Table B5

*Mean RT by Trial Type, Task and Switch Task Session for Equally Motivated Participants in Experiment 2 (N = 8)*

Trial Type <sup>a</sup>	Session 1			Session 2			Average		
	Letter task	Digit task	L - D <sup>b</sup>	Letter task	Digit task	L - D	Letter task	Digit task	L - D
Rep/NeutF	535	500	35	466	461	5	501	481	20
Rep/CompF	626	604	22	536	516	20	581	460	21
Sw/NeutF	774	738	36	590	602	-12	683	671	12
SW/CompF	904	852	52	667	704	-37	786	779	7

*Note.* Apparent minor discrepancies in mean values are due to rounding.

<sup>a</sup> Rep = Repeat; Sw = Switch; NeutF = Neutral Foil; CompF = Competing Foil. <sup>b</sup> Difference between letter and digit task trials.

Table B6

*Mean RT (ms) by Trial Type, Task and Switch Task Session in Experiment 3 ( $N = 8$ )*

Trial Type	Number of preceding-trial feedback beeps		
	0	2	6
Repeat/Neutral-foil	519	504	510
Repeat/Competing-foil	612	587	605
Switch/Neutral-foil	726	702	706
Switch/Competing-foil	847	837	836

Table B7

*Mean Base RT (ms) and Costs (ms) by Current Task Motivation and Switch Task Session in Experiment 4 (N = 16)*

Index	Session 1			Session 2			Average		
	Low <sup>a</sup>	High <sup>b</sup>	L - H <sup>c</sup>	Low	High	L - H	Low	High	L - H
Base RT	541	525	16	484	476	8	512	501	11
CI Cost	149	142	7	85	84	1	117	113	4
SW Cost	230	211	19	166	107	59	198	159	39
SWCI Cost	405	367	38	284	208	76	344	287	57

*Note.* Apparent minor discrepancies in mean values are due to rounding.

<sup>a</sup> Low-motivated task trials (2 points/zap during switch task). <sup>b</sup> High-motivated task trials (6 points/zap during switch task).

<sup>c</sup> Difference between low-motivated and high-motivated task trials.

Table B8

*Mean RT (ms) by Trial Type, Current Task Motivation and Switch Task Session in Experiment 4 (N = 16)*

Trial Type <sup>a</sup>	Session 1			Session 2			Average		
	Low <sup>b</sup>	High <sup>c</sup>	L - H <sup>d</sup>	Low	High	L - H	Low	High	L - H
Rep/NeutF	541	525	16	484	476	8	512	501	11
Rep/CompF	690	667	23	568	560	9	629	613	16
Sw/NeutF	771	737	34	650	582	67	710	660	51
SW/CompF	946	892	54	767	684	84	857	788	69

*Note.* Apparent minor discrepancies in mean values are due to rounding.

<sup>a</sup> Rep = Repeat; Sw = Switch; NeutF = Neutral Foil; CompF = Competing Foil. <sup>b</sup> Low-motivated task trials (2 points/zap during switch task). <sup>c</sup> High-motivated task trials (6 points/zap during switch task). <sup>d</sup> Difference between low-motivated and high-motivated task trials.

Table B9

*Mean Base RT (ms) and Costs (ms) by Current Task Motivation and Switch Task Session in Experiment 5 ( $N = 16$ )*

Index	Session 1			Session 2			Session 3			Session 4			Average		
	L <sup>a</sup>	H <sup>b</sup>	L-H <sup>c</sup>	L	H	L-H	L	H	L-H	L	H	L-H	L	H	L-H
Base RT	568	533	35	535	494	41	501	456	45	547	455	92	537	484	53
CI Cost	94	92	1	86	54	32	71	61	10	65	40	25	79	62	17
SW Cost	262	212	50	225	131	94	143	100	43	98	77	21	182	130	52
SWCI Cost	392	359	33	336	234	102	267	229	38	248	197	51	311	255	56

*Note.* Apparent minor discrepancies in mean values are due to rounding.

<sup>a</sup> Current low-motivated task trials (6 points/zap during training; 2 points/zap during switch task). <sup>b</sup> Current high-motivated task trials (2 points/zap during training; 6 points/zap during switch task). <sup>c</sup> Difference between low-motivated and high-motivated task trials.

Table B10

*Mean RT (ms) by Trial Type, Current Task Motivation and Switch Task Session in Experiment 5 (N = 16)*

Trial Type <sup>a</sup>	Session 1			Session 2			Session 3			Session 4			Average		
	L <sup>b</sup>	H <sup>c</sup>	L-H <sup>d</sup>	L	H	L-H	L	H	L-H	L	H	L-H	L	H	L-H
Rep/NeutF	568	533	35	535	494	41	501	456	45	547	455	92	537	484	53
Rep/CompF	662	625	36	621	548	73	572	517	55	612	495	117	616	546	70
Sw/NeutF	830	745	85	760	625	135	643	556	87	645.	532	113	719	614	105
Sw/CompF	959	892	67	871	728	143	767	685	82	795	652	143	848	739	109

*Note.* Apparent minor discrepancies in mean values are due to rounding.

<sup>a</sup> Rep = Repeat; Sw = Switch; NeutF = Neutral Foil; CompF = Competing Foil. <sup>b</sup> Current low-motivated task trials (6 points/zap during training; 2 points/zap during switch task). <sup>c</sup> Current high-motivated task trials (2 points/zap during training; 6 points/zap during switch task). <sup>d</sup> Difference between low-motivated and high-motivated task trials.

## APPENDIX C

*Sample of Instructions from Experiment 2*

## **General Instructions**

In the following experiment you will be asked to play a computer game involving simple letter and digit judgments.

The object of the game is to win as many points as possible by responding quickly and accurately to the stimuli presented. A good player is expected to score in the 100-120 point range.

There are two parts to this game. Part 1 should take about 15 minutes to complete. Part 2 lasts about 45 minutes. You will be given a short break approximately every 15 minutes.

Please take your time reading the instructions for both parts of the experiment. It is important to follow the procedures as indicated.

At the end of the game you will be asked to complete two brief questionnaires about your experience.

Thanks! You may now proceed to the instructions for Part 1.

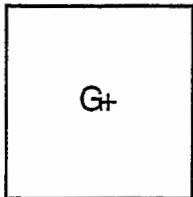
## Instructions: Part 1

In a moment you will be shown a pair of characters in the centre of a square on the computer screen. Each character pair will be made up of either a symbol (#, +, &, %) and a letter, or a symbol and a digit.

For the **letter task**, you are to indicate if the letter is a consonant (G, K, M, R) or a vowel (A, E, I, U) while ignoring the other character.

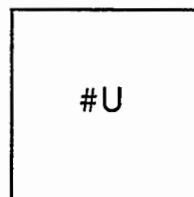
If the letter is a **consonant**, press the "<--" key with your **left index finger**.  
 If the letter is a **vowel**, press the "-->" key with your **right index finger**.

Example 1



(consonant)

Example 2



(vowel)



(L index)

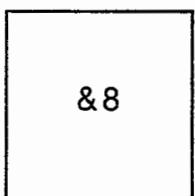


(R index)

For the **digit task**, you are to indicate if the digit is even (2, 4, 6, 8) or odd (3, 5, 7, 9) while ignoring the other character.

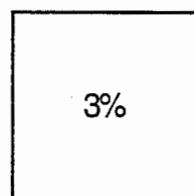
If the digit is **even**, press the "<--" key with your **left index finger**.  
 If the digit is **odd**, press the "-->" key with your **right index finger**.

Example 1

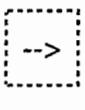


(even)

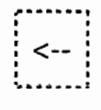
Example 2



(odd)



(L index)



(R index)

**TASK SUMMARY CHART**

	(left)	(right)
	<input alt="Left arrow icon" type="image"/>	<input alt="Right arrow icon" type="image"/>
letter task:	consonant	vowel
digit task:	even	odd

**POINTS**

You will complete 8 blocks of trials, each consisting of a sequence of 24 letter trials followed by a sequence of 24 digit trials, or vice-versa.

After the first block of trials (a practice block), you will earn points for every response that is both CORRECT and FAST. These correct and fast responses are called zaps.

**LETTER zaps will earn you 6 points each.**  
**DIGIT zaps will earn you 2 points each.**

**Two or six** beeps will sound each time you succeed in making a zap, indicating the number of points you have earned on that trial. If your response is CORRECT, but too SLOW, **no** points will be gained and you will hear **no** beeps.

If you make an INCORRECT response, you will hear a “boing” and will be given extra time to prepare for the next trial. **Please try to make as few errors as possible.** If you make fewer than 5 errors on a given block, a bonus of 10 points will be added to your total score for that block.

At the end of each block, you will receive a summary of your performance. Please record the number of points you earned on letter and digit zaps, your total number of errors, and your total score on the form provided and give it to the experimenter at the end of Part 1.

Note that this is a difficult task for which the challenge level is adjusted at the end of each block. **A good player is expected to score in the 100-120 point range on each block.**

**TIP:** To ensure that you can respond quickly, keep your fingers resting lightly on the keys at all times!

Do you have any questions? You may press any key to begin. **Good Luck!!**

### Instructions: Part 2

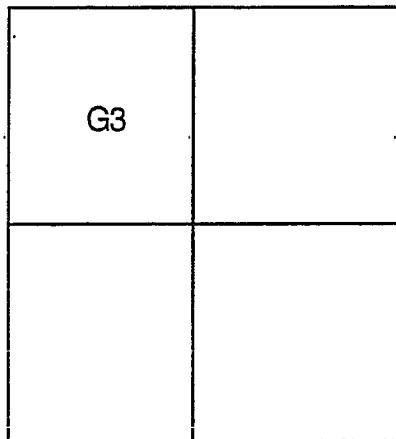
In Part 2, you will be shown a pair of characters in one of four quadrants on the computer screen. Each character pair will be made up of one of the following combinations: either a symbol (#, +, &, %) and a letter, or a symbol and a digit, or a letter and a digit. On successive trials, the position of the character pair will move clockwise to the next quadrant.

When the character pair is in either of the **two top quadrants**, you are to perform the **letter task**. As in Part 1, you are to indicate if the letter is a consonant (G, K, M, R) or a vowel (A, E, I, U) while ignoring the other character.

If the letter is a **consonant**, press the “<--” key with your **left index finger**.

If the letter is a **vowel**, press the “-->” key with your **right index finger**.

Example 1

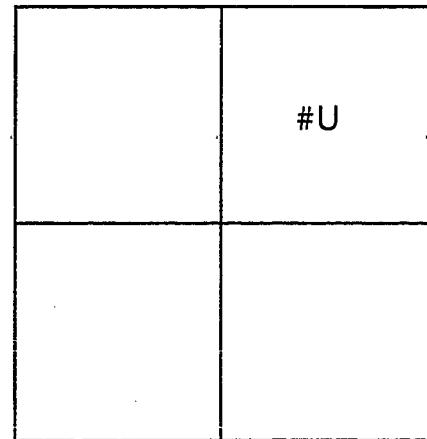


(consonant)



(L index)

Example 2



(vowel)



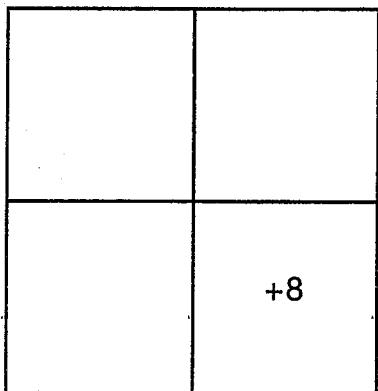
(R index)

When the character pair is in either of the **two bottom quadrants**, you are to perform the **digit task**. As in Part 1, you are to indicate if the digit is even (2, 4, 6, 8) or odd (3, 5, 7, 9) while ignoring the other character.

If the digit is **even**, press the “<--” key with your **left** index finger.

If the digit is **odd**, press the “-->” key with your **right** index finger.

Example 1

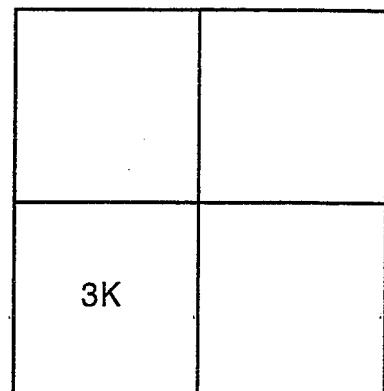


(even)



(L index)

Example 2

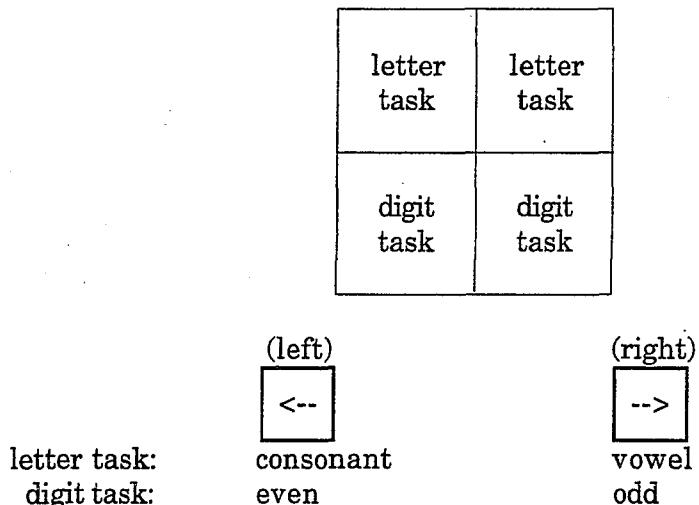


(odd)



(R index)

## **TASK SUMMARY CHART**



## **POINTS**

Part 2 is divided into two identical sections separated by a 10 minute break. Each section begins with a practice block of trials. This is followed by 8 game blocks during which you will earn points for every response that is both CORRECT and FAST. These correct and fast responses are called **zaps**.

**Performance on both letter and digit responses will be of EQUAL worth.**

Specifically: - **LETTER zaps** will earn you **4 points** each.

- DIGIT zaps will earn you 4 points each.

**Four** beeps will sound each time you succeed in making a zap, indicating the number of points you have earned on that trial. If your response is CORRECT, but too SLOW, **no** points will be gained and you will hear **no** beeps.

If you make an INCORRECT response, you will hear a "boing" and will be given extra time to prepare for the next trial. ***Please try to make as few errors as possible.*** If you make fewer than 5 errors on a given block, a bonus of 10 points will be added to your total score for that block.

At the end of each block, you will receive a summary of your performance. Please record the number of points you earned on letter and digit zaps, your total number of errors, and your total score at the end of each block on the form provided and give it to the experimenter at the end of the experiment.

Note that this is a difficult task for which the challenge level is adjusted at the end of each block. ***A good player is expected to score in the 100-120 point range on each block.***

**TIP:** To ensure that you can respond quickly, keep your fingers resting lightly on the keys at all times.

Do you have any questions? You may press any key to begin. ***Good Luck!!***