THE ROLE OF INHIBITORY CONTROL IN TASK SWITCHING

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ABSTRACTS

Previous research on task switching has been confounded by inhibitory control mechanism and there has been debate on the source of switch costs and how and when the inhibitory control occurs during task switching. In order to circumvent this problem, the thesis aimed to investigate the role of inhibition in task switching by examining switch costs, alternating switch costs and congruency effect in three tasks when two preparation intervals (short and long) are given. Task switching experiments in the present study captured both flexibility (changes in task) and anticipatory control (preparation interval between cue and target) and provided the measurement for inhibitory control, 'backward inhibition' by alternating switch cost. Backward inhibition was manifest in longer reaction times (and/or more errors) to alternating switch trials (ABA) than to double switch trials (CBA). Reaction time and error in the present study also reflected whether the task in the current trials were easy when it requires the same response as the task in the previous trials, i.e., whether the required response were congruent.

The results in the thesis provided the strong evidence for switch costs as one of cognitive control mechanism and it was reduced by the long preparation interval through all the experiments. When the cues were arbitrarily matched for each task, switch costs were increased, suggesting that high working memory load and the effort for interpretation of the cues might cause more additional process during switching tasks. On the other hand, the change of the cue type was insensitive to backward inhibition since there were no significant differences on the size of alternating switch costs. The results imply that the occurrence of backward inhibition is more prone to the type of task you perform and level of congruency.

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Chapter 1

GENERAL INTRODUCTION

A. Cognitive control

Our natural environment is surrounded by a number of possible actions that could be taken at any given moment. Thus, it is imperative that a kind of control mechanism has to be developed in order to resolve the conflicts and choose the most appropriate action by comparing the multiple possibilities. Although we tend to take the most appropriate action to perform the task successfully in many circumstances, we sometimes remain unresolved or confused and even make errors (wrong choices) without fully realising because we fail to resolve the conflict.
This happens especially when our environment is changing frequently or is full of multiple possibilities that are competing against one another. As a result, we take a certain amount of time for not making errors but choosing the best action between different possibilities. Whether the task we have to choose is highly demanding or not, it is important that our action toward the goal must be flexible. It is the flexibility that helps us to adapt for the most appropriate action in the face of interference or competition by promoting task-relevant information and changing the goal for the current demands.

Imagine if we do not have the control mechanism or if we have some deficits of the control mechanism, the outcome of our behaviour would be more confused and inconsistent. For example, there is now ample evidence that cognitive symptoms observed in striatal disorders bear strong similarities with those associated with frontal cortex lesions as well as studies on cognitive control deficits in attention, decision-making, action planning, reasoning, and retrieval from memory (Brown & Marsden, 1988a; Saga & Sullivan, 1988; Owen et al., 1992; Passingham, 1993; Lawrence, 1996; Fuster, 1997). These symptoms are frequently observed in patients with Parkinson's disease and Hungtinton's disease as well as other psychiatric disorders such as schizophrenia (Morris et al, 1995). A more dramatic case is "utilization behaviour" which is occasionally observed in patients with frontal lobe lesions (Shallice et al., 1989). These patients are unable to inhibit the performance of complete action patterns characteristically associated with everyday objects, such as toothpaste, comb, scissors, teabags etc, when they happen to encounter one of these objects in the environment, causing their actions to be contextually inappropriate. We also find some similar cases in non-patients in the class of everyday action errors. These are known as "capture errors" in which a person performs an action habitually associated with the context instead of the action intended. In this case, people might look simply absent-minded.

Alternatively, another approach to the study of cognitive control has been to explore the functions of the frontal lobe, on the assumption that frontal lobe functions are 'executive'. Thus, cognitive control mechanisms are often impaired following dysfunction of the frontal lobes, having devastating effects on everyday planning and social behaviour.

It is now well-known that damage of the frontal lobe can lead to '***executive dysfunction***' or '***frontal syndrome***' (e.g., Duncan et al, 1997). 'Executive dysfunction' or 'frontal syndrome' includes more specific manifestations of a loss of controlled behaviour such as a tendency to perseverative behaviour (Luria et al; 1964; Nelson, 1976; Sandson & Albert, 1987; Rogers et al, 1998), difficulties with response suppression (Burgess and Shallice, 1996), increased distractibility (Knight, 1984) and an inability to plan and coordinate a sequence of actions for the satisfaction of goals that are not immediately attainable (Shallice, 1982; Owen et al., 1990). The terms "frontal function" and "executive function" (cognitive control) are often used synonymously. However, it would be a mistake to ascribe the neural implementation of 'executive function' to a single brain region. Instead, 'executive function' probably encompasses a variety of specialized sub-processes mediated by circuits intimately associated with the frontal cortex (e.g., fronto-parietal and fronto-striatal circuits) (Lawrence et al. 1996; Lawrence, Sahakian & Robbins, 1998). Brass and Von Crammon (2002, 2004) also argued that executive functioning is likely to recruit a broader network of areas, both within and beyond the frontal lobes.

Cognitive control which is widely referred to as ***executive function*** is our ability to maintain and update our goals in order to select an appropriate action. Miller and Cohen (2001) also defined executive function as a set of higher-order functions that optimize and schedule lower-order ones. These higher-order functions include attention, memory, judgment, thinking process, goal maintenance, problem solving, decision making, action selection etc. However, they assumed that prefrontal cortex (PFC) serves a specific function in cognitive control: the active maintenance of patterns of activity that represent goals and the means to achieve them.

Psychologists have used various methods and paradigms to understand cognitive control. The Wisconsin Card Sorting Test (WCST) is the most commonly used paradigm for studying 'set-shifting', which is the ability to alter a behavioural response mode in the face of changing contingencies (Gotham et al., 1988; Cools et al., 2001). In this task, participants are asked to match the test cards to reference cards according to one of three classification rules which are acquired from the feedback provided after each matching response. Their performance is then measured by the perseverative errors (i.e., errors attributable to the fact that the subject incorrectly used the same classification rule after negative feedback).
Some early studies demonstrated that when the experimenter suddenly changes the rule, patients with frontal lesions are not able to shift to a new rule as efficiently as control subjects (Milner, 1963; Drew, 1974; Robinson et al., 1980). Furthermore, this deficit is associated with perseverative behaviour where patients with frontal lesions continue to sort the cards by the previously relevant but now-irrelevant rule (Nelson, 1976). The deficit exhibited by these patients seems to indicate a failure in controlling and sustaining the normal flexibility of behaviour (Rogers et al., 1998). However, Roger et al. (1998) outlined that performance on the WCST does not only rely on the ability to switch from one task-set to another, but it also relies on concept formation, rule learning, the ability to make effective use of error feedback and on the ability to maintain task-relevant rules in working memory while performing the task. In other words, WCST performance involves several distinct cognitive abilities: performance

deficits could therefore be due to one or more of several independent forms of dysfunction.

Another well-known behavioural paradigm is the Stroop test (Stroop, 1935; MacLeod, 1991). On incongruent trials, participants have to name the ink colour of a word (such as green) written in a different colour whereas on the congruent trials, participants have to name the word or colour of the ink when the word and ink colour are the same. To perform this task, they must selectively attend to one attribute. When naming the colour of conflicting stimulus on incongruent trials there is a strong proponent tendency to read the word ('green'), which competes with the response to the colour ('red'). The key dependent measurement is reaction time (RT) in the incongruent trials versus congruent trials. This task illustrates one of the most fundamental aspects of cognitive control: the ability to select a weaker, task-relevant response (or source of information) in the face of competition from an otherwise stronger, but task-irrelevant one (Miller and Cohen, 2001). Patients with frontal impairment have difficulty with this task (e.g., Perret, 1974; Cohen & Servan-Schreiber, 1992; Vendrell et al., 1995), especially when the instructions vary frequently (Dunbar& Sussman, 1995; Cohen et al., 1999), suggesting that they have difficulty adhering to the goal of the task or its rules in the face of a competing stronger (i.e. more salient or habitual) response.

The flanker test (Hazeltine et al., 2000; Hübner et al., 2003) is also related to the Stroop test in terms of inhibition of competing responses. In the original Eriksen and Eriksen's flanker paradigm (1974), the target stimulus is displayed in a predictable (central) location and flanked on both sides by irrelevant stimulus. Participants have to identify a target stimulus (usually letter or arrow) that is presented alone (unflanked) or with response-incompatible letters (or arrows pointing in different directions) flanking it. They usually take longer to respond to flanked trials than unflanked trials, demonstrating interference from stimuli that were associated with an irrelevant task. More precisely, it has been shown that transitions to a new task take longer when the stimulus contains an attribute that affords the current (n trial) and a previously executed task (n-1 trial) than when the stimulus is uniquely associated with only one of the tasks used in an experiment (e.g., Fagot, 1994; Rogers & Monsell, 1995). This interference has been attributed to automatic cuing of the previous task set (Hübner et al., 2003).

Another well-known paradigm is negative priming task that has been used extensively to study inhibition in normal individuals (Fox, 1995; Houghton and Tipper, 1994; May et al., 1995; Neill and Valdes, 1996). Typically, participants are presented consecutive stimulus arrays and are asked to identify a denoted target that is presented with distracting, irrelevant stimuli. In the critical condition of the task, called the "ignored repetition (IR) condition", what was a distractor in the previous stimulus array (N-1 trials) becomes the target in the N trials. Participants were significantly slower to identify the target in the IR condition as compared with other conditions in which the target and distractor stimuli in the consecutive stimulus arrays are different. The majority of the research examining this finding in normal individuals indicates that the negative priming effect (i.e., slower response to a target that had previously been a distractor) is due to a buildup of inhibition to the irrelevant distractor and that the increase in reaction time is the evidence which participants have to overcome this inhibition (Houghton and Tipper, 1996; Tipper & Cranston, 1985; Tipper et al., 1992, 1998). However, this paradigm was challenged on the grounds that the increased reaction time to select the new target which was previously a distractor could be explained by there being a tag associated with it that says 'do not respond' (Neil et al., 1992) or by there being a feature mismatch- for example, the target stimulus is a 'large object' on the prime trial but is then a 'smaller object' on the probe (MacDonald and Joordens, 2000; Tipper 2001).

Another paradigm which has been used during the last decade is called '**task switching**' paradigm (e.g., Allport, Styles, & Hsieh, 1994; Meiran, 1996; Rogers & Monsell, 1995). This paradigm captures two core features of goal-directed behaviour which is one of cognitive control mechanism: flexibility and anticipatory control: Flexibility is realized by introducing frequent changes of the relevant goal (i.e. the task to be performed), which is operationalised by the independent variable task transition (task switch vs. task repeat). Anticipatory control occurs when the upcoming task can be prepared in advance, which is operationalised by the independent variable preparation interval with either a short interval (no advance preparation) or a long interval (advance preparation).

Consequently, this paradigm became popular in the field of cognitive neuropsychology to study cognitive control mechanisms and has been implemented with a variety of experimental designs (Meiran, 2007).

For example, in terms of responses, the task may require manual responses (often key presses on the computer keyboard, e.g., Rogers and Monsell, 1995), vocal responses (e.g., Allport et al., 1994; Arbuthnott and Frank, appropriate configuration of mental resources, namely, ***task-set***[1] (Monsell, 2003). The task performed at each point is triggered partly by external stimuli (e.g., deadline, exam date, the lecture room etc) but each stimulus affords alternative tasks (e.g., instead of the textbook, reading the gossip from the tabloid magazine, cancelling the seminar and meeting friends in a café etc). In this situation, we exercise our intentional control to accomplish the different tasks for achieving the goal (e.g. having good exam results) successfully by resisting the temptation to do other tasks.

One could simply question how we manage to select the appropriate task set while having the possibility to attempt to do another task set. If we do so, how do we sustain our goal in the conflict situations and shift from one another flexibly?

In order to answer these questions, Roger and Monsell (1995) provided a task-switching paradigm which was the first paper to investigate task-set configuration processing for studying cognitive control mechanisms. However, the task switching paradigm was firstly introduced by Jersild (1927) who tested either repeating one task or alternating between two tasks. In his experiment, he presented 2-digit numbers. In an alternating

[1] The definition of task set in task switching literature is a bit vague. For example, Roger & Monsell (1995) wrote that "to adopt a task-set is to select, link and configure the elements of a chain of processes that will accomplish a task" (p. 208). However, Mayr and Keele (2000) proposed that task sets "specify the configuration of perceptual, attentional, mnemonic, and motor processes critical for a particular task goal" (p.5). These definitions have evoked some criticism later on (Altmann, 2003; Schneider & Logan, 2005).

Recently, Kiesel et al. (2007) suggested that task set refers to an internal configuration that relates the task-relevant stimuli to their corresponding responses, thereby ensuring task-appropriate performance on a given stimulus.

2000; Jerslid, 1927) or eye movement (e.g., Hunt & Klein, 2002; Mueller et al., 2005). In terms of memory access, the task may require perceptual classification (such as colour decision, e.g., Fagot, 1994), semantic retrieval such as odd-even on digits or vowel-consonant judgments on letters, Rogers and Monsell, 1995), spatial location judgments (De Jong, 1995; Merian, 1996) or episodic memory retrieval (Mayr and Kliegl, 2000). In terms of decision type, the tasks may require classification (e.g., Rogers and Monsell, 1995), odd-item-out decision (Mayr and Keele, 2000) or same-different judgment (Merian & Marciano, 2002).

Thus, there are many different tasks one could use for the task switching as measures of cognitive flexibility. They include the decision of which action to execute, the vivid representation of goals, the inhibition of previous goals, and the filtering of no-longer relevant information. These numerous processes contribute to cognitive flexibility allowing us to perform the task successfully and adjust our action for the goals. Furthermore, these processes can be carried out in preparation for action (anticipatory control).

B.Task switching

Our daily life requires us to switch constantly between different cognitive tasks. For example, if we are revising for exams, it often involves many highly-cognitive tasks such as reading the textbook, memorising, problem-solving with classmates, collecting the key notes from lectures, asking questions to tutors etc while having the time constraint (e.g., three day study plan). In each situation, these cognitive tasks require us to have

condition, subjects had to subtract 3 from every number (task A) and add 6 to every number (task B), alternatively (ABAB). In the control condition, they had either to subtract 3 from every number or add 6 to every number repeatedly (AAA or BBB). He found that the median time in the alternating lists was 115.5ms, compared to 84.5ms in non-alternating list. This result was also replicated by Spector & Biederman (1976).
In their experiment, participants were given columns of 2-digit stimulus numbers. For each column, the participants added 3 to every stimulus number and reported the sum verbally, subtracted 3 from every stimulus number and reported the difference, or alternated between adding and subtracting 3. No visual cues were presented to indicate which arithmetic operation should be performed next; instead, the relevant operations had to be recalled from memory. Under these conditions, participants took substantially took more time (over 400 ms per item) for task alternating between adding 3 and subtracting 3 from 2-digit numbers than task repetition.

However, without cue presentation in this method, there is a greater working memory load to keep track of the task sequence and maintain two tasks in a state of readiness and, as a consequence, it might promote greater effort and arousal (Rogers and Monsell, 1996; Monsell, 2003). Moreover, in Jersild (1927)'s method, participants must do two things in the alternating blocks that are not required in the pure blocks, thus they had to keep two task sets active or available and reconfigure between them on every trial. Hence, it was not clear which of these demands was indexed by the switch cost (Rogers and Monsell, 1996).

In order to avoid this problem, Roger and Monsell (1995) simply compared switch and non-switch trials within a block. They manipualted this by alternating between runs of trials of predictable length on each task so that participants know which tasks in every *n*-th trial. To help participants keep track, they used a cue indicating its position in the current run. In this method, participants alternated between runs of two (or more) trials of each task (AABBAABB....). The tasks were to classify either the digit number of a pair of characters as even/odd or the letter number as consonant/vowel by looking at the character pair (e.g., G7). Participants were told to perform the digit task when the character pair appeared in either of the bottom two positions and the letter task when the character pair appeared in either of the top two positions (e.g., G7 appeared in the right side of the top in the screen- letter task). They computed the ***switch cost*** by subtracting RT on the non-alternating or repetition trials (A**A**, B**B**) from RT on the corresponding switch trials (B**A**, A**B**).
By demonstrating the substantial switch costs, they argued that these costs would reflect an endogenously controlled, time-consuming, stage-like process of reconfiguration, which they referred to '***task-set reconfiguration***'- a sort of mental 'gear changing'- which must happen before appropriate task-specific processes can proceed (Monsell, 2003).

On the other hand, Allport et al. (1994) proposed that the switch cost reflects a kind of proactive interference from one trial to another. Within this account, a switch trial is harder because some residual activation from a previous trial, involving a different task, causes ***carry-over effects***. He also proposed that one must apply extra inhibition to the stronger task-set to enable performance of the weaker task set. They conducted a task switching experiment using Jersild (1927)'s paradigm. Two stimulus pairs were used each affording two different tasks: 1) incongruent Stroop colour words (e.g., RED printed in blue ink); participants had to name either the colour or word 2) the digit between 1 and 9 tokens of the same digit: participants had to name either the digit ('value') or the number of digits ('group size'), and these were all incongruent (in their experiment 4). Participants first performed a block where they read colour words printed in conflicting colours, named the digit in a stimulus (e.g, "3333"), or alternated between two tasks. In a subsequent block, they had to perform different tasks with the same stimuli (naming the print colour and counting the number of digits). Whereas in the first block, the switch costs were dissipated almost completely across 8 runs of trials, at the beginning of the second block they were significantly greater than in the first block. This was found throughout the block. The author interpreted this as evidence that the stimulus-response mapping from the first block persisted for at least some minutes and interfered with the tasks in the second block (pp, 436 in their article).

The authors also found that the costs of task switching were smaller when participants had to switch between pairs (e.g., between colour naming and value naming) than when they had to switch task within pairs (e.g., between colour naming and word naming). Their results supported the idea that task-switching is easier when the stimulus provides an effective cue for the task required and this idea of the cue has been developed in many task-switching experiments afterwards.

In line with Allport et al. (1994)'s idea, Sohn & Anderson (2001) and Sohn & Carlson (2000) compared switch and repeat trials with and without foreknowledge about whether to switch or repeat a task. They observed significant effects of task type (switch vs. repetition) and foreknowledge, but no interaction between task type and foreknowledge. Their results supported the view that switch costs represent an automatic carry-over effect that is not affected by advanced preparation and suggested that repeating the same task had benefits over task switching regardless of foreknowledge although foreknowledge allowed preparation of both repeat and switch trials.

In conclusion, Allport et al. (1994) proposed the term '***task set inertia (TSI)***' which is dissipated only after several minutes of performing other tasks. They argued that the switch cost was accounted for not by the duration of an executive reconfiguration process but by post-stimulus interference from a (recently activated) competing task set- task set inertia (pp. 436 in their article). Later on, Allport and Wylie (2000) suggested that during task-switching, stimulus-response associations are constantly modified. When a stimulus is presented, previous response-related information of that stimulus is retrieved. Accordingly, switch costs are increased for stimuli that have been previously associated with the alternative task set (Allport & Wylie, 2000; Gilbert & Shallice, 2002; Wazak et al., 2003). Note that unlike the task-set inertia idea, assuming that the task set persists in an active state, the stimulus-response association (i.e., stimulus-set binding) is that the task set gets automatically retrieved when the stimuli are re-encountered.

Meiran (1996) also agreed with Rogers and Monsell (1995)'s idea that the reconfiguration process is working proactively if enough time permits and especially he referred to this active readiness as ***advance preparation***. In his experiment, when the participants were allowed sufficient prewarning (precue) about the nature of the upcoming task, the task shifting cost was nearly diminished. In his experiment (1996), participants responded according to the position of a target stimulus, which was presented in one of the four quadrants of a 2 x 2 grid. The position of the target stimulus could thus be classified along both the vertical and the horizontal dimension for up-down and right-left discrimination respectively. The two tasks were ordered randomly within a block of trials so that participants were given an instructional cue in each trial in order to know which task to perform. Thus, the instructional precue enabled the process of advance reconfiguration to discriminate from that of fast dissipation of a carry-over effect. Nevertheless, she questioned that task shift manipulation between runs or between blocks of trials was potentially confounded with working memory demands and division of attention between perceptual dimensions.

Since Rogers and Monsell (1995) concluded that task set-reconfiguration process involves the selection, ordering and coordination of a set of elementary processes need to perform the task, therefore they suggested that switch costs reflect an additional control needed to reconfigure the system for switching to a new task. Merian (1996) also suggested that switch cost indicates a time-effort consuming process that operates after a task shift, precedes task execution, and presumably reflects the advance reconfiguration of processing mode. These two studies represented a breakthrough for task switching research as they argued that switch cost itself reflects the time consumed by the task set reconfiguration process, a kind of mental 'gear changing' set for the appropriate task-specific processes. More importantly, both studies showed the ***preparation effect***- if advance knowledge is given of the upcoming task and time allowed to prepare for it, the average switch cost is usually reduced (Monsell, 2003)- which implies that task switching is associated with a process that operates prior to task execution. In particular, Merian (1996) believed that the existence of this process is compatible with the notion of advanced reconfiguration and therefore with the idea of executive control processing. *Figure 1* captures the hypothetical result in the task switching paradigm.

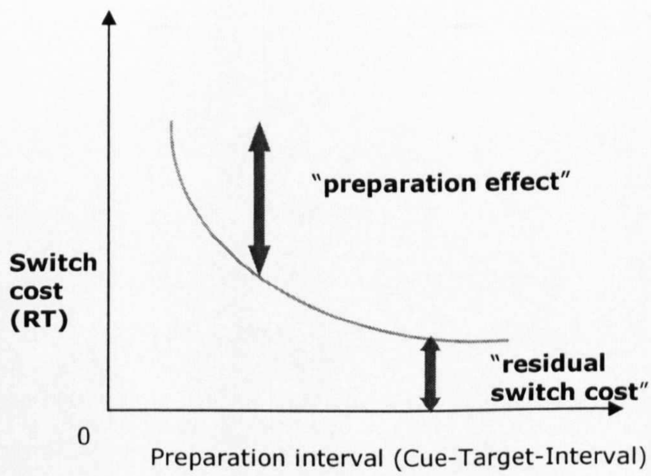

Figure 1. *Reduction in switch cost*[2] is found as preparation interval extended. Note that switch cost was not completely eliminated but remained despite the ample amount of preparation interval (residual switch cost).

[2] This is also known as *RISC* (Reduction in Switch Cost) effect which is equivalent to preparation effect in the literature. This effect has been interpreted an index of endogeneous control processes. The assumption is that, when the cue indicates that the task will change, the participants can take advantage of any time remaining before the stimulus to engage in task set reconfiguration (Monsell & Mizon, 2006).

Although the preparation effect indicates the time required to establish a task set, showing a benefit of longer cue-target-intervals (CTIs), it is not sufficient to demonstrate that a task set has been established during this period. For example, Sakai (2008) argued that the preparation effect may be due to facilitation of processes non-specific to the task, such as interpretation of task cues or general readiness for the presentation of a target. Alternatively, one can easily argue that the switch cost should be removed completely when participants are allowed to have sufficient time if ample amount of preparation is essential for advanced reconfiguration processing of that task set. Contrary to this simple logic for the preparation effect, Roger and Monsell (1996) found that no further decrease of switch cost occurred after 600 ms of response-stimulus interval (RSI) and a stubborn residual cost remained even when this RSI was as long as 1200ms. They suggested that a part of task set reconfiguration cannot be done until exogenously triggered by stimulus attributes that are associated with the task. This ***residual switch cost*** allowed researchers to believe that there is a substantial component of the switch cost that cannot be eliminated by allowing the participant enough time to prepare for switching tasks. This residual switch cost also suggests that complete reconfiguration is either impossible or at least difficult to achieve without actually executing the task (Mayr and Kliegl, 2003).

Rubinstein et al. (2001) characterised this part as retrieval of stimulus-response rules into working memory. They hypothesised that executive control processes include two distinct stages; a) goal shifting, presumably related to updating the contents of declarative working memory where task demands are represented and b) rule activation, related to the activation of procedural working memory aspects related to task performance. They believed that these two stage-like components respectively ensure that the contents of declarative working memory are appropriately configured for the task at hand. Suppose that some of the features enter declarative working memory before rule activation has finished for the next task, then the occurrence of such partial matches could make it more difficult to disable the preceding task's rules. Therefore, prolonging the rule-activating stage may indicate why the switch cost is not entirely eliminated by the ample amount of preparation interval. These considerations could also justify having the rule-activation stage as an exogenous (stimulus-triggered) control process (Rubinstein et al., 2001).

Alternatively, De Jong (2000) made no distinction between endogenous and exogenously-triggered task set reconfiguration. He proposed the 'failure-to-engage (FTE)' hypothesis in order to investigate the cause to the residual switch cost by providing two explanations: 1) failure to achieve endogenous task set reconfiguration on a proportion of trials, and 2) limitations to the completeness of reconfiguration attainable by endogenous means. Simply, this hypothesis started from the notion that advance preparation is optional. If so, advance preparation is useful because it promotes fast response to the imperative stimulus, but postponing task set reconfiguration until the arrival of the imperative stimulus still suffices to ensure an accurate, albeit slow response (De Jong, 2000). Fundamentally, the residual switch cost phenomena caused researchers to question the source of switch costs, either 1) time taken by control operations (Rogers & Monsell, 1995, Merian, 1996) or 2) transient task-set inertia (TSI, Allport et al. 1994) although many researchers now agree with the idea that these are not mutually exclusive (ref. pp, 22-23 in the current chapter).

Returning to the point where the residual switch cost was found in Roger and Monsell (1995)'s experiment, it was noteworthy to highlight the transient carry-over of task set activation from trial to trial by some studies (Merian, 2000; Ruthurff et al. 2001; Altmann, 2004; Hsieh & Cheng, 2006) for which they argued that a longer delay after the last performance of the previous task improved performance on the switch trial.
According to the Allport et al. (1994)'s task-set inertia (TSI) hypothesis, the residual switch cost is evidence for the continuing interference of past configuration settings on currently relevant sets.

Alternatively, Merian (1996) suggested that the residual switch cost reflects the retroactive adjustment and even if the residual switch costs reflect a kind of intrinsic limitation to prepare, he believed that this limitation is transient and can be overcome by practice (Merian et al., 2000, experiment 2). Merian et al. (2000) wanted to see how practice (session) affects switch costs and how it is modulated by RCI (response-cue-interval) and CTI (cue-target-interval) on switch costs in their experiment 2. The results showed that practice drastically reduced switch costs. These results paralleled exactly the practice effects reported by Merian (1996). However, the results of both experiments indicate that one session of practice reduced switch cost in the early CTIs, but had no effect whatsoever on the costs in the long CTI. Note that the practice was influential for the short CTI conditions (in her experiment 2, the CTI varied randomly from trial to trial 116, 316, 516 and 2016ms).

Merian et al. (2000) thus concluded cautiously that limited practice usually affects the preparatory reconfiguration, at least when instructional cues are supplied. After all, it was not possible to eliminate switch costs completely by either the ample amount of preparation interval or practice.

On the other hand, De Jong (2000) suggested that residual switch costs reflect a lack of motivation to prepare. He proposed that people are, in fact, capable of preparing their cognitive systems to perform a task-switch trial just as quickly and accurately as a task-repeat trial. He thought people have competence to prepare fully for a task-switch, yet their performance frequently does not reflect this competence. According to him there are factors that contribute to preparation failures: a) weak goal-driven intention (e.g., a lack of motivation), b) weak environmental support (e.g., a lack of explicit task cues or a lack of clear feedback), c) special circumstances such as fatigue. In this case, residual switch cost simply reflects the failure to utilise available control capabilities, which he termed as 'goal neglect' (De Jong et al., 1999).

It seems still controversial to interpret the reason why there is a residual switch cost even when participants are given enough time for advanced configuration processes. Therefore, there has been debate to interpret the source of switch cost and task preparation over the last decade. Rubinstein et al (2001) summarised two classical contradictory views on this matter. *Table 1.*summarises two contradictory empirical evidences from Rogers and Monsell (1995) and Allport et al. (1994)'s experiments.

	Task Set Reconfiguration (Rogers & Monsell, 1995)	**Task Set Inertia (TSI)** (Allport et al.,1994)
Evidence for	•Switch cost was reduced by providing enough preparation interval (Experiment 2)	•Switch cost was small when stimulus-response (S-R) mappings are dissimilar (Experiment 4) •Switch costs were increased by prior experience with currently irrelevant tasks (Experiment 4):residual proactive interference from S-R mappings of the intervening new task
Evidence against	•Switch costs remained after very long preparation interval (residual switch cost occurred) •Incongruent irrelevant characters induced large switch costs (Experiment 1)[4]	•Switch cost was virtually nil when TSI occurred[3](experiment 5).

Table1. presents two contradictory evidences from Rogers & Monsell (1995) and Allport et al. (1994)'s studies which led the classical debate on the interpretation of switch cost and its theoretical views. (modified from Rubinstein et al.,2001)

One proposes that switch costs represent the time taken for an executive process to establish a changed task set, with task reconfiguration views as an extra processing stage (or stages) inserted prior to completion of task-specific processing (De Jong, 2000; Kieras et al., 2000; Meiran, 1996, 2000; Rogers and Monsell, 1995; Rubinstein et al., 2001). Obviously, this theory was bolstered by the finding that switch costs decrease as the

[3] Participants should have suppressed colour naming and imposed word reading task set for the reverse Stroop task in alternating task block, thus switching back to standard Stroop task, involving colour naming rather than word reading, might have caused the switch cost. But the switch cost for this standard Stroop task was virtually nil.

[4] However, substantial switch costs were also found in the context of neutral irrelevant characters even though they presumably induced no proactive interference with the current task. Hence it might be that executive control processes are needed to switch between tasks regardless of which irrelevant characters appear in a stimulus display.

interval between trials (preparation effect), and thus between successive tasks, is lengthened, suggesting that when subjects are given longer preparation intervals, executive control process would enable them to accomplish more 'reconfiguration' of the system (e.g., Rogers and Monsell, 1995; Meiran, 1996, 2000). However, this view was questioned by those who observed that there appears to be no systematic relationship between the length of time subjects are given to prepare and the decrease in the switch cost, and the mere existence of residual switch cost (Allport and Wylie, 1999, 2000; Wylie and Allport, 2000).

The various researches about the cause of switch cost and residual switch cost have led other researchers to espouse another view which is a kind of competition hypothesis (Wylie et al, 2003). According to this hypothesis, a switch of task is accomplished by changing the weights in a competing cognitive system, thus switch costs result from the competition in the cognitive system as it settles to a stable state that is consistent with the newly instituted weightings. In other words, switch costs reflect the positive and negative priming: In a switching situation, there might be persisting suppression (negative priming) of a task now required and/or additional activation (positive priming) of the previous task resulting in performance decrements (Yeung and Monsell, 2003). This view is in line with Allport et al. (1994)'s task set inertia hypothesis on the ground that switch costs reflect interference between the previously used stimulus-response mapping and the now-required stimulus mapping.

Many parties to this debate now acknowledge that the switch costs reflect both task priming effects and the time taken by control processes (e.g., Allport & Wylie, 2000; Goschke, 2000; Kiera et al., 2000; Meiran, 2000; Monsell, Yeung & Azuma, 2000; Ruthrff et al., 2001; Sohn & Anderson, 2001; Yeung & Monsell, 2003). Consequently, researchers have been studying to determine the relative contributions of these factors and the relationship between them nowadays.

Recently, Ruge et al. (2005) discussed two different views on the relation between switch cost and preparation. These views were simply based on the empirical evidence that switch costs are often reduced with prolonged preparation intervals (Rogers and Monsell, 1995; Merian, 1996).

According to their one view, the system tends to perseverate because the previously adopted task set is persisting over time into the next trial. Thus, establishing the competing task set in a current switch trial requires additional time consuming control effort because proactive interference from the persistently activated, now misleading task set has to be overcome. In theory, this same process can be finished in advance of target presentation with sufficient preparation time. As proactive interference has been overcome during the preparation interval, it is no longer slowing down appropriate task implementation after the target has been presented (Ruge et al., 2005). According to the other view, a previously adopted task set is dissipating rapidly before the next trial is presented. Recent studies suggest that interference might be induced by the target stimulus itself which is retrieving the previous task set from memory (Allport & Wylie, 2000; Waszak et al., 2003; Wylie & Allport, 2000).

However, when every new trial starts with a neutral task set because interference is induced only after the target has been presented, there is nothing that can be done during the preparation but biasing the initially neutral task set in the direction of the currently instructed task set- and this is equal for both switch trials and repeat trials according to Ruge et al. (2005). Thus, the authors argued that it was not clear why advance preparation being equally engaged for both trial types should have a benefit that is differently stronger for switch trials compared to repeat trials as being indicated by reduced switch costs.

Despite the fact that researchers still struggle to understand different results and interpretations, now they agree with the assumption that there are at least two distinctions of control processes in the task switching paradigm: 1) overcoming inhibition of a previously performed task when re-engaging and 2) restarting a sequence of tasks after a period of interruption. Baddeley et al. (1998) also hypothesized that two processes are necessary for efficient task switching: activation of relevant task-sets, and inhibition of no-longer-relevant task sets. Behaviourally, these processes were reflected in the facts that: a) switching to a task that was recently performed takes longer than switching to a task less recently performed because it is unlikely to have fully recovered from **inhibition** and b) re-engaging in a sequence of tasks after a period of interruption transiently increases reaction time.

Mayr and Keele (2000) tested the hypothesis that disengagement during intentional shifts between task sets is accompanied by inhibition of the previous task set (**'backward inhibition'**). Backward inhibition of a no-longer relevant task has been proposed to be automatically triggered by competition between cognitive demands during task disengagement because it occurs even when participants know that the inhibited task will become relevant again in the immediate future (Mayr and Keele, 2000; Dreher and Berman, 2002). Since Mayr and Keele (2000)'s study on backward inhibition, the role of inhibition has been proposed to be a component process of cognitive (executive) control.

C. Backward inhibition

If the inhibition plays an important role in cognitive control and it is another component involved task switching, what kinds of evidence suggest that such inhibition is a critical component of task-switching, and that active maintenance of a new task-set is not enough?

Some evidence of the idea that task sets must be inhibited comes from Mayr & Keele (2000), in which they conducted a series of experiments where subjects select the object that does not belong among a set of four objects, namely the 'odd-item-out' task. In their experiments, participants were required to press one of four response keys that were spatially compatible with four objects. Three objects are the same colour, while one is a different colour. Another object has a different orientation than the other three. Lastly, a third of the four displayed-objects are moving, while the others remain still. Thus, this paradigm involved high perceptual demands, but response conflict between the tasks was rather low. The meaning of the responses probably did not change because they always referred to the same four object positions. Nevertheless, substantial backward inhibition occurred, which was calculated by subtracting the reaction time in the inhibition condition:e.g., colour (task **A**: n-2trial)- orientation (task **B**: n-1 trial)- colour (task **A**: n trial) from the reaction time in control condition: e.g., movement (task **C**: n-2trial)- orientation (task **B**: n-1 trial) – colour (task **A**: n trial). There was no significant difference between the backward inhibitions regardless of the different preparation interval. The reason why they varied the preparation intervals such as CSI (cue-stimulus-interval) and RCI (response-cue-interval) was that they thought preparation intervals would give a key to understand participants' active preparation for the upcoming task-set as well as the passive decay of the previous task-set. First, in the short RCI and short CSI condition, subjects should have little time to prepare a new task-set representation, and the previous task-set should have had little time to decay. Thus, participants should have more difficulty switching back to a task-set that had been used two trials ago- in other words, one that had recently been used, but then abandoned-than switching to a task set that had been used more than two trials ago (trial n-2). Second, in the long RCI and short CSI conditionI, the old task-set would have decayed, but participants should have little time to instantiate a new task set. In this case, subjects should show reduced backward inhibition when switching to a cue that had been recently used but then subsequently abandoned. Third, in the short RCI and long CSI condition, participants have a long time to instantiate a new task set so that they might be more able to activate the previously-used-but-more-recently-abandoned task set, and thus show less backward inhibition than the first preparation condition.

Although the second and third condition of preparation intervals showed less backward inhibition than the first one, there was no difference between the backward inhibitions found in terms of the different preparation interval conditions. This indicates that switching to a previously abandoned task set is not made easier by having longer to prepare- suggesting that 'task set inertia' (Allport and Wylie, 1994) appears to be unrelated to how strongly one is able to activate the new task. They interpreted this as evidence that switching involves inhibitory processes acting upon previous task sets.

Mayr and Keele (2000)'s results suggests that backward inhibition is not a side-effect of not having fully activated the now-relevant-task set, which would be predicted by many computational models of task switching (e.g., Burgess and Shallice, 2000; kieras et al.,2000; Yeung and Monsell 2003b; Logan & Schneider, 2004). Instead, it suggests that maybe old task-sets are actually inhibited. Because it suppresses representations of a to-be-abandonded task set, backward inhibition is thus presumed to support the application of a new task set in that it relieves competition from the preceding one (Hübner et al., 2003). In other words, Mayr and Keele (2000) suggested it would function as a counterforce to the persistent-activation property of control settings and thus, 'clear the slate' for the currently relevant task set (p. 5 in their article).

Mayr and Keele (2000) argued that selection of an appropriate set needs to occur against a task set which not only has full control over behaviour in a rapid transition but probably also has a tendency for self-sustained activation (e.g., Anderson, 1993; Goschke & Kuhl, 1993). They pointed out the problems of the competition model of selection (e.g., Cohen, Dunbar & McClelland, 1990), which causes insufficient activation to the appropriate code alone for differentiating between potentially relevant codes (e.g., Houghton & Tipper, 1994) when selection needs to occur against highly activated competitors.

In other words, they showed that there are much more processes going on than removing a code that is already highly active within an active-relevant representation in concurrent selection situations.
Thus, they assumed that passive decay of once-activated task sets would not be enough for avoiding the perseverations, which might cause slower response and errors. In that case, the other process might be helpful to avoid the perseverations which was called hypothetically '**backward inhibition**' in their article.

Although the notion of inhibition as a general sequencing mechanism and the low level of sequential inhibition such as a perceptual and motor code (e.g., Estes, 1972; MacKay, 1987; Rumelhart & Norman, 1981, Arbuthnott, 1996) was not new, Mayr and Keele (2000) questioned whether backward inhibition can be generalised to the domain of endogenous control of abstract situations such as goals or task sets. Because they realised that the empirical evidence of some theoretical models of inhibitory mechanism (e.g., Norman & Shallice, 1986) in terms of high-level control was only indirect. For example, some patients with frontal lobe damage exhibit problems with shifts between abstract control settings (Owen et al. 1994; Rubinstein, Evans & Meyer, 1994) and patients with Parkinson's disease have been reported with shift problems (.e.g., Downes et al., 1989; Hayes et al., 1998; Owen et al., 1993). Either way, it is not clear such deficits are due to incomplete inhibition of task sets (Downes et al., 1989) or a lack of sufficient activation of the appropriate schema (Cohen & Dehaene, 1998). I could only speculate that recently used task sets are never completely abandoned, but instead diminishing activation gradually as new task sets are activated. At this stage, this account would only be strengthened by an actual implementation of the backward inhibition phenomenon within computer network model.

Despite these reservations, Arbuthnott and Frank (2000) agreed with Mayr and Keele (2000)'s hypothesis that backward inhibition is automatically triggered by competition between task sets during task-set disengagements and suppresses to-be-abandoned task set unconditionally for a certain period of time. They also suggested that task-set inhibition is an executive control process. In both Mayr and Keele (2000) and Arbuthnott and Frank (2000) studies, they agreed that resolving inhibition associated with an previously abandoned task-set may be the main process underlying residual switch costs. However, it was more an assumption rather than their conclusion because their research idea was based on the task-set inhibition as an important executive control processes, rather than the cause of residual switch costs.

Therefore, the authors in both studies suggested that any type of switch cost reflected the time necessary for executive control process to operate. The reason why they assumed that BI effect might be another explanation for residual switch cost was that the previous studies for task switching only involved two tasks and thus, every switch necessarily was a switch back to a recently inhibited task set. They proposed that the residual switch cost probably contained an inhibitory component whereas the other explanations for residual switch costs such as proactive interference (Allport et al., 1994) and retroactive adjustment (Merian, 1996) were overlooking the inhibitory component in switching situations.

So far, it seems that backward inhibition (or sequential inhibition) is present only when there is sufficient interference with a current trial. Thus, the most recent task would result in the most interference, and thus would receive the most inhibition. It might be also possible to think that this inhibition decays over the time, and so it is likely to be only observable when performance requires the inhibited task to be used again immediately (alternating switching trials). This means that backward inhibition could be found in any task switching situation, however, the studies on backward inhibition shows that backward inhibition in task switching would only be measurable by subtracting RT at the current trial in the alternating switch sequence (e.g., task A at the n-2 trial→ task B at the n-1 trial→ task **A** at the n trial) from RT at the current trial in the double switch sequence (e.g., task C at the n-2 trial→ task B at the n-1 trial → task **A** at the n trial), requiring the three-task design for studying backward inhibition in task switching. Slower RT at the current trial in the alternating switch sequence, which suggests the backward inhibition effect, is also known as ***alternating switch cost*** [5](Arbuthnott & Frank, 2000; Arbuthnott and Woodward, 2002; Arbuthnott, 2005). *Figure 2* idealises the alternating switch cost between alternating switch trials and double switch trials.

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[5] The authors reserved using the term 'backward inhibition' for this cost because this cost is one of independent variables that measure backward inhibition. For example, Hübner et al. (2003) measure backward inhibition by using a flanker task paradigm. Some researchers use the term "lag-2 repetition cost" (Mayr and Keele, 2000; Druey and Hübner, 2007).

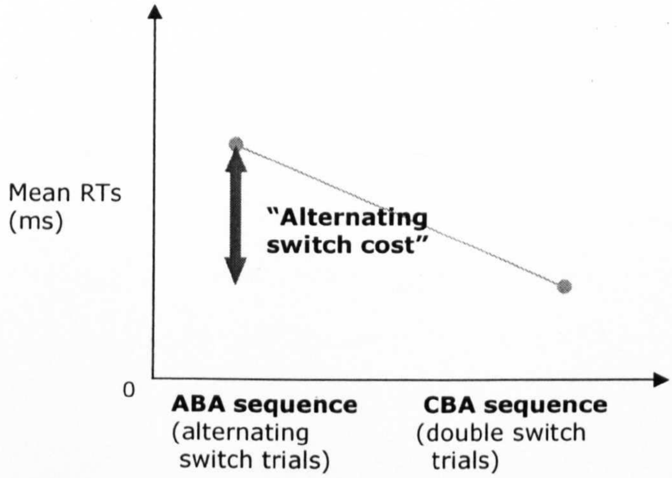

Figure 2. presents the alternating switch cost which is found from slower RT in the alternating switch trials than in the double switch trials.

Hypothetically, the additional cost for alternating switches occurs because the just-abandoned task set is still in an inhibited state and extra time is needed to overcome this residual inhibition in order to perform that task. To avoid confounding an observed effect with its hypothesized mechanism (MacLeod, 1999), Arbuthnott and Frank (2000) and Arbuthnott and Woodward (2002) referred to the greater switch cost for alternating tasks as alternating-switch cost and reserved the term backward inhibition for discussion of the proposed source of the effect.

Hence, it was simply possible to obtain the backward inhibition effect between alternating task switching sequence and double switching task sequence as well as the switch cost effect between switching tasks and repeating tasks. Measuring both backward inhibition and switch cost might give more answers for some unresolved issues in both phenomenona to broaden the understanding of cognitive control. Arbuthnott and Frank (2000) originally provided both BI effect and switch costs in their study.

In their experiment, participants had three tasks: the digit (odd/even), letter (vowel/consonant) tasks that had been used by Roger and Monsell (1995) and the symbol (math/text context) task. They manipulated the switch condition by sequencing the order of tasks across a five-trial series. The first two trials in the sequence involved the same task (trial 2=no-switch condition), the third trial was one of the other tasks (one switch condition), the fourth trial was the remaining task (double switch condition), and the fifth trial was a return to the trial three task (alternating-switch condition). The CTI (cue-target-interval) was 500ms for ample warning of the upcoming task as this duration of 500ms CTI has been previously observed to reduce switch cost to asymptotic level (Mayr and Keele, 2000; Merian, 2000), suggesting that the preparatory retrieval of the task set is completed. The cue was presented in the centre of the screen (i.e., Odd or Even? / Vowel or Consonant? / Math or Text?) and this cue question then joined by the three character stimuli until the participant's vocal response. They found that RTs in the alternating switch conditions (1318 ms) were longer than the other conditions (1178ms, 1180ms, and 1220ms for the no-switch, 1-switch and 2-switch condition respectively). The 1-switch and 2-switch conditions did not differ, and neither differed significantly from the no-switch condition. From these results, they suggested that switch costs for 1-switch and 2-switch were equivalent and the alternating switch cost (108ms in this experiment) effect reflects an executive control process. In addition, their argument was in accordance with Mayr and Keele (2000) by saying that task set inhibition is the most likely explanation of selective interference for alternating tasks. They also suggested that when a recently abandoned task-set must be reinstated, resolution of task-set inhibition would result in longer RTs for an alternating switch than for a switch to a less recently inhibited task-set.

Additional evidence for the involvement of inhibition in task switching came from Logan and Burkell (1986), who studied inhibition within the framework of the stop-signal paradigm (Logan, 1994, for review). In the stop signal paradigm, subjects were first pre-trained on a task to create a strong tendency to execute this task. Afterwards, they were required to withhold task execution on a certain (low) proportion of the trials, and their inhibitory abilities were measured. Their paradigm required that instead of withholding responses (as in the standard stop-signal paradigm), subjects execute another task. In that respect, it resembled the task switching paradigm. Their result indicates that inhibition was less effective (and more demanding) in this stop-switch paradigm as compared to the standard stop signal paradigm in which no task switching was required. Nevertheless, the difference was not large but just about 40 ms. However, this paradigm would not give any measurement for switch cost in task switching situation, which is not practically applicable for studying the role of inhibition in task switching.

Although both the Mayr and Keele (2000) and Arbuthnott and Frank (2000)'s studies really drew attention for inhibitory control mechanisms in task switching and there have been more interests in backward inhibition effect since then, it is not clear to conclude whether the backward inhibition effect is really part of task switching to give the insight for inhibitory control mechanism, or it could be the independent process which is not necessarily found in the two-task switching paradigm. Note that by comparing RT difference between ABA̲ (alternating switch sequence) and CBA̲ (double switching sequence), it had not been shown that this inhibition indeed facilitates the application of a new task set by reducing competition from the preceding one.

In order to address whether backward inhibition reduces interference from a preceding task set, Hübner et al. (2003) focused on the impact of a to-be-abandoned task set on performance in the following task instead of comparing the executability of task sets that were more or less recently switched away from. Using a flanker paradigm, they replicated the finding of backward inhibition in Mayr and Keele (2000)'s experiment 3.
Moreover, they provided evidence that the backward inhibition mechanism reduces interference from a directly preceding task set compared with a task set not as recently applied when a switch to a new task is endogenously prepared for (in their experiment 1). In their flanker paradigm, three simple classification tasks were applied: odd vs. even, vowel vs. consonant, straight line symbol vs. curved line symbol. And these tasks have three aspects: a) one that on each trial executed as the relevant task, b) one that was executed directly in advance (i.e., the preceding task), and c) one that was not executed as recently (i.e., the control task). On a task switch trial, the target stimulus was presented alone, either flanked by a stimulus of the preceding task, or flanked by a stimulus of the control task, with equal probability (i.e., one third each).

The results showed that flanker characters from the preceding task interfered more than flanker from the control task and they accounted for this in terms of residual activation of the task set most recently executed:

If an abandoned task set is not inhibited, interference might be stronger because it is the most recently used task set. But in this case, the results showed that abandoned task set (preceding task) was inhibited, thus backward inhibition actually reduced the interference from the preceding task set. More importantly, they found that flankers from the preceding task interfered significantly less than flankers from the control task on switch trials that were precued and this was expected on the assumption that the preceding task set is subject to backward inhibition.

Thus, they concluded that backward inhibition facilitates switching task sets by reducing perseverative tendencies. In summary, their study supports the idea that executive control processes reduce interference by inhibiting representation (backward inhibition) and this backward inhibition has the effect of shielding the application of a novel task set by selectively reducing interference from the preceding one.

Mayr and Kliegl (2003) also demonstrated that backward inhibition affects the actual configuration, not the retrieval stage according to their two stage model. Their initial question was on what level of representation or processing backward inhibition has its effect. One hypothesis was that inhibition affects encoding of the cue or of processes that lead from the cue to a task-set representation in working memory (cue-associated process). Another hypothesis was that backward inhibition would affect the application of a task set to the stimulus after it has been loaded into working memory (cue-independent application stage). These hypotheses stemmed from two distinct serial processing stages they proposed: 1) retrieval stage: cue-driven retrieval of rules for upcoming task demands from long-term-memory (LTM) to working memory. They believed that this stage can be triggered through any internal or external signal that indicates an upcoming task, and it can run off in an anticipatory manner (i.e., before the response-relevant stimulus appears). 2) application stage: In this stage, task rules are applied in a relatively automatic manner once the stimulus is presented.

They proposed that these two stages are critical during changes of task configurations thus for the emergence of switch costs.

To explore their hypotheses, they used 2:1 mappings between cues and tasks to distinguish between these two theoretical options. In other words, there were two alternating switching conditions: one was where the cue was repeated ($A_{cue\ 1}$- $B_{cue\ x}$- $\mathbf{A}_{cue1}$), the other was where the cue was changed ($A_{cue\ 1}$- $B_{cue\ x}$- $\mathbf{A}_{cue\ 2}$). Participants had to judge an object's colour (red vs. blue: task A), shape (circle vs. square: task B) or size (small vs. large: task C). The task cues were letters (i.e., D and R for the colour task, M and V for the shape task, and T and K for the size task).

When they compared RTs from these two alternating switch sequences (one for the cue repeat, the other for the cue change) with CB**A** sequence, they found the significant backward inhibition effect (51 ms) in the cue-change condition. However, there was no significant backward inhibition found in the cue-repeat condition (18ms of difference which was not reliable: $t\ (14) = .067$, $p > .6$).

This result suggested that inhibition affected the representation associated with the task-set application. Although they concluded that backward inhibition affects the actual task-set configuration, they were cautious for their interpretation and open to another possibility that the absence of backward inhibition in the cue-repeat condition might be the result of a cue specific, positive priming effect that occluded the otherwise observable inhibition effect.

It can be reasonably supposed that backward inhibition is part of the executive control (cognitive control) according to several studies' findings (Mayr and Keele, 2000; Arbuthnott and Frank, 2000; Hübner 2003; Mayr and Kliegl, 2003) but it is not clear how much the role of inhibition affects the switch cost and whether alternating switch costs is a good measurement to understand the role of inhibition in task switching. Moreover, the relationship between switch cost and alternating switch cost for backward inhibition has not been fully examined and little literature is available on the dynamics of these two phenomena in task switching.

D. Congruency

Based on the assumption that there are at least two distinctions of control processes in task switching paradigm: 1) overcoming inhibition of a previously performed task when re-engaging and 2) restarting a sequence of tasks after a period of interruption (ref. page 23in the current chapter), one could simply question how to overcome the persisting inhibition of a previously performed task. As discussed earlier, one mechanism to overcome this persisting inhibition is backward inhibition because it suppresses the to-be-abandoned task set unconditionally for a certain period of time according to Mayr and Keele (2000). However, it is noteworthy that persisting activation of a previous task set might affect the switching performance, depending on whether it activates a response that is the same (congruent) as or different (incongruent) from the response activated by the new upcoming task set (current task set). In this case, persisting activation could either interfere with or facilitate a subsequent task switch.

In other words, task switching performance not only depends on the currently relevant task-set, but is also influenced by irrelevant task-sets. This can be most clearly seen in the finding that stimuli which are assigned different responses under the two task instructions (incongruent stimuli) yield longer RTs and higher error rates than stimuli that are assigned the same response under both task instructions (congruent stimuli) (e.g., Fagot, 1994; Merian, 1996; Rogers & Monsell, 1995). This **congruency effect**[6] presumably reflects response activation according to the irrelevant task's stimulus-response (S-R) rules, resulting in performance decrement due to response conflict in the incongruent trials and/or facilitation due to parallel activation of the same response in the congruent trials (Kiesel et al, 2007).

In order to test this hypothesis, Goschke (2000) conducted an experiment with two tasks: a letter task and a colour task. Stimuli for these two tasks were the capital letters A, B, C, D which would appear in the colour red, green, blue or yellow. Among these, letter C and D and colour blue and yellow were irrelevant stimulus and were not mapped to any responses

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[6] Later on, Yehene & Merian (2007), Merian & Kessler (2008) named it as "task rule congruency effect (TRCE)". Note that congruency effect is the short term for task rule congruency effect or response congruency effect in the task switching literature.

whereas letter A and colour red were mapped to the left key and letter B and colour green were mapped to the right key for half of the participants and the other half received the reverse mapping. In one third of the trials of each block, the task relevant and task irrelevant dimensions were mapped to the same response (congruent trials); in one-third of the trials, the two stimulus dimensions required different responses (incongruent trials); and in one-third of the trials, the value of the task-irrelevant dimension was not mapped to any response (neutral trials). He found that there was a reliable congruence effect: switch costs were greater on incongruent than on neutral trials, whereas they were smaller on congruent than on neutral trials, indicating that the previous task set persisted in a state of residual activation (at least after a short RCI (response-cue-interval) condition).

The author argued that these findings were evidence for more specific, trial-to-trial after effects of recently activated task sets. Interestingly, he also suggested that preparatory processes during RSI helped to suppress the preceding task set on the grounds of the result that the congruence effect was almost completely attenuated after a long RSI=1500ms. Basically, the interaction between congruence and switch costs was only present with a small amount of preparation, RSI=140ms (experiment 1). However, it should be noted that some of early studies (e.g., Meiran, 1996; Rogers & Monsell, 1995) have reported no reduction of congruency effect with an increasing opportunity for preparation.

Consequently, he questioned if the reduction of the switch cost and attenuation of the congruency effect after the long RSI might have been due not to activate preparation, but merely to induce rapid dissipation of the previous task set. In addition, he questioned if the task retrieval is actually an important component of advanced preparation.

To test this, he used only long RSI (1500ms) and participants had either to verbalise the next task before the stimulus (retrieval group), or to perform a verbal distractor task during the long RSI (blocking group). The results showed that the mean RT was on average 31ms longer on incongruent than neutral trials and RT was 22ms shorter on congruent than on neutral trials (p=.005) in the task switch block. However, RT difference between incongruent and neutral trials in the repeat block was not significant, suggesting that congruence has a big effect on the task switch block but no effect on the task repeat block. The effect of congruency on the switch cost was greater in the blocking group than in the task retrieval group, indicating that the interpretation in terms of passive decay of the previous task set during the long RSI is not supported. Based on the result, the author interpreted that the preceding task set neither decayed in a passive manner as a function of the length of the RSI nor was it deactivated by a urelated intervening activity: it was suppressed only by retrieval of a new intention. Switch costs were again reliably greater after incongruent than after congruent trials, wherea previous congruence had a small reverse effect on task repeat trials. The author argued that the results would give the supporting evidnce for the assumption that task-irrelevant precetual dimension was inhibited when it activated an incompatible response.

Arbuthnott (2005) also examined the congruency effect (i.e., response congruency effect in her paper) as an indicator of cross-task interference. She speculated that the absence of alternating switch cost for spatially cued tasks in her experiment 1 (three digit-judgment tasks were used-magnitude, parity, and prime with the stimuli 2, 3, 4, 6 , 7 and 9) might be attributed to differences in the relative activation of category-response rules (i.e., task rules) for the competing sets, with spatially cued tasks requiring less inhibition of competition prior to response than verbally cued tasks. She suggested that congruence effects indicate the influence of factors not directly related to a current task. For example, congruence between spatial location of a stimulus and its correct response can influence performance, even when location itself is not relevant to a current judgment (e.g., Lu & Proctor, 1995).

In the context of her experimental design, congruence refers to the same response to a digit (i.e., left or right key press) across all three tasks. If other response rules are suppressed because of backward inhibition, congruence between responses across the tasks would have little effect on performance. Conversely, significant effects of congruence would indicate less suppression of the response for other component tasks.

By using a single pair of keys to indicate responses for all three tasks (i.e., trivalent response options), all the left responses for 3 and all right response for 6 were thus congruent stimuli and the remaining digits required mixed responses across the task, two of one response and one of the other, and were thus incongruent with respect to stimulus-association across the tasks. In this experiment, it was found that congruent responses (900ms) were faster than incongruent responses (900 ms vs. 938ms thus 38ms of congruency effect).

This congruency effect has greater influence with spatial cues (56ms) than verbal cues (19ms), indicating that other tasks remain activated to a greater degree for spatial cues than for verbal cues. The author interpreted that spatial localization of tasks could provide a distinctive means to discriminate task sets during judgment, resulting in greater activation of the current category-response rules relative to competing rules whereas retrieval of verbal cues might result in less distinctive means to discriminate the task set, resulting in lesser activation of the current category-response rules.

So far, the evidence supports the view that the congruency effect is another important issue to understand the dynamics of switching between different tasks, however, many researchers more focused on the underlying mechanism in switch costs and its relationship with preparation interval in task switching.

In conclusion, the congruency effect indicates that performance is better for the target stimulus in which both attributes are associated with the correct response compared to the target stimulus to which two stimulus attributes are associated with different correct responses regardless of which paradigm is used for the experiment. In task-switching experiments, it is generally found that responses to incongruent stimuli are slower amd more error-prone than response to congruent stimuli (Monsell & Mizzon, 2006).
If the currently irrelevant stimulus-response mappings were completely suppressed, there would be no congruency effect; thus, this effect may index the ability to overcome conflict, as exemplified in the task switching paradigm. However, little work has been done despite the significance and there have been many different interpretations. For example, this conflict and/or competition might due to the irrelevant task set persisting from previous trials (Allport et al.,1994: Yeung & Monsell 2003b) and/or

retrieved by the stimulus (Allport & Wylie, 2000; Wazak, Hommel & Allport, 2003). Monsell & Mizzon (2006) suggested that this congruency effect is often larger on task-switch trials (Rogers & Monsell, 1995), reflecting either greater carry-over when the other task set has just been abandoned (Allport et al., 1994; Yeung & Monsell, 2003b) or greater susceptibility to competition from retrieved task sets when the task set is as yet insecurely established (Allport & Wylie, 2000; Wazak et al., 2003).

Judging from the different interpretations, one has to raise the issues in order to clarify the nature of the congruency effect and how this effect interacts with switch cost and backward inhibition under task switching.

E. Outline of the thesis

The goal of the thesis is to investigate the role of inhibition in task switching by backward inhibition and to examine if backward inhibition is the main process in cognitive control or independent processing. To achieve this goal, the thesis examined the backward inhibition effect (alternating switch cost) and switch costs in a three- task situation. A new experimental paradigm was introduced and the work reported in this thesis aimed to investigate the relationship between these two important phenomena in cognitive control and possibly, providing the conceptual framework (model) to understand the dynamics of activation and inhibition in task switching by applying two simple distinct hypotheses: both activation of relevant task sets and inhibition of no-longer relevant task sets for task switching. Additionally, in order to examine the conflict and interference from other task sets, the congruency effect was discussed when a stimulus has attributes relevant to the three currently active task sets while switching.

The thesis is separated into a general introduction, general methods section for the experimental paradigm, 6 experimental chapters, 1 descriptive chapter for a proposed model and a general discussion.

The current chapter (***chapter 1***) so far provided an overview and introduction to classical issues in task switching and backward inhibition as well as the congruency effect in the context of cognitive control.

The details of the experimental paradigm and overall analysis procedure will be presented in the general method (***chapter 2***).

Experiment 1 (***chapter 3***) aims to pilot a task switching paradigm for exploring the relationship between inhibition of previous task sets and activation of upcoming task sets.

Experiment 2 (***chapter 4***) aims to examine task switching deficits and inhibitory deficits in patients with an early stage of Parkinson's disease by running the same experiment as experiment 1.

Experiment 3 (***chapter 5***) aims to see the verbal cue effect in the arrow and location task for switch cost and alternating switch cost: if the verbal cues reduces switch cost and induce alternating switch cost, based on the previous literature (Arbuthnott, 2005) that backward inhibition was incrreased by using verbal cues.

Experiment 4 (***chapter 6***) aims to examine the cue type effect by using arbitrary cues in all three tasks and find their influence on the size of switch cost and backward inhibition then compare the results with experiment 3 to investigate the underlying mechanisms the different cue types in task switching.

Experiment 5 (***chapter 7***) aims to understand if the feature of the target would be another important factor to influence the size of switch cost and BI effect. In order to disentangle the combined information in the target (word information and perceptual information), the word 'Up'/'Down' inside the arrow stimulus is removed and positioned next to the target.

Experiment 6 (***chapter 8***) aims to examine whether cue-target joint presentation is crucial for obtaining BI effect and switch costs. The target is no longer joined together after the cue presentation. In order to compare the results from the previous experiments for the cue type, two experiments were conducted: **a)** all verbal cue experiment **b)** all arbitrary cue experiment.

Chapter 9 aims to introduce some of task switching models and propose the conceptual model of backward inhibition which I developed in order to understand the relationship between task switching and backward inhibition.

Lastly, the important findings of all the experiments and theoretical background will be summarized and discussed in the **General discussion** (***chapter 10***). The brief conclusions and implications for the current thesis and possible future investigation will be also included in the last chapter.

Chapter 2

GENERAL METHODS

A. The Paradigm and Overview of Experiments

The central idea of the research was from the Mayr and Keele (2000)'s hypothesis: switching to a task set that recently had been abandoned, and thus is unlikely to have fully recovered from inhibition, should take longer than a switch to a task set that had been less abandoned, so may have fully recovered from residual inhibition. Based on Mayr and Keele (2000)'s idea on backward inhibition, three tasks, which participants had to switch between three tasks, were developed. Sample trials in this design are shown in *Figure 3*.

In this thesis, the task used was a simple judgment task: arrow, location and word task. These three tasks were instructed by the precue for each task in order to give the information for participants which task they had to perform and the stimulus was always presented by the arrow shape on the screen which was used for the three tasks: 1) arrow task was to make a response by the arrow pointing either 'up' or 'down' 2) location task was to make a response by the arrow located in either top (position : 'up') or bottom (position: 'down') of the screen 3) word task was to make a response by the word inside the arrow written either 'up' or 'down' (see *Figure 3*).

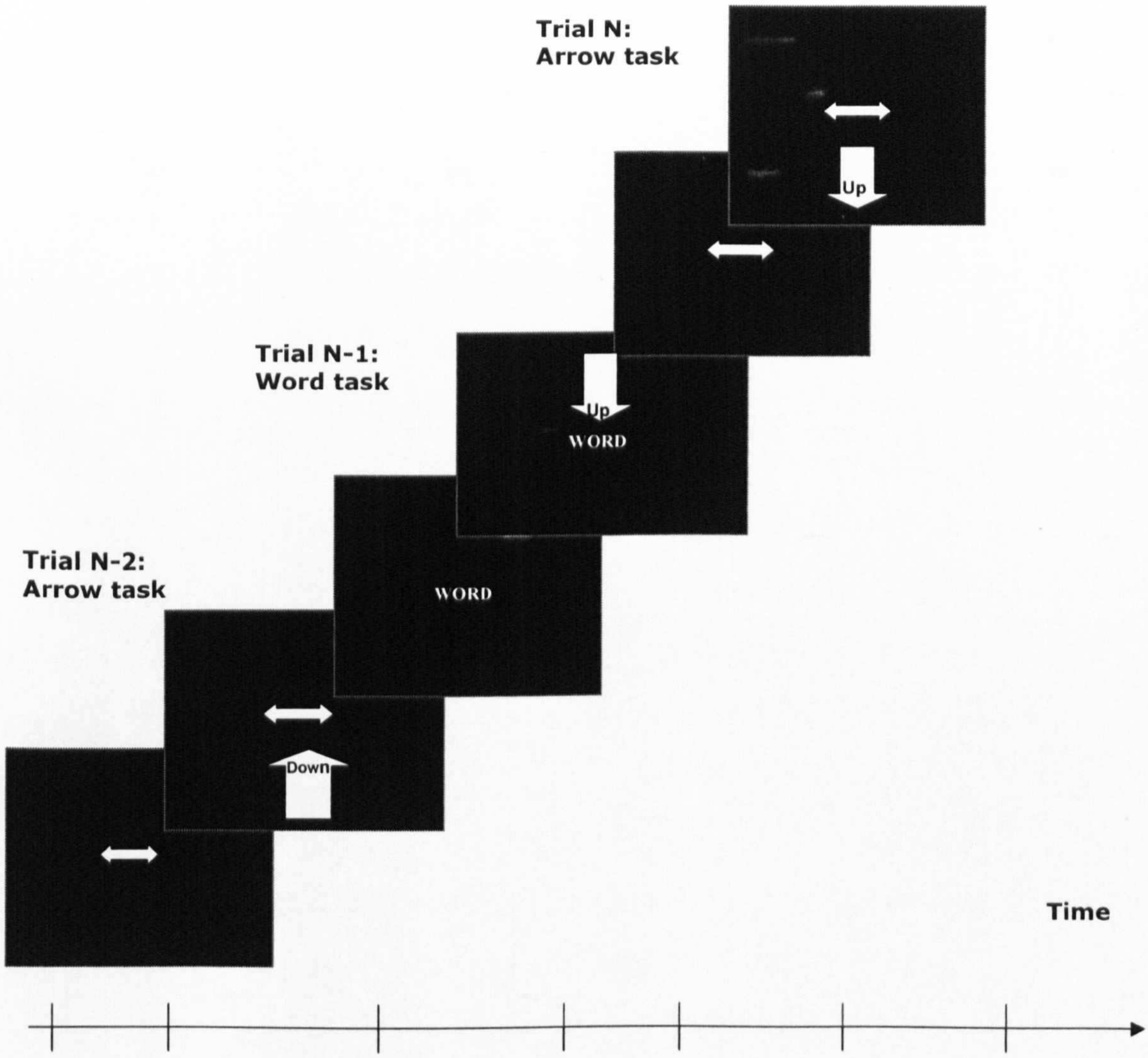


Figure 3. shows the example of the experimental paradigm. In this case, the alternating switch trials from the experiment 1 are presented. 'Time' represents the cue-target-interval (CTI) and response-cue-interval (RCI). All the experiments had fixed CTI-RCI manipulation: if the CTI was 100ms, the RCI was 1900ms and if the CTI was 1200ms, the RCI was 800ms. The figure does not represent the exact scaling of the stimuli. Note that in Experiment 6a and b the task cue was disappeared once the target stimulus was presented, whereas Experiment 1 to 5, the cue and the target stimulus were presented as shown in the figure.

In order to develop three tasks which were suitable for all the different age groups and a clinical group, the task had to be very simple. By using the arrow shape as a stimulus, it was now possible to manipulate the task. For example, the shape of the arrow itself already had 'two' features: direction (for the arrow task) and spatial location (for the location task). As the arrow stimulus was embedded with these two features, the third task had to be also part of the stimulus. Thus, the word information inside arrow (for the word task) enabled participants to do the separate task. Since, it was embedded in one single target, participants would have to inhibit the previous task set as well as to overcome the competition from the irrelevant task information while performing the current task. In other words, the stimulus for the current task had the task information which was not only potentially irrelevant but also all congruent for the correct responses.

The participants' task was to make the correct response by pressing the mouse button indexed either 'up' or 'down' (see *Figure 4*) depending on what kind of task was involved: arrow, location and word task.

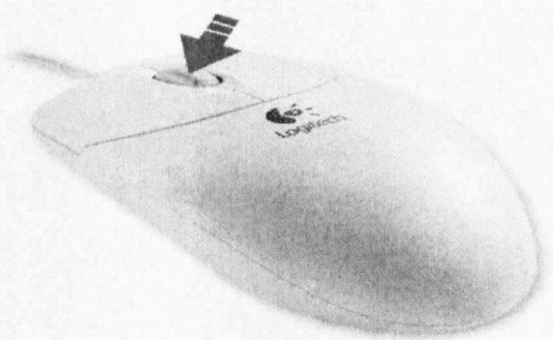


Figure 4. present the mouse key for the response selection which was indexed with 'up' and 'down' button. The middle key was not allowed to press and it was fixed on the desk with blue stick glue.

The arrow stimulus also gives the two other possible responses: left and right. However, it might be complicated to have four different responses with three tasks for participants as well as the analysis. Moreover, right/left stimulus might provide the lateralization effect in the imaging experiment such as fMRI and ERP which can be used in the near future. Therefore, two responses (up/down) were only used throughout the thesis.

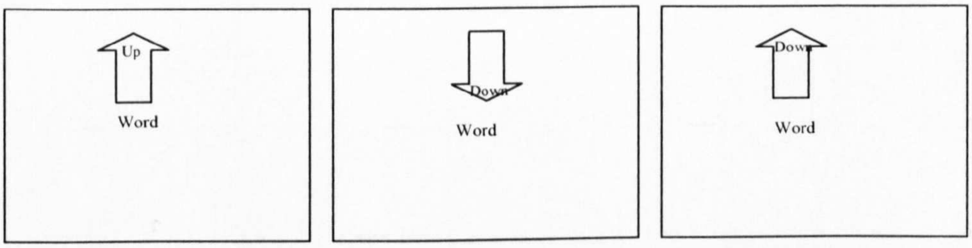
In the arrow task, they had to attend to the point of the arrow irrespective of the word inside the arrow or its spatial position of the arrow in the screen. For example, if the arrow is pointing upward, the correct response should be the 'up' button. In the location task, participants had to respond to the position of the arrow whether it was located at the bottom or top of the screen. For example, if the arrow is up at the top of the screen, they had to press "up" button and if the arrow is down at the bottom of the screen, they had to press "down" button. Lastly, in the word task, they had to attend to the word inside the arrow target. For example, if the word inside the arrow was 'up', they had to press the 'up' button. The advantage of this experimental paradigm is that the direction, the position, and the word inside the arrow could indicate different response for each task, thus the participants had to attend the appropriate attribute to perform the current task.

Two CTI (Cue-Target-Interval) - RCI (Response-Cue-Interval) conditions were implemented, resulting in 100ms of CTI + 1900ms of RCI and 1200ms of CTI +800ms RCI. In the short preparation interval (CTI=100ms) when RCI is long, there was time for the preceding task set to dissipate but little time for preparing the next task set, whereas in the long preparation interval (CTI=1200ms) when RCI is short, there was sufficient time to prepare for the next task set but little time for the preceding task set to decay passively. The rationale for this manipulation was based on Mayr & Keele (2000)'s original idea that they wanted to provide the evidence about the time sensitivity of a potential inhibitory process. The authors pinpointed that participants might entertain sequential expectations about upcoming tasks that contain a bias against ABA sequence (lag-2 repetitions from the original paper) as they could jugde the probability or frequency of a sequence by considering how much the sequence resembles available data as opposed to using a Bayesian calculation (e.g., Kahneman & Tversky, 1972). In that case, they could exhibit a bias toward expecting all three possible sets to occur within runs of three trials rather than ABA sequence (lag-2 repetitions). In order to rule out the alternative explanation that an 'inhibitory effect' could be the result of expectancy violations, the authors believed that the manipulation of the CTI would provide a direct test of the expectancy account. For example, if the sequential expectancy was the relevant process that produces an increase in RT one would expect an effect only in the case of short CTI. In contrast, a CTI of about 500ms was known to be sufficient for effective preparation for the upcoming task set (e.g., Rogers & Monsell, 1995), so that incorrect expectancies should be 'overwritten'. Thus, if the expected RT effect was not modulated through the CTI manipulation, a sequential expectancy explanation would seem very unlikely (Mayr & Keele, 2000). This CTI-RCI manipulation was used in all the experiments presented in the thesis. The order of trials and CTI/RCI manipulation were all in a random order, thus participants had all different task interval conditions in every block in order to engage them more to the task. Each block had 60 trials and the experimental session had 12 blocks, resulting in 720 trials in total during the experiment. The experiment was designed by E-Prime version 1.1 and run by Window 98' PC.

Backward inhibition was measured by alternating switch costs by comparing RTs in the alternating switch trial (e.g., AB**A**) and the RTs in the double switch trial (e.g., CB**A**). For example, in the figure 3 (see *page 46*), RTs in the arrow task from the N trial could be compared with RTs in the location task from the N trial. The main idea for the slower RTs in the alternating switch trials compared to the RTs in the double switch trials was based on the assumption that successful performance for switching task requires inhibition of the previous task set which is no longer useful for the upcoming task set as well as to activate the upcoming task set. By measuring the backward inhibition effect with alternating switch costs, it was possible to see if this is a part of executive control mechanism that can be independent and separable. Simultaneously, switch costs were measured by comparing RTs in the switch trials (e.g., B**A**) and repeat trials (e.g., A**A**) to understand the relationship between backward inhibition and switch costs in task switching. Congruency effects were also measured by comparing RTs in the incongruent trials and RTs in the congruent trials.

Specifically, there are three different types of congruency as can be seen in *Figure 5*.

Congruent trials are when three tasks have all the same responses (the correct response of the current task is congruent to that of the other two tasks) whereas incongruent trials are when three tasks have different responses (the correct response of the current task is incongruent to that of the other two tasks). In one-third of the trials of each block, task-relevant information and task-irrelevant information were mapped to the same response (congruent condition), in one-third of trials, task-relevant information and task-irrelevant information were mapped to the different responses: one is the single incongruent condition that the response of the current task was incongruent to one of the other tasks. The other one is the double incongruent condition that the correct response of the current task is incongruent to the other two tasks.



1) *Congruent* **2) *Single incongruent*** **3) *Double incongruent***

Correct responses for the current task and the other two tasks

1) Congruent	2) Single incongruent	3) Double incongruent
Word: Up	Word: Down	Word: Down
Arrow: Up	Arrow: Down	Arrow: Up
Location: Up	Location: Up	Location: Up

***Figure 4*.** The word task as an example shows three different congruent conditions on the current trial. Within a block of trials, these congruent conditions are presented in a random order.

The goal of this study was to demonstrate the backward inhibition effect as well as the switch cost effect by using a simple paradigm. The main question was whether there would be any backward inhibition effect in a three-task switching paradigm in order to support the idea that suppressing the old (previous) task sets is as important as activating the new (upcoming) task set when you have to switch constantly and differently. Another question was also raised if the interference from the irrelevant task set really exists in task switching. In order to answer this question, congruency effect was also measured. Specifically, I reported results from six experiments using my experimental paradigm and the results will be presented in detail throughout the thesis.

B. Analytic Procedures

Because of the same experimental paradigm throughout the thesis, the analysis for each experiment was adapted in the same manner. The measurements (Independent variables) from the each experiment were as follows.

Switch cost was measured by subtracting the mean RT (percent error scores) in the switch trials from mean RT (error percentage) in the repeat trials. For the analysis, switch trials were defined as any task switch between N-1 and N trials. Thus, all kind of switch type trials including alternating switch and double switch trials were categorised as switch trials[1]. In the previous analysis for switch cost, switch trials are defined as any task switch between N-1 and N trials. Thus, all kinds of switch trials including alternating switch and double switch trials were categorised as switch trials. Note that switch trials are more often than repeat trials

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[1] Note that switch trials are more often than repeat trials (switch trials: repeat trials =72%: 28%) and the proportion among the switch trials are nearly equal (1-switch: 2-switch: alternating switch = 23%: 25%: 22%) and the task sequence was in a random order for each block so each block had different task sequence order within this percentage of trials.

1) Repeat trials: AAA, BAA, CAA, ABB, BBB, CBB, ACC, BCC,CCC

2) One switch trials: BBA, CCA, AAB, AAC, CCB, BBC

3) Two switch (double switch) trials: CBA, ABC, BAC, CAB, BCA, ACB

Alternating switch trials: ABA, CAC, BAB, ACA, BCB, CBC (switch trials: repeat trials =72%: 28%) and the proportion among the switch trials are nearly equal (1-switch: 2-switch: alternating switch = 23%: 25%: 22%) and the task sequence was in a random order for each block so each block had different task sequence order within this percentage of trials.

1) Repeat trials: AAA, BAA, CAA, ABB, BBB, CBB, ACC, BCC,CCC
2) One switch trials: BBA, CCA, AAB, AAC, CCB, BBC
3) Two switch (double switch) trials: CBA, ABC, BAC, CAB, BCA, ACB
4) Alternating switch trials: ABA, CAC, BAB, ACA, BCB, CBC

Alternating switch cost was measured by subtracting the mean RT (error percentage) in the alternating switch trials from mean RT (error percentage) in the double switch trials.

Congruency effect was measured by subtracting the mean RT (error percentage) in the incongruent trials from mean RT (error) in the congruent trials. As discussed earlier, there were two different incongruent trials: single incongruent and double incongruent and these are summed up for the average RT of the incongruent trials. The congruency effect was analysed in both current trials and previous trials and the reasons are as follows.

a. congruency on the current trials was analysed to see how active the other task sets remain. In other words, The current congruency effects indicates that the current level of activation interferes from the activation of the other task sets, depending on whether it activates a response that is the same (congruent) as or different (incongruent) from the response activated by the new upcoming task set (current task set).

The congruency effect on the current trials was measured by subtracting the mean RT (error percentage) in the incongruent trials from mean RT (error) in the congruent trials. In other words, it is calculated by the mean RTs (error percentage) in the incongruent conditions (single incongruent 1+ single incongruent 2+ double incongruent)/3 - mean RTs (error percentage) in the congruent condition. Additionally, the current congruency was analysed with trial type (switch vs. repeat) and switch type (alternating switch vs. double switch) in order to determine whether the interference from the other task sets on the current trials are interacting with different switch conditions.

b. congruency on the previous trials was also analysed to see if the persisting activation of a previous task set can interfere with or facilitate a subsequent task switch, depending on whether it activates a response that is the same (congruent) as or different from the response (incongruent) activated by the new task set. In the present paradigm, the congruent and double incongruent conditions on the current N trials are not necessarily influenced by the previous trials N-1; however, single incongruent conditions on the current N trials are inevitably influenced by the previous N-1 trials. Note that *single incongruent 1 is congruent to the previous N-1 trials and single incongruent 2 is incongruent to the previous N-1 trials.* Thus, two different single incongruent conditions on the current N trials shows whether it is harder to do a task during the single incongruent 2 condition on the N trials compared to a task during the single incongruent 1 condition on the N trials. It is noteworthy that participants have to ignore the features of irrelevant task sets in both single incongruent conditions.,However, the difference between single incongruent 2 and single incongruent 1 is to see the interference from the previous congruency is stronger in the single incongruent 2 condition. Thus, the performance will be suffered as it might be more difficult to ignore the features of irrelevant task sets during the single incongruent 2 condition on the current trials.

The mean RT (error percentage) between single incongruent 2 and single incongruent 1 was compared in this analysis.

C. Statistical Procedures

For the statistical analysis, significance was tested in an analysis of variance (ANOVA) for repeated measures. The alpha level of significance was set to $p < 0.05$. All raw data were screened prior to analysis. The distribution of the raw data was tested for normality and homogeneity of variance. For all the experiments except the chapter 4, RTs were removed if it was larger than 3,000 ms and smaller than 300 ms from the raw dataset. This cut-off criterion for outliers[2] was made after calculating the mean of the raw dataset and 2-way standard deviation for each experiment. By this 300-3,000 ms cut-off, mean of median[3] RT which only included correct responses and mean error percentage were analyzed as dependent variables. After collecting the dataset for the analysis, the following procedures were used for the all the experiments. If four- interactions (or

[2] For the chapter 4, the cut-off criterion was 600-6,000ms for Old control and patients with an early stage of PD.

[3] Mean of median RT was used for all the experiments.

high level) were significant, these interactions were split in separate three-way (or more-way) ANOVAs one for each stage at each level. Two-way interactions for within factor comparisons in the repeated-measured ANOVA were followed up with Paired-Samples T-tests.

Error data were calculated as percentage of errors and subjected to repeated-measured ANOVA with the same factors as for the RT.

First, trial type (switch/repeat) x CTI (CTI=100ms /CTI=1200ms) x task (arrow/location/word) x congruency (congruent/single incongruent 1/ single incongruent 2/ double incongruent): 2 x 2 x 3 x 4 repeated-measure analysis of variance (ANOVA) with the independent variables task switch, CTI, task and congruency on the current trials was run. This 4-way ANOVA was run separately for RT and error. If there was 4-way interaction, it was broken down by each task and 3-way ANOVA by each task was presented. If there was 3-way interaction by each task, 2-way ANOVA by CTI was presented. If there was 2-way interaction by each CTI, congruency effect was examined by each trial type (switch/repeat trials).

Second, switch type (alternating switch / double switch) x CTI (CTI=100ms /CTI=1200ms) x task (arrow / location / word) x 3 (congruent / single incongruent 1/ single incongruent 2/double incongruent): 2 x 2 x 3 x 4 repeated-measure analysis of variance (ANOVA) with the independent variables alternating switch, CTI, task and congruency on the current trials was run. This 4-way ANOVA was run separately for RT and error. If there was 4-way interaction, it was broken down by each task and 3-way ANVOVA by each task was presented. If there was 3-way interaction by each task, 2-way ANOVA by CTI was presented. If there was 2-way interaction by each CTI, congruency effect was examined by each switch type (alternating switch/double switch trials).

Third, Paired-Samples T-test between single incongruent 1 and single incongruent 2 was run to see if the single incongruent 2 condition made slower RT and more errors because of the interference from the previous incongruence to the current trials. This t-test was run separately for RT and error for the effect of task switching (trial type: switch/repeat) and the effect of alternating task (switch type: alternating switch/ double switch).

Finally, group analysis between experiments was run with a repeated measured ANOVA. Table 2. shows the summary of the comparison between experiments. The group comparison will be discussed in the result section and the ANOVA table for the group analysis will be presented in the Appendix.

	Aim	**Overlapping condition**	**Comparisons**
Exp 1 **Vs.** **Old control in Exp 2**	To examine the effect of age on switch cost and backward inhibition effect	Task- oriented cue experiment Arrow task: ⟺ Location task: ☐ ☐ Word task: WORD	Young controls Vs. Old controls (average age: 27 vs. 59)
Exp 1 **Vs.** **Exp 3**	To see if the verbal cue effect on switch cost and alternating switch cost	-Young controls -the cue for the word task is the same as exp 1	Exp1: task-oriented cue Vs. Exp3: all verbal cue
Exp 3 **Vs.** **Exp 4**	To see whether the strength of the cue-target association influence the performance of switch cost and alternating switch cost (strong cue vs. weak cue comparison)	Young controls	Exp3: all verbal cue vs. Exp4: all arbitrary cue Arrow task cue: &&&&& Location task cue:%%%%% Word task cue:#####
Exp 3 **Vs.**	To examine if the separate information in the target feature	-Young controls -all verbal cues	Exp 3: the word information inside the arrow stimulus vs.

Exp 5	(verbal /visual) influences the magnitude of switch cost and alternating switch cost		Exp 5: the word information outside the arrow (e.g. ⇩ Up)
Exp 3 **Vs.** **Exp 6a**	To see the different cue-target joint/ separate display influences the switch cost and alternating switch cost	-Young controls -All verbal cue	Exp 3:target is jointed with cue vs. Exp6a: target is presented after cue disappeared
Exp 4 **Vs.** **Exp 6b**	To see the active preparation for the upcoming task even when the cue information is disappeared when the cues are arbitrary.	-Young controls -All arbitrary cue	Exp4:target is jointed with cue vs. Exp6b: target is presented after cue disappeared
Exp 6a **Vs.** **Exp 6b**	To see the strength of the cue -target association when both cue and target for all the tasks are presented separately.	Cue and target are separately presented	Exp 6a: all verbal cue Vs. Exp 6b: all arbitrary cue

Table 2. presents a brief summary of group comparisons between experiments. The analysis for different experiments will be discussed in the experimental chapter. Note that this group analysis was made mainly to see the effect of cue type or cue-target temporally overlapping or separately presented in terms of backward inhibition mainly and the switch costs. However, the congruency effect was also examined if there is any change between group comparisons.

D. Research Questions

Throughout the thesis, same research questions were raised for the results. All the results in the thesis were presented with reaction time and error percentage separately. The structure of the discussion in each experiment also followed the questions in order to answer this question based on the results.

First, the research questions for ***the effect of task switching*** were presented and the results for all the experiments follow the questions.

a. ***Is there any switch cost?***

This question is the fundamental and important for task switching. In order to answer the question, the switch costs for reaction time and error were calculated for each task. If there is any switch cost, the next question is to know whether it is reduced by the long preparation interval and whether it is influenced by the different type of cues and tasks. The presence of switch cost in task switching simply gives more evidence to support the idea that it is an index of extra time to reconfigure the upcoming task set while switching tasks.

b. ***Is there a main effect of congruency?***

The main effect of congruency on the current trials shows how active and persistent the other task sets remain, indicating that the current level of activation from the current task get interference from the activation of the other task set. As described earlier, the congruency effect is calculated for each task in order to see whether the congruency influences the task differently. Additionally, it is interesting to see if the congruency effect is immune to the preparation interval or not.

c. ***Does congruency interact with switch/repeat trials (trial type)?***

The main interest in this question is to see if the switch trials are more influenced by the congruency than the repeat trials and to see if the switch costs are reliably bigger on the incongruent trials than the congruent trials. If there is significantly bigger congruency effect on the switch trials than repeat trials, it might be assumed that switching different tasks have more interference from the other task sets which are on a currently activated state. Additionally, it is interesting if the interaction depends on the task and preparation interval.

d. Is there any previous congruency effect?

Previous congruency effect shows if the persisting activation of a previous task would interfere with or facilitate a subsequent task switch or repeat trials, depending on whether it activates a response that is the same as (single incongruent 1 condition on N trials) or different from the response activated by the new task set (single incongruent 2 condition on N trials). To answer the question, the single incongruent 1 and single incongruent 2 on the current trials are compared as both trials are directly influenced by the previous N-1 trials. Previous congruency effect on reaction time and error is examined for each preparation interval and task separately as well as the each trial type (switch/repeat).

Second, the research questions for ***the effect of alternating task*** were presented and the results for all the experiments follow the questions.

a. Is there any alternating switch cost?

This question gives the evidence of backward inhibition in task switching. In order to answer the question, the alternating switch costs for reaction time and error were calculated for each task. If there is any alternating switch cost, the next question is to know whether alternating switch cost is reduced by preparation interval or not. According to the previous literature (Mayr & Keele, 2000; Arbuthnott & Woodward, 2002; Arbuthnott, 2005), they have argued that backward inhibition is immune to the preparation interval. Moreover, it is interesting to see if the different cue type and tasks also influence the backward inhibition.

b. Is there a main effect of congruency?

The definition of the congruency effect is the same as before, however it is noteworthy that the congruency effect occurs in three-task switching; one is the alternating switch and the other is double switch. Thus, this question is about whether the interference from the irrelevant task sets influences the switching trials. Congruency effect is calculated for each task and preparation interval separately.

c. Does congruency interact with alternating switch/double switch trials (switch type)?

This question is related to the previous question b. If there is any congruency effect, it is interesting to find whether the congruency influences the alternating switch and double differently. One could argue that if an abandoned task set is not fully inhibited, the interference from that just-abandoned task set might be stronger. According to Hübner et al (2003)'s study, backward inhibition could reduce the interference from the preceding task set. Hence, it is interesting to find if the congruency effect is smaller on the alternating switch trials than double switch trials on the basis of the assumption that backward inhibition in the alternating switch trials can reduce the interference by inhibiting the task set representation which has just been abandoned.

d. Is there any previous congruency effect?

The main interest of this question is the same as before; if the residual activation of the task set on the N-1 trials interfere with or facilitate the current trials which are either alternating switch trials (e.g., task

A→***B***→A) or double switch trials (e.g., task C→***B***→A). Note that the previous trials in both alternating and double switch trials are the same tasks, thus this previous congruency is about the response congruency effect. In other words, if current task on N trials have the different response as the previous task on N-1 trials (single incongruent 2 condition) have more interference from when the current task on N trials have the same response as the previous task on N-1 trials (single incongruent 1 condition). This effect of previous congruency on reaction time and error is examined for each preparation interval and task separately as well as each switch type (alternating switch/double switch).

Lastly, the effect of cues between experiments (see *Table 2, page 57 in the current chapter*) is examined by the previous research questions and presented only for the important issues.

Chapter 3

Experiment 1: Switch cost and backward inhibition with task-oriented cue: Pilot study

INTRODUCTION

Mayr and Keele (2000)'s rationale for backward inhibition (BI) was simple: the previous task set must be inhibited to implement a new task set. Because a to-be-established task set is always a recently abandoned one in the task switching paradigm, persisting inhibition must be overcome. Schuch and Koch (2003) argued that when switching between only two tasks, inhibition of task sets cannot be distinguished from activation of task sets. That is, proactive interference might result from persisting inhibition of the currently relevant task set and/or from persisting activation of the previously relevant task set. Thus, they suggested that switch costs between two tasks may be due to the relative activation of one task set as compared with the other, but it cannot be decided whether inhibition is involved as an extra component. They also questioned that which processes involved in task switching are related to the inhibition mechanism. In order to answer this question, they made two hypotheses: 1) if backward inhibition is related to preparation process, the onset of a new task cue during the preparation interval might trigger inhibition of the previous task set, or 2) if backward inhibition is related to response process, in other words, if response related processes required inhibition of the competing task set, then this would imply that a new task set could be prepared without inhibiting the previous one. For example, Meiran (2000b) varied the degree to which the response sets of two tasks overlaps and the result demonstrated that residual switch cost occurred when the same two response keys were used for the two tasks but no residual switch costs occurred when if the different sets of response keys were associated with the task. This implied that response-selection requirement indeed played an important role in task switching. Thus, Schuch and Koch (2003) suggested that if the response conflict between the current and previous task set is resolved by inhibiting the previous task set, in other words, they wanted to examine backward inhibition as a function of response selection.

In order to answer these, three tasks were used by digits: 1) smaller-larger task (if the digit is smaller or larger than five) 2) odd-even task and 3) number classification task- whether a number was centrally located, i.e., 3, 4, 6, 7 or peripherally located, i.e., 1, 2, 8, 9 by using Go/No-go paradigm, indicating whether the response selection was required.

Of importance, this Go/No-go signal was provided by the different sound only at the time of stimulus onset, and it was completely unpredictable. This Go/ No-go paradigm enabled them to explore the role of response selection for inhibition of task sets. The result showed that backward inhibition (BI) was affected by No-go signals: large BI effect was observed in the Go condition but not in the No-go condition. Therefore, Schuch and Koch (2003) concluded that preparation processes do not involve backward inhibition in line with the notion that backward inhibition did not interact with preparation interval as Mayr and Keele (2000)'s result, because response selection cannot start during the preparation interval.

However, No-go manipulation would not only affect response execution but also response selection because no response had to be given in No-go trials (Schuch and Koch, 2003). Thus, they had another experiment where participants had to press the two response keys simultaneously (double press trials) when the No-go signal occurred. This way all possible responses were executed without requiring the selection of one response against another competing response. In other words, these double press trials required execution of all possible responses but not selection. Again, the result was that backward inhibition was found after Go trials but not found in the double press trials where response selection was not required, providing evidence that the inhibition does not depend on response execution but on response selection.

Schuch and Koch (2003)'s findings showed that backward inhibition is immune to the preparation interval in line with Mayr and Keele (2000) and Arbuthnott and Frank (2000)'s previous findings, furthermore, their double press trial manipulation in the No-go trials demonstrated that selecting a response caused inhibition of previous response meanings because they are interfering, and such persisting inhibition must be overcome when switching back to this task.

However, it is noteworthy that Go/ No-go paradigm is only limited to measure the response inhibition, hence it is difficult to generalize or conclude that backward inhibition only occurs in the process of selecting responses because task sets interfere with respect to response selection. That is, inhibition is always inhibition of something (e.g., a response, previous stimulus, previous stimulus-response mapping, and intention) in switching different tasks. For this reason, there is an open issue that any putative task also involves other process for backward inhibition. In their study, there was only one stimulus at a time, and stimulus dimension was purely cognitive, so that visual search and perceptual filtering process could not have played any role unlike Mayr and Keele (2000)'s odd-item-out paradigm. In this case, there was no conflict or interference once the stimulus was presented. Hence, one could argue that there might be another possibility that backward inhibition might influence specific stimulus representation or cue-processing.

For example, Hübner et al (2003) observed selective reduction of interference for all characters associated with a just-abandoned task for incongruent trials in a flanker task: If the target was '5A5' (letter task: vowel/consonant) on *n*-1 trial, interference was reduced for 'H#H' (symbol task: if the symbol contains straight line or curved line) on *n* trial and the author suggested that backward inhibition mechanism played a role in reducing inference from a directly preceding task set (flankers from the preceding task) compared with a task set not as recently applied (flankers from control task) when a switch to a new task is endogenously prepared for by a precue (experiment 1). However, when they manipulated the precue/ no-cue condition where precue did not specify the identity of the upcoming task- the only information by a precue was that there was going to be a task switch on the next trial, leaving open which of the two possible tasks would follow- there was no reduction of interference from preceding task set in this condition (experiment 2). This result demonstrated that the mere knowledge of having to abandon a task set without the option to prepare specifically for the new task is not sufficient for backward inhibition to occur. Furthermore, such a result would be line with by Mayr and Keele

(2000) with the idea that backward inhibition emerges only as a consequence of the activation of a new task set. The authors concluded that a finding of no reduction of interference from flankers of the preceding task in the precue condition demonstrated that backward inhibition is bound to the option of task-specific preparation. They also supported the idea that result from their experiment 1 was not by accelerated classification of flankers from the preceding task as irrelevant.

Hübner et al (2003)'s results suggested that backward inhibition may serve to reduce interference from all potentially competing task sets depending on their competitive strength. However, they admitted that it is unclear whether the interference reduction found in their experiment 1 was due to a reduction of response conflict or to a more general from of task competition. In their experiments, response sets were disjointed between tasks, and thus target and flankers were always associated with different responses, resulting in the contradictory view with Schuch and Koch (2003)'s view that backward inhibition works on response selection processes.

If the existence of the cue affected the size of backward inhibition in Hübner et al (2003)'s study, one could speculate that cue processing is an important factor influencing backward inhibition. Arbuthnott and Woodward (2002) examined these questions and whether task-relevant information provided by task cues influences the size of switch costs and alternating switch costs (measurement for backward inhibition). Cues presented 500ms prior to trivalent stimulus and three tasks were performed which was used by Arbuthnott and Frank (2000) previously: participants had to categorise three types of characters 1) digits (odd/even) 2) letters (vowel/consonant) 3) symbols (primary text/match use) by the task information from three types of cue. First, verbal cues (i.e., Odd or Even? / Vowel or Consonant? / Math or Text?) were presumed to have a pre-existing association with the various tasks and characters. Second, the appropriate tasks were indicated by the position of the stimulus array on the screen precued by a row of asterisks appearing at the relevant location (spatial cues). Third,: distinctive objects indicated the relevant task (✱ for the digit, ♫ for the letter, ♥ for the symbol judgment) (shape cues).

The results showed that substantial switch cost with recently learned cue-task associations (i.e., spatial/shape cue condition, 297ms and 283ms respectively) and greatly reduced switch cost (105ms) in the verbal cue condition where prior association exists with the relevant tasks or characters. However, alternating switch costs was observed in both pre-existing (i.e., verbal cue condition, 102ms) and recently learned cue-task associations (i.e., shape cue condition only[1], 134ms). Thus, alternating switch cost was not influenced by the strength of the cue-task association unlike switch costs, indicating that alternating switch cost reflects somewhat different processes than switch cost per se, specifically the time necessary to resolve inhibition of a recently abandoned task sets.

It appears that backward inhibition might affect the cue process and response selection as discussed earlier. However, there are theoretical and methodological disagreements on these issues, resulting in the lack of

[1] Alternating switch cost in the spatial location cue was nearly eliminated (8 ms cost). Thus, the author presumed that cue may influence the application process as Mayr and Kliegl (2003)'s suggestion.

generalization. Although both stimulus-based and cue-based information can activate the relevant task set possibly providing the evidence to support the role of inhibition in endogenous control processes, it is not clear whether the inhibition is actively and independently occurs in the cue-task association, preparation processing, response selection, causing more speculations. In order to examine these hypotheses from the previous literature, the current experiment was designed to capture these in three task switching paradigm which I introduced in the general method (see *page 43 in the chapter 2*).

The purpose of this pilot study was to simply measure the switch cost and backward inhibition by the alternating switch cost and to understand the relationship between those two by providing the evidence to support the idea that backward inhibition plays an important role in task switching and this effect is independent processing from switch costs. Additionally, it was also possible to measure the congruency effect to examine the interference from other irrelevant task sets.

METHODS

Participants

Twenty two participants (14 women) were recruited from the University of Nottingham through the advert and 12 of them were undergraduates and the rest of them were postgraduate in the psychology department. The participants ranged age from 18 and 31 years (M= 24.4, SD=6), reported normal and corrected-to normal vision and were all right-handed. They received £4 as an inconvenience allowance after completion of the experiment. The study took approximately 50 min to complete including the instruction and practice session.

Stimuli and Design

Stimuli for the target in the experiment were the shape of arrow either pointing up or down which was made for the whole procedure (height: 5 cm, width: 3cm). The target was always located either below (horizontal: 11.1 cm, vertical: 12.3 cm, from the top left corner) or above (horizontal: 11.1 cm, vertical: 2.13cm, from the top left corner for the position on slide) of the centre of the screen.

In each target, the text saying either 'up' or 'down' was presented inside the arrow and it was located in the arrow point part with the word in font Arial, Bold size 20. This text was shown in black ink within a white arrow target on a black background.

In order to guide participants as to which task they should be doing, a cue for the each task was visually displayed in the centre of the screen: two pointed arrow shape ('⇔') for the arrow task, two separate squares ('▫▫') for the location task, and letter ('WORD') for the word task in Arial font in upper case size 20. The cue for each task was presented first and was joined by the arrow target until a response was made (see the figure 4).

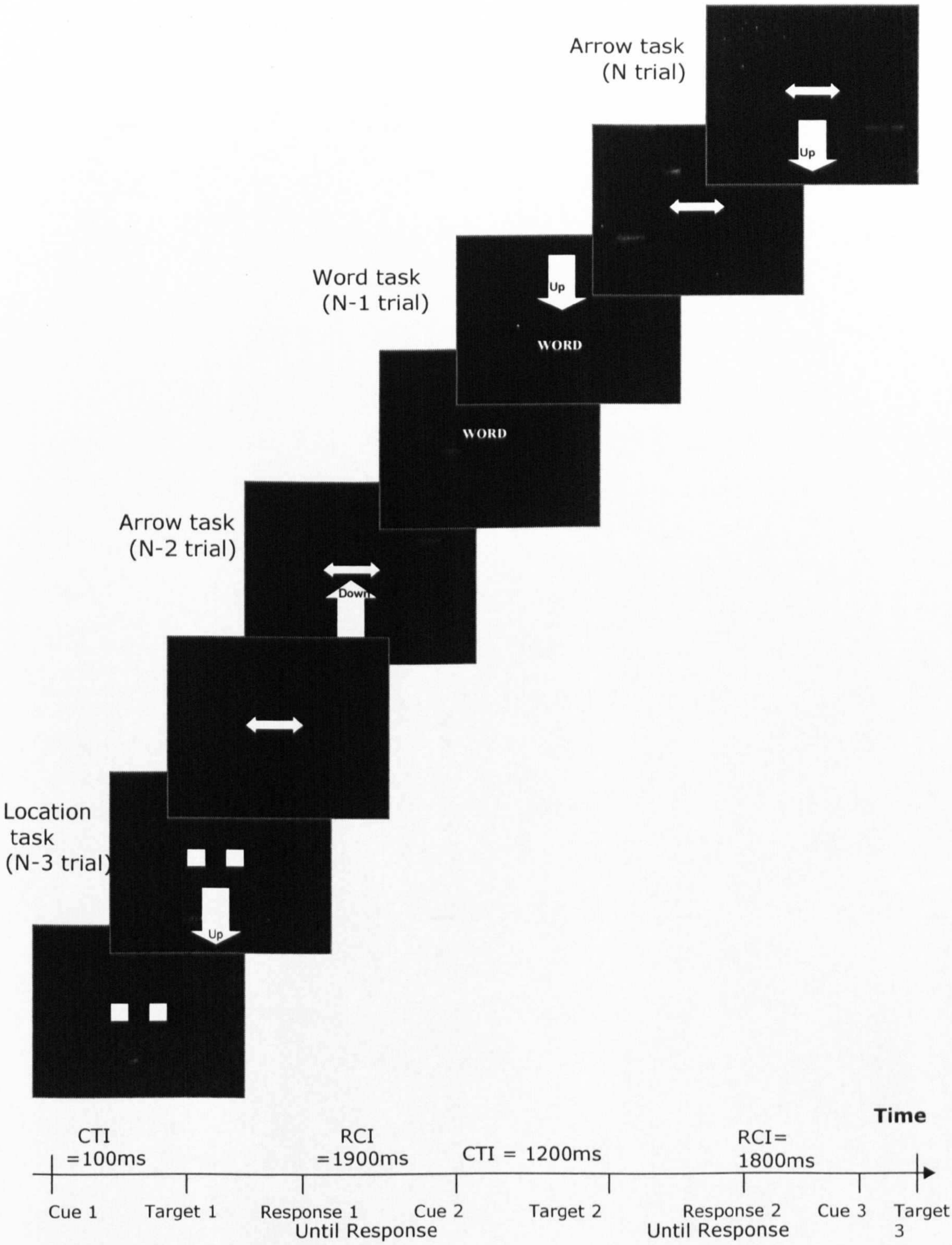


Figure 4. An example of the time course of task presentation in Experiment 1. Tasks were described here were three tasks: arrow, location and word task. As can be seen, if the CTI (cue-target-interval) was short (100ms), RCI (response-cue-interval) was long (1900ms) and if CTI was long (1200ms),

Apparatus and Procedure

The participants were tested individually in a room with dimmed lighting. The tasks were explained verbally using the examples of the cues and targets for each task. The each task was presented using a Window 98 desktop computer with a 14-inch monitor. The software was programmed in E-prime version 1.1 (W.Schneider, Eschman, & Succolotto, 2002) in all experiments including the current one. The PC in the experimental room was connected to the projector in the next room where participants were tested. They had to look up the wall to see the enlarged screen (width: 110cm, height: 85ms) and press the mouse button for the correct response on the desk.

Participants started with a short practice session, which consisted of repeating each task (16trials for each task) separately followed by switching between tasks (36 trials). During the practice, feedback (correct/ wrong) after each response was given. Participants were instructed to respond as quickly and accurately possible. During the switching practice trials, if participants achieved less than 27 correct out of 36 trials, they returned to another block of switching practice.

Following the practice session, the experimental session was presented with 12 blocks of 60 trials each, resulting in a total of 720 trials. Unlike in the practice session, no feedback was provided. At the end of each block, participants had a break and they pressed any button to start the next block when they were ready.

RESULTS

One participant was excluded from data analysis because she was interrupted by her mobile phone.

1) Effect of task switching

Four research questions for the effect of task switching were raised. They are as follows.

a. *Is there any switch cost?*

b. *Is there a main effect of congruency?*

c. *Does congruency interact with switch/repeat trials (trial type)?*

d. *Is there any previous congruency effect?*

On Reaction Time (RT)

Analysis of the 4-way repeated measured ANOVA with factors CTI (100, 1200), trial type (switch, repeat), task (arrows, location, word), and congruency (congruent, single incongruent[2] 1, single incongruent 2, double incongruent) revealed a significant 4-way interaction: **[F (5, 93) =2.4, p =.05]** (*see the Appendix, page 397 table 1*a). This interaction was explored by conducting three separate 3-way (factors CTI, trial type, and congruency) repeated measures ANOVAs for each task. These are reported below.

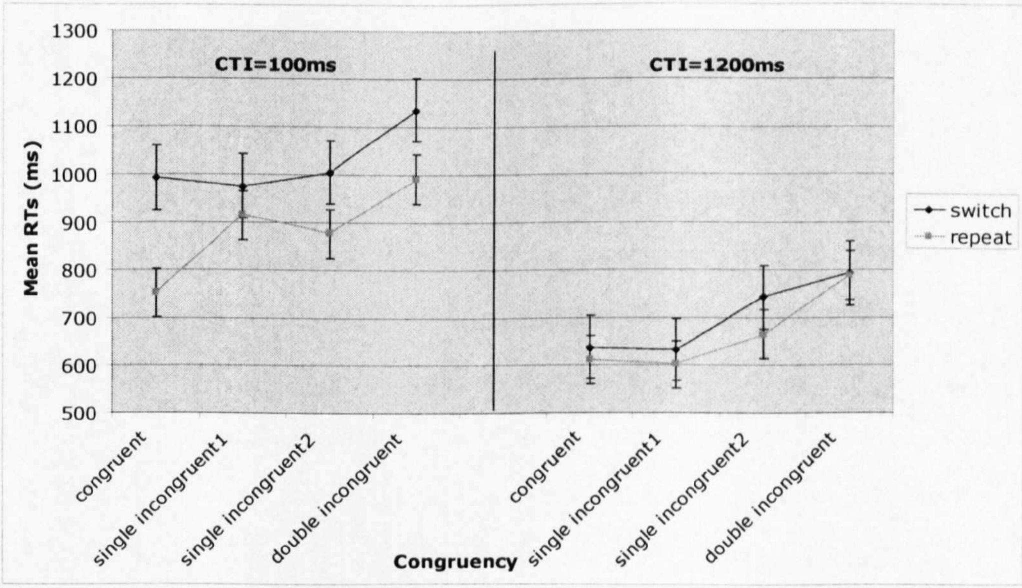
[2] The distinction between single incongruent 1 and single incongruent 2 lies in the previous N-1 trials. If the current task is *congruent* to the previous task on the N-1 trials, this is the current condition of the single incongruent 1. If the current task is *incongruent* to the previous task on the N-1 trials, this is the current condition of the single incongruent 2.

On Error (%)

Analysis of the 4-way repeated measured ANOVA with factors CTI (100, 1200), trial type (switch, repeat), task (arrows, location, word), and congruency (congruent, single incongruent 1, single incongruent 2, double incongruent) revealed a non- significant 4-way interaction: **[F (3, 72) =.51, p =.71]** (*see the Appendix, page 397 table 1b*). There was only a marginally significant 3-way interaction (CTI, task and congruency), **[F (3, 61) =2.5, p=.07]**. This marginal 3-way interaction was explored by presenting 3 separate figures by each task as these figures were previous presented on the reaction time (RT). Each figure is reported below.

Arrow task

a. RT



b. Error

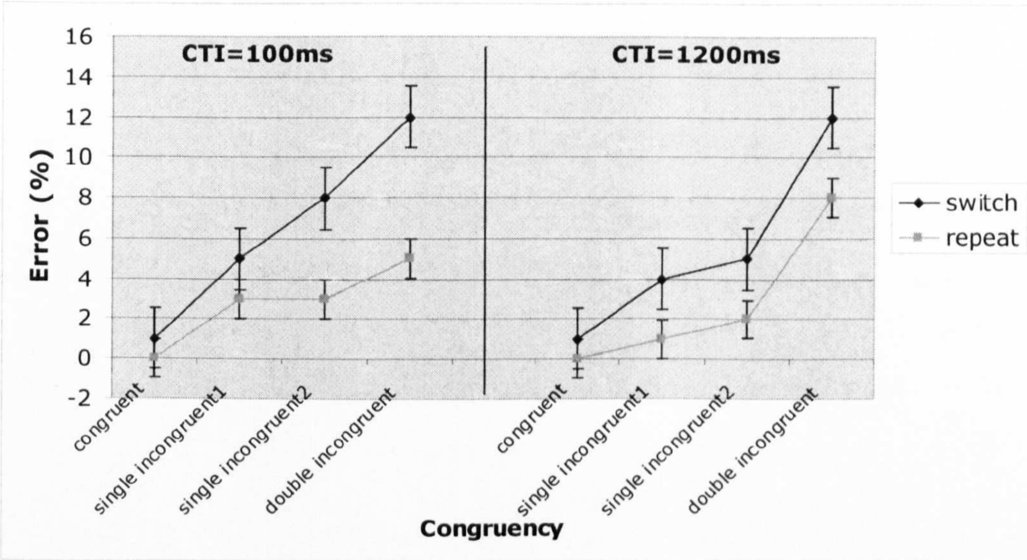


Figure 6. a. Mean RT (with standard error) (figure 6 a) and b.percent error scores (figure 6 b) in congruency and trial type in two CTI conditions for the arrow task.

RT (ms)

A significant difference between switch and repeat trials was only found at CTI =100, **[F (1, 22) =2, p <.001]** *(142ms of switch cost: switch RT minus repeat RT, M =1026 [SE: 59] vs. M= 884 [SE: 43]: switch vs. repeat*) but not at CTI=1200, *[F (1, 20) = 2, p =.17]*. (See *Figure 6* a).

There was also a marginal significant 3-way interaction (CTI, trial type and congruency) for the arrow task, **[F (2, 49) =2.5, p =.08]** which resulted from two effects which impacted CTI=100 but not CTI =1200. Both of these effects can be clearly seen in Figure 6 a and were confirmed an analysis of the simple effects (the factors trial type and congruency were examined at each CTI separately).

Firstly, there was a significant 2-way interaction between trial type and congruency at the CTI=100, **[F (3, 54) = 3.2, p =.04]** but not the CTI=1200, [F (2, 47) = .60, p =.58]. Paired-samples T-test revealed that at the CTI =100 switch trials were significantly slower than repeat trials for all levels of congruency: **t (20) =8.9, p <.001** in the congruent *(234ms of switch cost, switch M= 991 [SE: 54] vs. repeat M= 753 [SE: 36])*, **t (20)= -2.5, p =.02** in the single incongruent 2 *(123ms of switch cost, switch M= 1000 [SE: 60] vs. repeat M= 877 [SE: 54])*, and **t (20)= -2.7, p= .014** in the double incongruent *(145ms of switch cost, switch M= 1135 [SE: 73] vs. repeat M= 990 [SE: 58])*, except in the single incongruent 1, t (20) = -1.2, p =.26 *(60ms of switch cost, switch M = 914 [SE: 64] vs. M= 914 [SE: 72])*.

Secondly, and more interestingly although there was a significant effect of congruency for both switch and repeat trials at both CTI=100 **[F (2, 41)= 8, p<.001]** and CTI=1200 **[F (2, 37)= 11, p <.001]**, the impact of congruency was much larger on the repeat trials, **[F (2, 48)= 7.8, p <.001]** *(191ms of congruency effect, incongruent RT minus congruent RT: congruent M = 753 [SE: 36], single incongruent 1 M= 938 [SE: 75] single incongruent 2 M= 880 [SE: 53], double incongruent M =1013 [SE: 59])* than switch trial, **[F (2, 46) = 9.8, p <.001]** *(35ms of congruency effect, congruent M = 1018 [SE: 61], single incongruent 1 M= 982 [SE: 67], single incongruent 2 M= 1023 [SE: 63], double incongruent M= 1153 [SE: 74])* during the CTI=100.

At CTI=1200, switch and repeat trials were equally and significantly affected by the factor congruency, **[F (2, 37) = 11, p <.001]**. During the CTI =1200, the congruency effect was slightly larger on the switch trials **[F (2, 40) = 12, p <.001]**, *(106ms of congruency effect, congruent M= 641 [SE: 44], single incongruent 1 M= 633 [SE: 40], single incongruent 2 M= 760 [SE: 55], double incongruent M= 849 [SE: 76]*) than on the repeat trials, **[F**

(3, 56) = 6.1, p <.001] *(71ms of congruency effect, congruent M= 617 [SE: 39], single incongruent 1 M= 603 [SE: 35], single incongruent 2 M= 666 [SE: 39], double incongruent M= 795 [SE: 57]*).

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was not significant either on the repeat trials, t (20)= .87, p =.39 nor on the switch trials, t (20)= -1.3, p=.22.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was only significant on the switch trials, t (20)= -3.4, p=.003 but not on the repeat trials, t (20)= - 1.5, p =.15.

Error (%)

There was a non-significant 2-way interaction (trial type and congruency) in both at CTI=100, **[F (2, 45) = 1.7, p=.18]** and CTI=1200 **[F (2, 39)=1.0, p=.37]**.

A significant difference in error percentage between switch and repeat trials for the arrow task was found in both at CTI=100, **[F (1, 20) = 9.4, p=.006]** and CTI=1200, **[F (1, 20) = 11, p=.003]**.

The effect of congruency was also significant at CTI=100, **[F (2, 47) = 8.8, p<.001]** and at CTI=1200, **[F (1, 29) = 18, p<.001]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was not significant either on the repeat trials, t (20)= .11, p =.91 nor on the switch trials, t (20)= 1.4, p=.18.

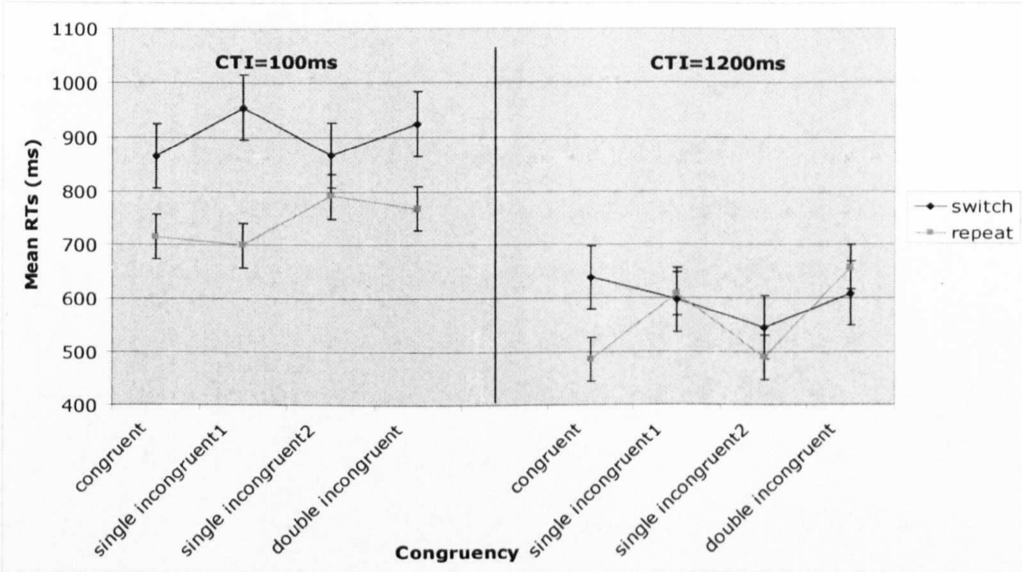
At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was only significant on the switch trials, $t(20) = -3.4$, $p = .003$.

Summary

a. A main effect of switch costs for the arrow task only occurred at the short preparation interval condition for reaction time whereas there was a main effect of switch costs in both short and long preparation interval condition on the error
b. A main effect of congruency for the arrow task was observed for both reaction time and errors for both short and long preparation intervals.
c. The interpretation for the interaction between congruency and trial type (switch/repeat trials) is difficult as it goes different direction for reaction time and error.
d. The effect of previous congruency for the arrow task only occurred during the switch trials for the long preparation interval on reaction time.

Location task

a. RT (ms)



b. Error (%)

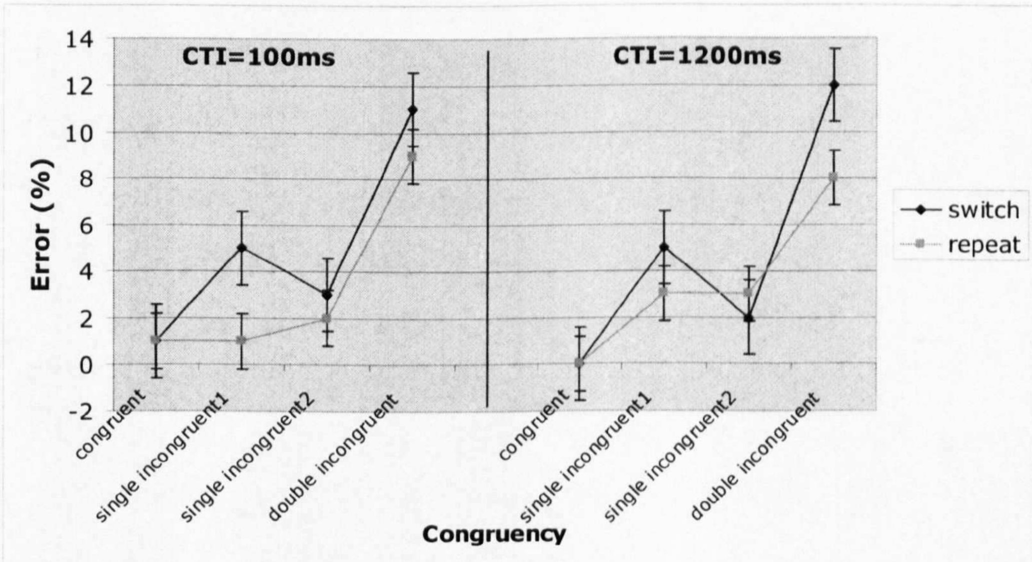


Figure 7. Mean RTs (and standard errors) (figure 7 a) and percent error scores (figure 7 b) in congruency and trial type in two CTI conditions for the location task.

RT (ms)

A significant difference between switch and repeat trials was found at CTI= 100, **[F (1, 20) = 36, p <.001]** *(160ms of switch cost, M = 903 [SE: 47] vs. M= 743 [SE: 35]: switch vs. repeat)* but not at the CTI=1200, [F (1, 20) = .16, p =.70] (see *Figure 7 a*).

There was a significant 3-way interaction (CTI, trial type and congruency) for the location task, **[F (2, 48) = 3.0, p=.05]** which resulted from two effects which impacted CTI= 100 but not CTI= 1200. Both of these effects can be clearly seen in *Figure 7 a* and were confirmed an analysis of the simple effect (the factors trial type and congruency were examined at each CTI separately).

Firstly, there was a significant 2-way interaction between trial type and congruency at the CTI=100, **[F (2, 44) = 3.0, p =.05]** but not the CTI=1200, [F (2, 44) = 1.2, p =.30]. Paired-Samples T-test revealed that at the CTI=100 switch trials were significant slower than repeat trials for all levels of congruency: **t (20) =- 3.2, p =.004** in the congruent *(151ms of switch cost, switch M= 866 [SE: 54] vs. repeat M= 715 [SE: 45])*, **t (20)= -7.5, p <.001** in the single incongruent 1 *(255ms of switch cost, switch M= 955 [SE: 48] vs. repeat M= 700 [SE: 35])*, and **t (20)= -4.2, p< .001** in the double incongruent *(156ms of switch cost, switch M= 924 [SE: 51] vs. repeat M= 768 [SE: 42])*, except in the single incongruent 2, t (20) = -1.4, p =.17 *(77ms of switch cost, switch M = 868 [SE: 44] vs. M= 791 [SE: 60])*.

Secondly, there was a significant effect of congruency for both switch and repeat trials at the CTI= 1200, **[F (2, 51) =12, p <.001]** *(88ms of congruency effect, congruent M= 496 [SE:31], single incongruent 1 M= 603*

[SE: 42], single incongruent 2, M= 517 [SE:29], double incongruent M= 633 [SE: 45]) but not the CTI=100 [F (2, 47) = 1.5, p =.22] *(44ms of congruency effect, M= 790 [SE:44] vs. M= 827 [SE: 39] vs. M= 829 [SE: 43] vs. M= 846 [SE: 43]).* At the CTI=100, the switch trials were significantly affected by the factor congruency: 50ms of congruency effect *(congruent M= 866 [SE: 54], single incongruent 1 M= 955 [SE: 48], single incongruent 2 M= 868 [SE: 44], double incongruent M= 924 [SE: 51])* in the switch trials, **[F (2, 54) = 6.9, p =.001]** but not in the repeat trials, [F (3, 43)= 1.3, p =.27].

At the CTI=1200, the switch and repeat trials were also significantly affected by the factor congruency: 79ms of congruency effect *(M= 505 [SE: 35] vs. M= 597 [SE: 44] vs. M= 545 [SE: 40] vs. M= 609 [SE: 46])* in the switch trials, **[F (2, 36)= 3.1, p=.05]** and 99ms of congruency effect in the repeat trials, **[F (2, 42)= 6.4, p =.003]** *(M= 486 [SE: 34] vs. M= 608 [SE: 44] vs. M= 658 [SE: 53]).*

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was only significant on the switch trials, **t (20)= 3.8, p=.001.**

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant both on the repeat trials, **t (20)= 2.8, p = .01** and on the switch trials, **t (20)= 2.1, p=.05**.

Error (%)

There was a non-significant 2-way interaction (trial type and congruency) in both at CTI=100, [F (2, 48) =2.3, p=.10] and CTI=1200, [F (1, 32) = 2.4, p=.12].

A significant difference in error percentage between switch and repeat trials for the location task was only found at CTI=1200, **[F (2, 37) =13, p<.001]** not at CTI=100, [F (1, 20) = 2.9, p=.10].

The effect of congruency was significant both at CTI=100, **[F (1, 24) = 10, p=.003]** and at CTI=1200, **[F (2, 37) = 13, p<.001]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was not significant either on the repeat trials, t (20)= .57, p =.58 or on the switch trials, t (20)= -1.8, p=.09.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was only significant on the switch trials, **t (20)= -2.8, p=.01** but not significant on the repeat trials, t (20)= .00, p =1.0.

Summary

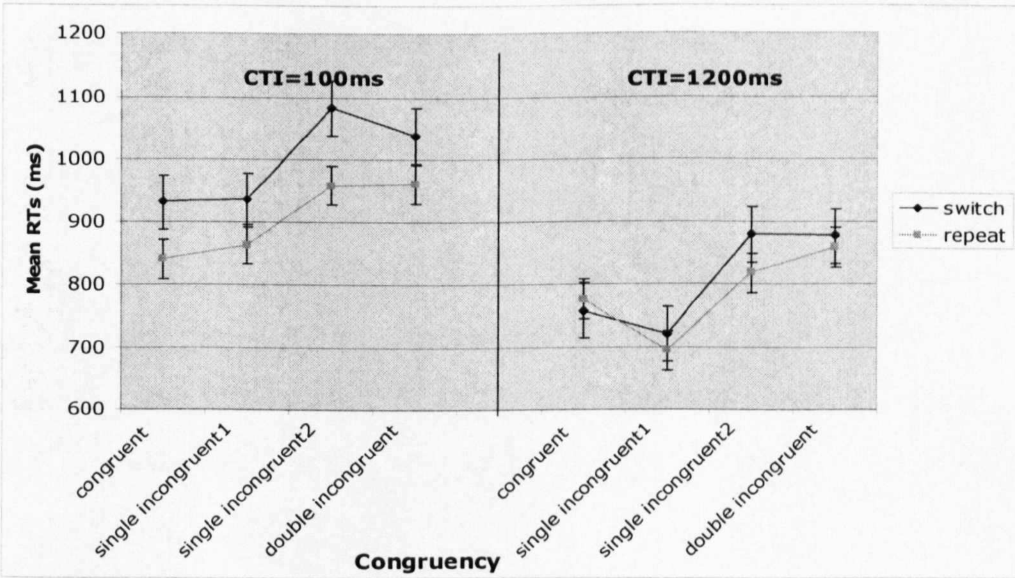
a. A main effect of switch costs for the location task only occurred in the short preparation interval condition on the reaction time. However, it did not occur in the long preparation interval condition on the error.
b. A main effect of congruency was observed on the reaction time for the long preparation interval only and on error for both short and long preparation interval.

c. The interpretation for the interaction between congruency and trial type (switch/repeat trials) is difficult to interpret the congruency effect only based on RT result because only switch trials were affected by the congruency in RT but not in error.

d. The effect of previous congruency was occurred during the switch trials for the short preparation interval and during the repeat and switch trials for the long preparation interval for the reaction time. However, it was all reversed previous congruency effect where the single incongruent 1 was significantly slower than single incongruent 2. It was not occurred for the error.

Word task

a. RT (ms)



b. Error (%)

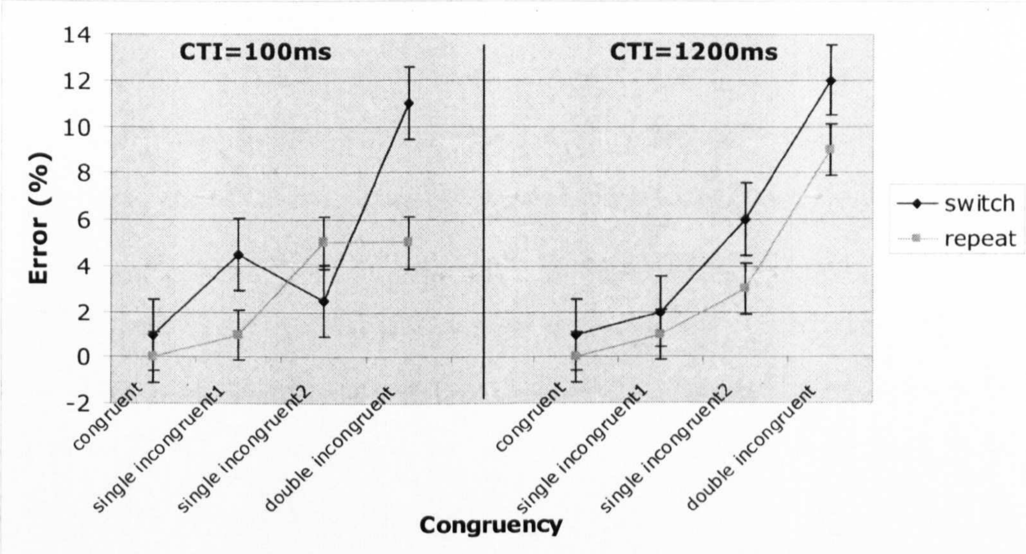


Figure 8. Mean RTs (and standard errors) (figure 8 a) and percent error scores (figure 8 b) in congruency and trial type in two CTI conditions for the word task.

RT (ms)

A significant difference between switch and repeat trials was found at CTI= 100, **[F (1, 20) = 13, p =.002]** *(89 ms of switch cost, M = 979 [SE: 41] vs. M= 890 [SE: 39]: switch vs. repeat)* but not at CTI=1200, [F (1, 20) = 2, p =.16] (see *Figure 8 a*).

There was a non-significant 3-way interaction (CTI, trial type and congruency) for the word task, [F (3, 54) = .30, p <.80].

However, a significant effect of congruency for both switch and repeat trials was found at both CTI=100, **[F (2, 32) = 7.7, p =.003]** and CTI=1200, **[F (2, 36) =13, p <.001]**.

This effect of congruency was found in both switch trials, **[F (2, 40)= 6.6, p =.003]** *(62ms of congruency effect, M= 933 [SE: 41] vs. M =934 [SE: 42] vs. M= 1041 [SE: 55] vs. M= 1009 [SE: 38])* and repeat trials, **[F (2, 32)= 5.6, p =.013]** *(53ms of congruency effect, M= 859 [SE: 43] vs. M= 840 [SE: 33] vs. M= 960 [SE: 64] vs. M= 936 [SE: 42])* during the

CTI=100. At CTI=1200, only switch trials were significantly affected by the factor congruency: 44ms of congruency effect, **[F (2, 50)= 20, p <.001]** *(M= 753 [SE: 40] vs. M =710 [SE: 29] vs. M= 829 [SE: 41] vs. M= 853 [SE: 33])* in the switch trials but not repeat trials, [F (2, 39)=2.1, p=.13].

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the switch trials, **t (20)= -2.9, p=.009** but not on the repeat trials, t (20)= -1.7, p =.10 .

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant both on the repeat trials, **t (20)= -6.4, p < .001** and on the switch trials, **t (20)= -4.9, p<.001**.

Error (%)

There was a non-significant 2-way interaction (trial type and congruency) in both at CTI=100, [F (2, 44)= .29, p=.77] and CTI=1200, [F (2, 40)=.75, p=.48].

A significant difference in error percentage between switch and repeat trials for the word task only found at CTI=1200, **[F (1, 20) = 7.7, p=.01]** not at CTI=100, [F (1, 20) = 1.4, p=.24].

The effect of congruency was significant both at CTI=100, **[F (2, 39) = 6.2, p=.005]** and at CTI=1200, **[F (2, 33) = 22, p<.001]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was marginally significant on the repeat trials, **t (20)= 1.9, p =.07** but not on the switch trials, t (20)= 1.4, p=.18.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was only significant on the switch trials, **t (20)= 2.6, p=.02** but on the repeat trials, t (20)= 1.1, p =.30 .

Summary

a. A main effect of switch costs for the word task only occurred in the short preparation interval condition on the reaction time whereas in the long preparation interval condition on the error.
b. A main effect of congruency was observed on the reaction time and on error for both short and long preparation interval.
c. The interaction between congruency and trial type (switch/repeat trials) occurred on the reaction time when it was the long preparation interval condition but it was not in error.
d. The effect of previous congruency occurred during the switch trials for the short preparation interval and during the repeat and switch trials for the long preparation interval for the reaction time. It was also occurred during the switch trials for the long preparation interval.

2) The effect of alternating tasks

Four research questions for the effect of alternating tasks were as follows.

a. *Is there any main effect of alternating switch cost?*
b. *Is there a main effect of congruency?*
c. *Does congruency interact with alternating switch/double switch trials (switch type)?*

d. Is there any previous congruency effect?

On Reaction Time (RT)

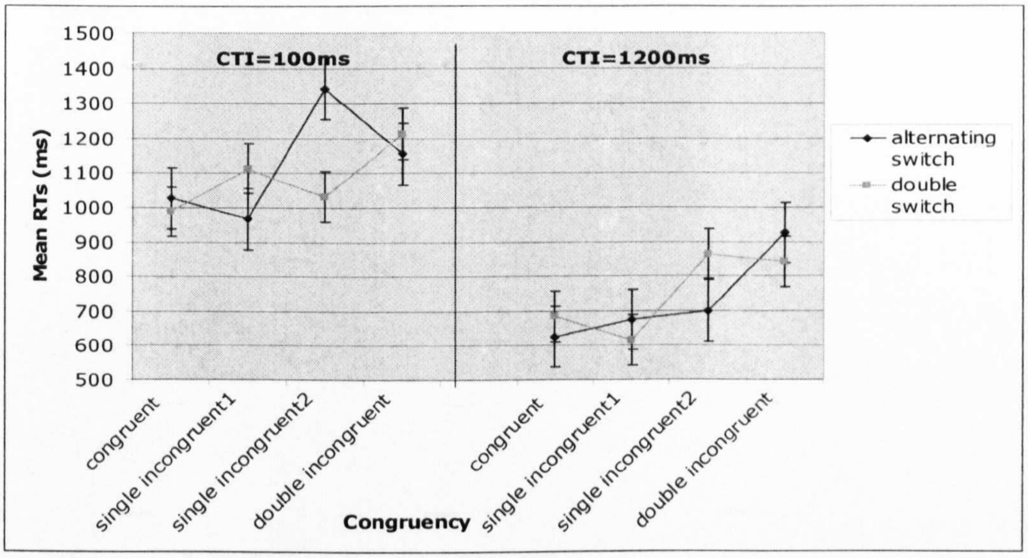
The repeated measures ANOVA with the factors CTI, switch type, task, and congruency revealed a significant 4-way interaction, **[F (2, 47) =3.6, p =.03]** (*see the Appendix, page 398 table 2a*). This four way ANOVA was split into three separate 3-way repeated measures ANOVA for each task separately. Each of these is reported below.

On Error (%)

Analysis of the 4-way repeated measured ANOVA with factors CTI (100, 1200), switch type (alternating switch, double switch), task (arrow, location, word), and congruency (congruent, single incongruent 1, single incongruent 2, double incongruent) revealed a non-significant 4-way interaction: [F (3, 67) =.58, p =.65] (*see the Appendix, page 398 table 2 b)*. There was only a significant 3-way interaction (CTI, task and congruency), **[F (4, 74) =2.8, p=.03]**. This 3-way interaction was explored by presenting 3 separate figures by each task as these figures were previous presented on the reaction time (RT). Each figure is reported below.

Arrow task

a. RT (ms)



b. Error (%)

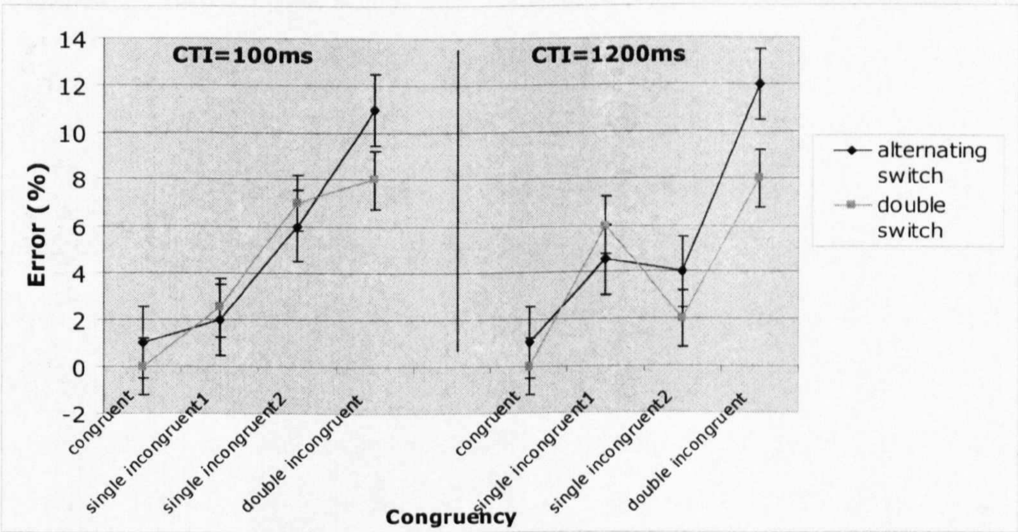


Figure 9. Mean RTs (and standard errors) (figure 9 a) and percent error scores (figure 9 b) in congruency and switch type in two CTI conditions for the arrow task.

RT (ms)

There was a significant 3-way interaction between CTI, switch type and congruency, **[F (2, 41)= 7.9, p=.001]**. The simple effects of this interaction were explored by examining each of the CTIs separately.

The effect of alternating tasks at the CTI= 100 *(37ms of alternating switch cost, alternating minus double switch, M = 1124 [SE: 70] vs. M= 1087 [SE: 69]: alternating switch vs. double switch)* was non-significant, [F (1, 20) = 1.4, p =.24]. It was also non-significant at CTI =1200, [F (1, 20) =.51 p=.48] *(-20 ms of alternating switch cost, M = 732 [SE: 46] vs. M = 752 [SE: 55])*.

At CTI=100, there was a significant interaction between switch type and congruency, **[F (2, 39) = 5.3, p=.01]**. As is clear from an examination of *Figure 9 a*, this was as a result of a large difference in RT between the alternating and double switch comparison in the second single incongruent condition only *(310ms of alternating switch cost, alternating switch minus double switch, alternating switch M=1343 [SE: 84] vs. double switch M= 1033 [SE: 91])*. This difference was confirmed as significant by a Paired-Samples T-test: t (20) = 3.4, p =.002.

At CTI=1200, there was also a significant interaction between switch type and congruency, **[F (3, 55) = 4.0, p=.014]**. As is clear from an examination of *Figure 9 a*, this was as a result of a large difference in RT between the alternating and double switch comparison in the second single incongruent condition only *(-165ms of alternating switch cost, alternating switch minus double switch, alternating switch M=700 [SE: 47] vs. double switch M= 865 [SE: 85])*.

In both CTI conditions, the effect of congruency was significant, **[F (2, 39) = 7.88, p <.001]** *(130ms of congruency effect, congruent M= 1008 [SE: 63], single incongruent 1 M= 1041 [SE: 71], single incongruent 2 M= 1188 [SE: 75] , double incongruent M= 1185 [SE: 84])* in the CTI=100 and **[F (2, 41) =12, p <.001]** *(116ms of congruency effect, congruent M= 655 [SE: 41], single incongruent 1 M= 645 [SE: 41] , single incongruent 2 M= 783 [SE: 58], double incongruent M= 884 [SE: 77])* in the CTI=1200.

During the CTI=100, alternating and double switch trials were equally and significantly affected by the factor congruency, **[F (2, 39) = 5.3, p=.01]**.

At CTI=100, congruency impacted both the alternating switch trials, **[F (3, 54) = 10, p<.001]** *(129ms of congruency effect, congruent M= 1027 [SE:79], single incongruent 1 M= 968 [SE: 69], single incongruent 2 M= 1343 [SE:84], double incongruent M= 1157 [SE: 95])* and double switch trials, **[F (2, 37) = 2.9, p=.07]** *(131ms of congruency effect, congruent M= 988 [SE:67], single incongruent 1 M= 675 [SE: 51], single incongruent 2 M= 701 [SE:47], double incongruent M= 927 [SE: 89])* at the CTI=100.

During the CTI=1200, although there was a significant effect of congruency for both alternating switch and double switch trials, **[F (2, 41)= 12, p<.001]** the impact of congruency was larger on the alternating switch trials, **[F(2, 44)= 9.4, p<.001]** *(142ms of congruency effect, congruent M= 626 [SE:36], single incongruent 1 M= 675 [SE: 51], single incongruent 2 M= 701 [SE:47], double incongruent M= 927 [SE: 89])* than on the double switch trials, **[F (2, 46) =7.9, p=.001]** *(89ms of congruency effect, congruent M= 685 [SE: 60], single incongruent 1 M= 616 [SE: 37], single incongruent 2 M= 865 [SE:85], double incongruent M= 842 [SE: 74])*. This may also be contributing to the significant 3 way interaction.

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials**, t (20)= -5, p <.001** but not on the double switch trials, t (20)= .72, p=.48.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the double switch trials, **t (20)= .-3.6, p=.002** but not on the alternating switch trials, t (20)= -.49, p = .63.

Error (%)

There was a non-significant 2-way interaction (switch type and congruency) both at CTI=100, [F (2, 40) = .31, p=.73] and CTI=1200 [F (2, 42) =.43, p=.67].

A difference in error percentage between alternating switch and double switch trials for the arrow task was non-significant both at CTI=100, [F (1, 20) = .007, p=.93] and CTI=1200, [F (1, 20) = .04, p=.84].

The effect of congruency was significant at CTI=100, **[F (2, 39) = 5.0, p=.012]** and at CTI=1200, **[F (2, 40) = 14, p<.001]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was not significant either on the alternating switch trials, t (20)= 1.2, p =.25 or on the double switch trials, t (20)= .98, p=.34.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was not significant either on the alternating switch trials, t (20)= -.48, p =.64 or on the double switch trials, t (20)= .60, p=.56.

Summary

a. A main effect of alternating switch costs for the arrow task did not occur on the reaction time and on the error.

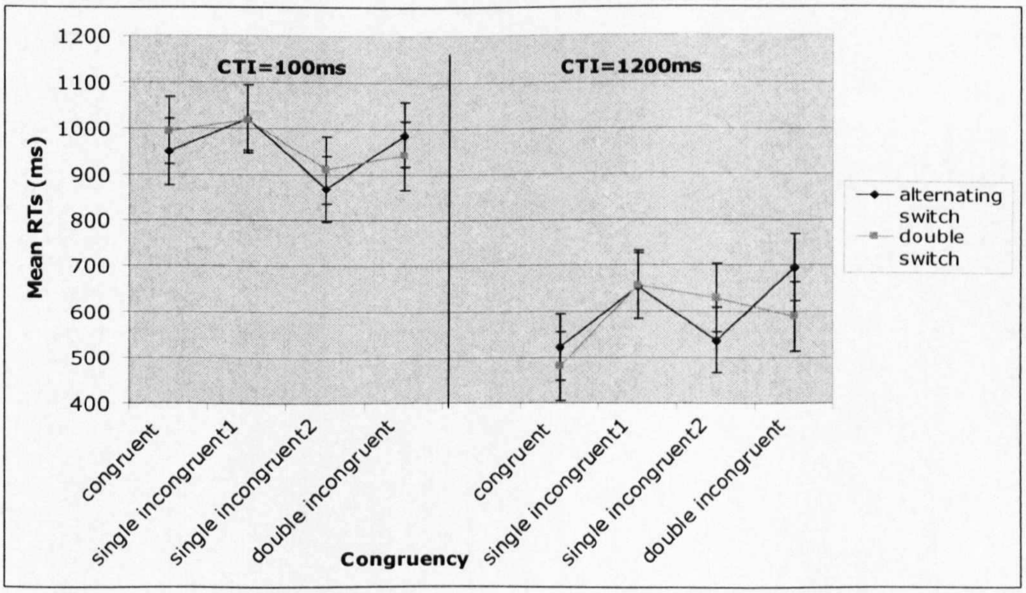
b. A main effect of congruency was observed on the reaction time and on error for both short and long preparation interval, showing that congruency affected both alternating switch and double switching trials.

c. The interaction between congruency and switch type (alternating switch/double switch trials) occurred on the reaction time not in error.

d. The effect of previous congruency for the arrow task occurred only during the alternating switch trials for the short preparation interval whereas it occurred only during the double switch trials for the long preparation interval on the reaction time. It did not occur on error.

Location task

a. RT (ms)



b. Error (%)

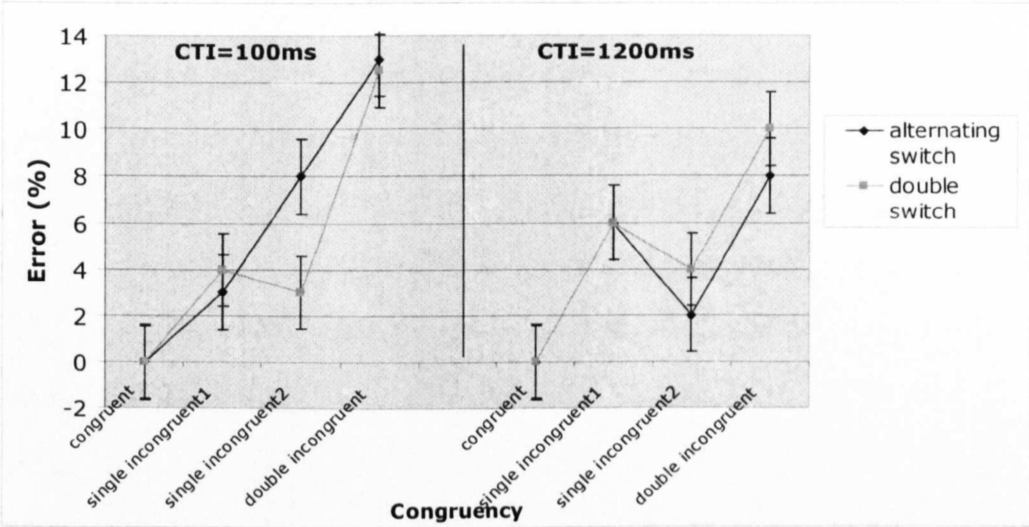


Figure 10. Mean RTs (and standard errors) (figure 10 a) and percent error scores (figure 10 b) in congruency and switch type in two CTI conditions for the location task.

RT (ms)

There was a non-significant 3-way interaction (CTI, switch type and congruency) for the location task, [F (2, 34) = 46, p =.60] and 2-way interaction (CTI and congruency), [F (1, 31)= 2.6, p=.10], (CTI and switch type), [F(1,20)=.51, p=.48] and (switch type and congruency), [F (2, 46)= 1.5, p =.22].

The effect of alternating tasks was non-significant both at the CTI= 100, [F (1, 20)= .22, p =.65] and at the CTI=1200, [F (1, 20)= .48, p =.50] (See figure 8).

The effect of congruency was only significant at the CTI= 1200, **[F (2, 44) =7.7, p =.001]** *(125ms of congruency effect, congruent M= 502 [SE: 39]* *vs. single incongruent 1 M= 656 [SE: 65] vs. single incongruent 2 M= 583 [SE: 52] vs. double incongruent M= 643 [SE: 57]).*

At CTI=100, alternating switch trials were not significantly affected by the effect of congruency, [F (2, 40) = 1.6, p =.21] *(9.3ms of congruency effect, congruent M= 949 [SE: 107] vs. single incongruent 1 M= 1022 [SE: 76] vs. single incongruent 2 M= 867 [SE: 48] vs. double incongruent M= 986 [SE: 60]).* Furthermore, response of the double switch trials was slowed by the congruent condition, **[F (2, 50) = 3.1, p=.04]** *(-38ms of congruency effect, congruent M= 523 [SE: 47] vs. single incongruent 1 M= 655 [SE: 72] vs. single incongruent 2 M= 695 [SE: 72] vs. double incongruent M= 589 [SE: 61]).*

At CTI=1200, the impact of congruency was slightly larger on the double switch trials, **[F(2, 42) =2.9, p=.06]** *(145ms of congruency effect, congruent M= 480 [SE: 39] vs. single incongruent 1 M= 657 [SE: 79] vs. single incongruent 2 M= 629 [SE: 78] vs. double incongruent M= 589 [SE: 61])* than on the alternating switch trials, **[F (2, 43)= 3.8, p=.03]** *(106ms of congruency effect, congruent M= 523 [SE: 47] vs. single incongruent 1 M= 655 [SE: 72] vs. single incongruent 2 M= 537 [SE: 45] vs. double incongruent M = 695 [SE: 72]).*

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant both on the alternating switch trials, **t (20)= 2, p =.05** and on the double switch trials, **t (20)= 3.8, p=.001.**

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (20)= 2.3, p = .03** but not on the double switch trials, t (20)= . 53, p=.60.

Error (%)

There was a non-significant 2-way interaction (switch type and congruency) in both at CTI=100, [F (2, 40) = .31, p=.73] and CTI=1200 [F (2, 42) =.43, p=.67].

A difference in error percentage between alternating switch and double switch trials for the arrow task was non-significant in both at CTI=100, [F (1, 20) = .007, p=.93] and CTI=1200, [F (1, 20) = .04, p=.84].

The effect of congruency was significant at CTI=100, **[F (2, 39) = 5.0, p=.012]** and at CTI=1200, **[F (2, 40) = 14, p<.001]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (20)= -2.0, p =.05** but not on the double switch trials, t (20)= -.68, p=.50.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was not significant either on the alternating switch trials, t (20)= -1.5, p =.15 or on the double switch trials, t (20)= -.94, p=.35.

Summary

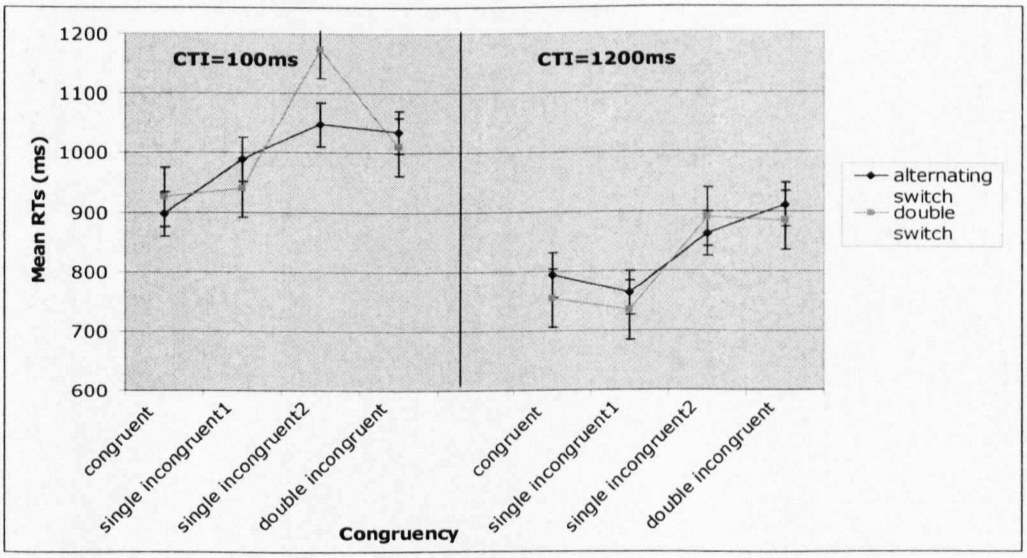
a. A main effect of alternating switch costs for the arrow task did not occur on the reaction time and on the error.
b. A main effect of congruency was observed on the reaction time (short preparation interval only) and on error (both short and long preparation interval), showing that congruency affected both alternating switch and double switching trials.

c. The interaction between congruency and trial type (switch/repeat trials) occurred on the reaction time but not on error. However, marginal interaction was present in the long preparation interval as the congruency effect was slightly larger on the double switch trials.

d. The effect of previous congruency for the location task occurred during the alternating switch trials and double switch trials for the short preparation interval and during the alternating switch trials for the long preparation interval on the reaction time. It was occurred only during the alternating switch trials for the short preparation interval on error. However, these were all reversed previous congruency effects.

Word task

a. *RT (ms)*



b. *Error (%)*

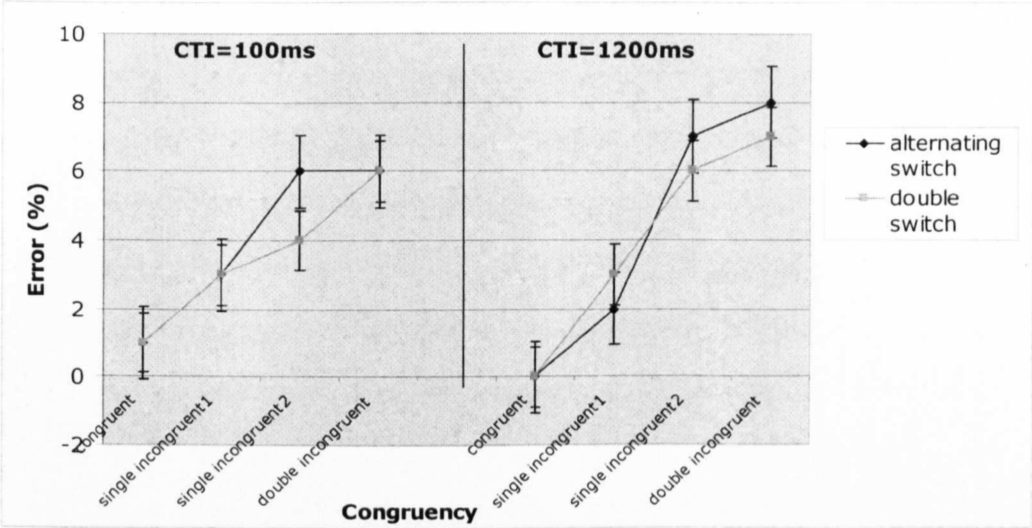


Figure 11. Mean RTs (and standard errors) (figure 11 a) and percent error score (figure 11 b) in congruency and switch type in two CTI conditions for the word task.

RT (ms)

There was a non-significant 3-way interaction (CTI, switch type and congruency) for the word task, [F (1, 32) = 6.7, p=.48]. A marginally significant interaction (switch type and congruency), **[F (2, 38) = 3.0, p=.06]** which was as a result from a large RT on the double switch trials when it was single incongruent 2 (see *Figure 11*).

The effect of alternating task was non-significant both at the CTI= 100, [F (1, 20)= .57, p =.46] and at the CTI=1200, [F (1, 20) = .59, p =.45] (see Figure 9).

The effect of congruency was significant both at the CTI=100, **[F (3, 53) = 11, p <.001]** *(121 ms of congruency effect, M= 911 [SE: 38] vs. M= 964 [SE: 47] vs. M= 1110 [SE: 93] vs. M= 1022 [SE: 42])* and at the CTI=1200, **[F (3, 53)= 11, p <.001]** *(67ms of congruency effect, M= 774 [SE: 40] vs. M= 749 [SE: 32] vs. M= 876 [SE: 47] vs. M= 897 [SE: 47]).*

At CTI=100, congruency significantly affected both on the alternating switch trials, **[F (2, 47)= 5.2, p=.006]** *(127ms of congruency effect, M= 896 [SE: 39] vs. M= 988 [SE: 57] vs. M= 1047 [SE: 64] vs. M= 1034 [SE: 44])* and double switch trials and double switch trials **[F (1, 23)=3.9, p=.05]** *(115ms of congruency effect, M= 926 [SE: 40] vs. M= 940 [SE: 46] vs. M= 1174 [SE: 131] vs. M= 1010 [SE: 43]).*

AT CTI=1200, the impact of congruency both on the alternating switch and double switch trials was reduced, however, it was still significant on the alternating switch trials, **[F (3,54) =6.4, p=.001]** *(52ms of congruency effect, congruent M= 794 [SE: 54] vs. single incongruent 1 M= 764 [SE: 34] vs. single incongruent 2 M= 862 [SE: 58] vs. double incongruent M= 911 [SE: 47])* and double switch trials, **[F (2, 46)=7, p=.002]** *(82 ms of congruency effect, congruent M= 754 [SE: 38] vs. single incongruent 1 M= 735 [SE: 35] vs. single incongruent 2 M =890 [SE: 58] vs. double incongruent M= 884 [SE: 50]).*

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the double switch trials, **t (20)= -2.1, p=.05** but not on the alternating switch trials, t (20)= -1.1, p =.28.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant both on the alternating switch trials, **t (20)= -2.5, p = .02** and on the double switch trials, **t (20)= -2.9, p=.008**.

Error (%)

There was a non-significant 2-way interaction (switch type and congruency) both at CTI=100, [F (2, 46)= .74, p=.49] and at CTI=1200, [F (2, 35)= 2.8, p=.09].

A difference in error percentage between alternating switch and double switch trials for the arrow task was non-significant in both at CTI=100, [F (1, 20)=.001, p=.97] and CTI=1200, [F (1, 20)= 2, p=.17].

The effect of congruency was only significant at CTI=1200, **[F (2, 34)= 13, p <.001]** not at CTI=100, [F (2, 40)= 2.4, p=.10].

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was not significant either on the alternating switch trials, t (20)= 1.5, p =.15 or on the double switch trials, t (20)= .38, p=.71.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (20)= 2.2, p =.04** but not on the double switch trials, t (20)= 1.3, p=.21.

Summary

a. A main effect of alternating switch costs for the word task did not occur on the reaction time and on the error.
b. A main effect of congruency was observed on reaction time and on error in both short and long preparation interval, showing that congruency affected both alternating switch and double switching trials.

c. The interaction between congruency and switch type (alternating switch/double switch trials) did not occur on the reaction time and on error.

d. The effect of previous congruency for the word task occurred during the double switch trials for the short preparation interval and it also occurred during the alternating switch trials and double switch trials for the long preparation interval on the reaction time. It was occurred only during the alternating switch trials for the long preparation interval on error.

DISCUSSION

The main aim of this experiment was to pilot a task switching experiment to see if the current experimental paradigm would be applicable and measurable to answer a simple research question: the relationship between inhibition of previous task sets and activation of upcoming task set by providing the switch cost and backward inhibition (BI) effect. Additionally, the congruency effect from irrelevant task set information was also examined to see if the persisting activation or inhibition from the irrelevant task set can interfere with or facilitate the switch cost and BI effect.

The present results have shown how switch costs and alternating switch cost were influenced by various separable processes, including advance preparation, proactive interference from recently activated task set, task-specific effect etc.

1) Effect of task switching

- ***Switch costs*** in all three tasks were dramatically reduced for the long preparation interval in terms of reaction time compared with the short interval, suggesting that participants used long preparation interval for advanced reconfiguration. Having significant switch costs on error during the long preparation interval demonstrate that participants still made errors while making a fast response (cf. speed-accuracy trade-off).

- ***Congruency effect on the current trials*** shows how active the other task sets remain. More precisely, it is shown that the current level of activation still interfered from the other tasks even when participants are given a long time to prepare to switch the task and even repeat the same task. The effect was depending on whether it activates a response that is the same (congruent) as or different (incongruent) from the response activated by the new upcoming task set (current task set). In other word, task switching performance was not only depended on the currently relevant task-set, but was also influenced by the set of temporary irrelevant task. In all three tasks, they demonstrated big congruency effect in reaction time and error, suggesting that participants made slower response and more errors when it was incongruent regardless of the preparation interval. Note that significant congruency effects were observed in both switch and repeat trials. Having congruency effects during the repeat trials for all three tasks suggests that the persistent activation of the irrelevant task set indeed interfered with the current task set because there was no need to suppress the irrelevant task set during the repeat trials, causing the other task set to be persistently activated.

- ***The interaction between congruency and trial type (switch/repeat)*** shows whether switch trials are more influenced by congruency than the repeat trials. If so, the bigger congruency effect on the switch trials suggests that switching different tasks are more influenced by the level of activation from the other task sets on the current trials. However, the current experiment demonstrated the significant congruency effect on the repeat trials as well as switch trials. It might be possible to speculate that there is no need to suppress the irrelevant task set during the repeat trials, causing the irrelevant task sets to be persistently activated. In the current experiment, the significant interaction between current congruency and trial type was inconsistently observed.
- ***Previous congruency*** shows that the task set from the previous N-1 trials remains in a state of residual activation. In other words, the persisting activation of previous task set interfered with a subsequent task switch, depending on whether it activates a response that is the same as or different from the response by the new task set on the current trials. In the current experiment, two different single incongruent conditions (single incongruent 1 vs. single incongruent 2) were compared to see if the RT and error are slower/larger on the single incongruent 2 condition (when the current task is incongruent to the previous trials) than single incongruent 1 (when the current task is congruent to the previous trials). Word task only showed a significant previous congruency effect compared to the other tasks. Word task was significantly influenced by the previous incongruent trials during switch tasks as well as repeating the same task. The previous congruency effect on the word task occurred in both preparation interval on the

reaction time and in the short preparation interval on error, suggesting that word information which is visually displayed in the target is the most conflicting information with the other task set information (e.g., the point of the arrow for the arrow task, the position of the arrow for the location task), resulting in the robust previous congruency effect.

2) Effect of alternating task

- ***Alternating switch costs*** were not observed on reaction time and error for any of the three tasks, suggesting that participants are not using backward inhibition in this paradigm to shift between tasks. However, it is noteworthy that arrow task during the short preparation interval demonstrated a huge alternating switch cost (310ms) only when it was single incongruent 2 condition. This indicates that backward inhibition might play a role in reducing the interference from previous trials only when it was incongruent to the current arrow task during the short preparation interval. Overall, the lack of backward inhibition might be due to 4-way ANOVA analysis by adding 4 levels of congruency condition, causing loss of statistical power. For example, arrow task during the short preparation interval showed 37ms of alternating switch cost which could be statistically reliable if the factor of congruency has not be included.
- ***Congruency effect on the current trials*** shows how active the other task sets remain. In all three tasks, they demonstrated big congruency effect on reaction time and error, suggesting that participants made slower response and more errors when it was incongruent regardless of the preparation interval. Although the congruency affected both alternating and double switch trials in all three

tasks, the size of effect on reaction time was different among tasks. For example, the arrow task showed larger congruency effect on the alternating switch trials (see *page 88*) whereas the location task showed larger congruency effect on the double switch trials (see *page 93*). For the word task, it did not show any interaction between alternating switch and double switch trials. It suggests that the level of activation is different depending on the task.

- ***The interaction between congruency and switch type (alternating switch/double switch)*** demonstrates if the interference of the irrelevant task sets occurs the backward inhibition. For example, there was a significant interaction between switch type and congruency (p=.01) during CTI=100 in the arrow task and it was as a result of a huge alternating switch cost (310ms) at the single incongruent 2 condition. Note that single incongruent 2 condition is when the current task is incongruent to the previous trials, suggesting that participants indeed used the backward inhibition to reduce the interference from previous trials for the arrow task.

However, the congruency effect affected on the alternating and double switch trials equally in other two tasks, causing non-significant alternating switch costs.

- ***Previous congruency*** significantly affected the alternating switch trials in the short preparation interval and the double switch trials in the long preparation interval for the arrow task (only RT). The word task was also affected by the previous congruency during the double switch trials in the short preparation interval and during the both alternating switch and double switch trials in the long preparation interval in terms of reaction time. Word task also showed the previous congruency effect in the alternating switch trials for the long preparation interval on error. This previous congruency effect in the word task was previously observed in the effect of task switching analysis, indicating that word information is indeed the most conflicting information with the other task features and participants had struggled to suppress the irrelevant task sets when their response was incongruent to the response of the word task on the current trials. It also suggests that different control processes may be involved than in the other tasks.

For example, the location task showed the reversed previous congruency effect which was significant, indicating that participants had more difficulties performing the location task when it was congruent to the previous task.

CONCLUSION

The present experiment in this chapter demonstrated that a substantial amount of switch costs and strong congruency effects throughout all three tasks whereas alternating switch costs only occurred in the arrow task when it was single incongruent 2 condition during the short preparation interval.

Incongruent trials were slower and more error prone than congruent trials regardless of the trial type (repeat, switch, alternating switch or double switch trials). It is noteworthy that congruency effect was even found in the repeat trials. This shows that even when a task set is repeated and presumably more strongly activated than on switch trials, there are still lots of interference from the other tasks in this paradigm, suggesting that repeat trials are actively represented and not inhibited. The previous congruency effect indicates that the task set from the previous trials persisted in a state of residual activation especially when the task set is competing with the other two tasks and that previous task set interfered with a current task set. In the current experiment, word task only demonstrated the significant effect of previous congruency, suggesting that word task set is more prone to be influenced by previous incongruent trials.

Chapter 4

Experiment 2: Backward inhibition in the early stage of Parkinson's disease

INTRODUCTION

The basal ganglia are a subcortical complex of nuclei through which parallel circuits pass in a segregated fashion on their way from and back to the cortex via nuclei of the thalamus (Alexandar et al, 1986; Middleton & Strick, 2000; Shook et al, 2005). These circuits emanate from sensorimotor, prefrontal, temporal, parietal, cingulated, limbic, and paralimbic areas (Parents, 1990), and therefore involve both motor and non-motor regions of the brain. Parkinson's disease results from degeneration of dopamingergic neurons in the substantia nigra pars comparcta (SNc) and a consequent loss of dopaminergic innervation of the basal ganglia (Hornykiewicz, 1973). This dompamine depletion, a lesser extent, a loss of mesocorticolimbic dopamine (DA) system known to play a role in cognitive processes of working memory (Williams and Goldman-Rakic, 1995; Zahr et al., 1997; Arnsten, 1998). This suggests that behaviours that rely on the integrity of basal ganglia circuitry are dopamine-dependent, as it has been demonstrated for many of the cognitive and motor symptoms of Parkinson's disease.

In particular, the cognitive impairments are shown even at its early stage, resembling those seen in frontal lobe patients (Lange et al., 1992; Taylor et al., 1986; Owen et al., 1992). Thus, recent attention has turned to possible cognitive functions of the basal ganglia, although once regarded as a motor structure, given motor symptoms are most readily apparent in Parkinson's disease.

With inputs from virtually the entire cerebral cortex and outputs to areas in the frontal cortex that influence the control of movement, the basal ganglia are ideally situated to play a role in response selection that allows some inputs to receive preferential processing and thereby exert greater influence during response selection (Albin, Young & Penny, 1989; Jackson & Houghton, 1995; Mink, 1996). The authors agreed that if this model of the basal ganglia function was accurate, then it should be possible to observe the behavioural evidence of altered efficiency during the response selection when basal ganglia function is compromised, particularly when the selection of a target response must be made in the presence of competing response possibilities. Typically, 'selection problem' arises whenever two or more competing systems seek simultaneous access to a restricted source. In this case, effective behaviour requires resolving the conflicts between incompatible actions appropriately and rapidly. Conflicts are also arising in domains when behavioural expression is more indirect, for instance between systems competing for access to limited cognitive resources. Redgrave et al. (1999) advocated that basal ganglia have evolved to resolve conflicts over access to limited motor and cognitive resources by selecting between competing systems. They proposed that the basal ganglia provide the vertebrate brain with a specialised, central selection mechanism to resolve the conflict between competing systems at different functional levels.

Alexander, De Long and Strick (1986) also reviewed that the basal ganglia participate in at least five loops with the cerebral cortex. These loops were designated to the skeletomotor, oculomotor, dorsolateral prefrontal, lateral orbitofrontal, and anterior cingluate circuits, based in part on the cortical target of their output layer of processing. According to this scheme, the output of the basal ganglia has the potential to influence not only the control of movement but also higher-order cognitive and limbic functions subserved by prefrontal, orbitrofrontal, and anterior cingulated cortex.
In addition, basal ganglia damage has been linked to impaired performance on a number of switching tasks that asses both the accuracy (Owen et al., 1993; Downes et al., 1989; Gotham et al., 1988; Taylor et al., 1986) and speed of set shifting (Hayes et al., 1998; Brown & Marsden, 1988).

Several studies, for example, have indicated that PD patients are impaired on a wide variety of attention-demanding tasks. Specifically, patients with PD have been shown to be impaired on task requiring divided attention (Brown & Marsden, 1991; Caligiuri et al., 1992); selective attention (Dujardin et al., 1999; Filoteo & Maddox, 1999; Hayes et al., 1998; Henik et al., 1993; Maddox et al., 1996; McDowell & Harris, 1997; Sharpe, 1990, 1992); visual search (Filoteo et al., 1997); task switching (Downes et al., 1993; Flowers & Robertson., 1985); and orienting of attention (Filoteo, Delis, et al., 1997; Wright et al., 1990; Wright et al., 1993; Yamaguchi & Kobayashi, 1998).
Apparently, there has been considerable amount of literature on set cognitive deficits, especially set-shifting performance in Parkinson's disease patients as it gives more clues to understand the function of basal ganglia as well as the application of improving the patients' quality of life.

However, for the most part, subject numbers tend to be small and the groups are heterogeneous. Moreover, some of inconsistencies in the literature probably stem from uncontrolled variability in selecting patients in terms of medication status and progress of the disease. Besides, there are some contradictory results in terms of task-set shifting in Parkinson's disease patients although a difficulty with the executive control of task-set has been widely cited as one of the central cognitive changes in Parkinson's disease.

For example, Cools et al (1984) have claimed, on the basis of impaired performance on the WCST (Wisconsin Card Sorting Task) and assorted motor sequencing tasks, that Parkinson's disease caused a generalised deficits in 'shifting aptitude[1]'. However, some studies (Brown and Marsden, 1988a; Downes et al, 1993) have failed to provide evidence that Parkinson's disease patients are impaired at accomplishing these shifts compared with control subjects. Apart from the fact that these studies were quite old, recent studies have not provided the definite evidence on task switching or inhibitory control mechanism in Parkinson's disease since their materials and designs for the experiment were various. Thus, it is still difficult to question how Parkinson's disease patients achieve the cognitive control mechanisms and which part on the frontal cortex are particularly impaired.

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[1] Ability to recognize behaviour according to the requirement of the tasks (Cools et al, 1984).

The main reason is that there is a difference between set shifting[2] and task switching although it appears to be quite similar in terms of the executive control in the cognitive processing. Because of that, the recent studies have shown some contradictory results and their materials and designs for the experiments were quite diverse. Moreover, some evidence in support of the hypothesis that the attentional deficits displayed by patients with PD might not be well explained because the impairments in inhibitory attentional processes (Filoteo et al., 2002; Filoteo & Maddox, 1999) are still not in the stage of collecting all the consistent results to consolidate as a theory. Besides, the studies were confounded with attentional processes and there have been very few studies that have evaluated PD patients using direct measurement of inhibition.

Despite this methodological limitation in studying the role of inhibition in patients with PD, Filoteo et al. (2002) sought to examine inhibitory processes by the negative priming task. In their task, participants were presented two stimulus arrays, a prime and a probe array, that consist of one target letter and three distractor letters and they had to indentify the underlined letter. In the IR (ignored repetition) condition, the target letter in the probe array was the distractor letter in the prime array.

Negative priming was examined by determining the amount of RT slowing in the IR condition as compared with a control condition in which the target and distractor letters were different in the prime and probe array.

PD patients who are classified as mild/moderate and medicated did not display any evidence of negative priming effect observed in the control

[2] Set shifting can be measured by WCST, Odd-man-out task, intra-dimension/extra-dimension (ID/ED) paradigm, task switching paradigm.

group which was matched to the patients in terms of age, education, and global cognitive status. The finding that PD patients did not display a normal pattern of negative priming is consistent with the notion that the striatum is involved in some form of inhibition. However, the authors remained the possibility that the locus of inhibitory deficits may be at the level of response selection. Mink (1996), for example, has proposed that the striatum is involved in inhibiting 'motor pattern generators' through active inhibition of output regions of the globus pallidus. Strayer et al. (Malley & Strayer, 1995; Strayer & Grison, 1999) have also suggested that negative priming occurs in normal participants because the representation of two stimuli (the target and distractor) are highly activated after repeated presentations and these two representations must compete for a response.

Contrary to Filoeto et al (2002)'s result, Wylie and Stout (2002) found the striking result that PD patients showed larger negative priming effect than control group. PD patients were again early/mid stage with medication and control group was matched with education and cognitive capacity.

It is well-regarded that reduced or absent negative priming implies a breakdown of cognitive inhibitory processes, leading to greater interference during the selection of a target response on a current trial and little lingering inhibition on subsequent trials. On the basis of the cognitive inhibitory interpretation, authors suggested that inhibitory processes in PD are overactive, generating larger residual inhibition effects during the probe trials. They also suggested another alternative explanation that enhanced negative priming effect could be explained as an increased difficulty overcoming the effects of normal inhibition, a possibility that does not require overactive inhibitory processes.

More recently, Fales et al (2006) attempted to examine backward inhibition in task switching in PD patients and control subjects. Their idea was from the assumption that cortico-striatal loop in the basal ganglia are involved in inhibiting response sets during switching while additional prefrontal regions are engaged in reactivating inhibited task sets. They hypothesized that patients with PD may have difficulty in overcoming backward inhibition due to the impairment in directing attention to the new task set, thus patients with PD may particular difficulty with alternating switch trials. This hypothesis was supported by the idea that deficits in shifting attention to the new task set underlie switching deficits in Parkinson's disease (PD) Patients (Brown and Marsden, 1988; Woodward et al., 2002). Three tasks previously used by Arbuthnott and Frank (2000) (ref. pp. 30 in the chapter 1) were conducted for both medicated PD patients (dopamine precursor/or agonist) who were classified as an early/mild stage by Hoehn and Yahr scale (1967) and healthy controls which were matched to mean age and education attainment. Both group showed significant backward inhibition effect (approximately 240ms of size according to the figure 1 in their article page 4) but both group showed nearly equivalent response time, resulting in no group difference ($p<1.0$). However, patients made significantly more errors during the alternating switch trials (ABA) than did controls but both group showed the same accuracy during the double switch trials (CBA). A neuropsychological battery showed that the patients as a whole exhibited no strong evidence of executive dysfunction. The author speculated that this would be the result from the medication affecting the dopaminergic system. For example, Cools et al (2003) demonstrated that L-dopa medication may increase cognitive flexibility in PD (improving switching performance by reducing switch costs) compared to the healthy controls, while increasing impulsivity. Thus the overcoming backward inhibition ought to be related to cognitive flexibility, and thus dopaminergic medication should have a beneficial effect on this measure.

It is important to pinpoint that the author was not able to show any switch cost in both groups so did not discuss the result related to switch cost. Basically, the both groups showed slower RT in the repeat trials than 1-switch trials (ref. figure 1 in their article page 4). In summary, they tentatively suggested that Parkinson's disease is associated with either increased backward inhibition or reduced ability to overcome this inhibition when reactivating a recently abandoned task set. Thus, it is inconclusive whether patients with PD have cognitive impairment in backward inhibition assumed to be a kind of helping mechanism to overcome the persisting inhibition from the previous task set.

Therefore, there was a need to investigate the cognitive control mechanism, especially, inhibitory process in patients with PD and to achieve this goal, the same design of experiment as it was in the pilot study (ref. Chapter 3) were used in the present study. By looking at both switch costs and backward inhibition effect as independent variables, it was possible to compare the healthy control controls with patients with PD and see any significant differences in their performance.

The aim of this experiment was to examine the backward inhibition and switch cost in patients with early stage of Parkinson's disease (PD) and see if the paradigm used in this study permits a preliminary examination of the role of the inhibitory processes in the context of task switching. Another aim was to investigate the congruency effect in PD patients if the response conflict in the incongruent trials would cause the abnormal decrement in their task switching performance. In order to do that, the same experiment as the pilot study was conducted in PD patients and healthy controls. The prediction is that slower RTs overall in PD patients compared to the controls and PD patients might show the bigger switch cost and abnormal (either bigger or smaller) backward inhibition effect compared to the controls. For the congruency effect, I also predict that PD patients might struggle to overcome the irrelevant task set information, causing more congruency effect than healthy controls.

METHODS

Participants

Patients

Twenty-five participants were initially recruited through the advertisement from the local hospital (QMC and Derby hospital). All participants were diagnosed by consultant neurologist or specialist PD nurses as an early stage (mild or moderate) of Parkinson's disease in the 'on' medication stage based on UK Parkinson's disease Brain Bank Criteria and assessed the Unified Parkinson's Disease Rating Scale (UPDRS, Fahn, et al., 1987). Participants ranged in age from 50 and 75 years (Male: Female =10:15, mean age=67 years). Exclusion criteria were MMSE score of < 25 and BDI score of> 20 and if patients had any neurological or serious medical conditions other than PD they were also excluded. Although twenty five participants agreed to take part in the experiment and interview, three of them withdrew from the expriment at the beginning and five of them reported fatigue and confusion during the experiment. Thus, only seventeen participants accomplished the interview and experiment. Their clinical information are shown in *Table 3*.

Number	Gender (Male: Female)	Age	Years with PD	UPDRS* Classification	PD Medications (and dosages)
1	M	63	3	1	Ropimnerol 2mgs
2	M	55	4	2	Pramipexole 0.7mgs 1.25 tabs
3	M	74	2	2	None
4	F	73	6	3	Sinemet Plus two tabs
5	M	75	4	2	Sinemet plus 2 tabs
6	M	58	2	1	Requip 5mgs
7	F	71	8	3	Amantadine 100mgs Madopar CR two tabs Selegilene 1.25mgs Co-beneldopa one tab
8	F	72	6	3	Ropinerol 3mgs
9	M	50	4	2	Ropinerol 8mgs sinemet 125mgs
10	F	71	9	3	Careldopa one tab careldopa slow release
11	M	57	5	2	Ropinerol 4mgs Ropinerol 3mgs Sinemet Plus one tab Artane (Trihexyphenidyl HCI) tabs 2mgs
12	F	52	3	2	Zelopar 1.25mgs Amantadine 100mgs Ropinerol 7mgs
13	F	52	4	2	Amantadine 100mgs Selegilene 1.25mgs Sinemet Plus 1.5 tabs
14	M	58	4	1	Pramipexole 1mg Cabergoline 2mgs Cabergoline 4mgs Sinemet Plus one tab
15	M	64	1	1	Pramipexole 1 mg two tabs

16	M	70	2	1	Sinemet Plus one tab Sinemet Plus one tab
17	F	65	1	1	Mirapexin 1mg plus 250mcg three tabs a day

Table 3. Clinical data of PD patients (dosage: per day in milligrams)

* UPDRS= Unified Parkinson's Disease Rating Scale

Controls

Twenty participants were recruited through the advertisement from the QMC initially, and the local church in the Nottingham city and the village church in desford, Leicester. Some of volunteers withdrawn after their visits for the experiments. In total, twenty-one participants were used for data analysis. Those who have Parkinson's disease, transient ischemic attack, multiple scelerosis, Hungtington's Disease, Alzheimer's disease, encephalitis, meningitis, brain surgery or having been unconscious for more than 10 minutes due to head trauma, history of depression was excluded in the study as these exclusion criteria were given to people who showed the interest in the study after the advertisement. The age of participants ranged from 50 and 75 years which was the age band for the recruitment and 8 of them were male and the rest were female (mean age=67 years). This group was matched to the patient group in terms of mean age and educational attainment. All the participants had normal or corrected-to-normal vision, were right-handed except two participants. Apart from the exclusion criteria for the presence of any neurological or serious medical condition, a score of <25 on the Mini-Mental Status Exam (MMSE, Folstein et al., 1975) and a score of >20 on the Beck Depression Inventory (BDI, Beck et al.,1996) were also measured to screen the control group. Demographic information and the basic neuropsychological assessments of the two groups is shown in *Table 4* .

	PD	Controls
N	17	21
Age	66.7	65.9
Gender	13M, 11F	12M, 9F
Education (years)	15.4 (2.6)	15.6 (2.3)
MMSE	29.0 (1.2)	28.9 (1.4)
BDI	5.0 (2.2)	7.3 (4.3)
NART estimated verbal IQ	112 (2.6)	
Verbal fluency test		
(total number of output)		
Animals (semantic)	29.7 (8.1)	34.3 (12)
Letter 'A' (phonetic)	16.7 (7.9)	17 (8.3)
Letter 'F'	17.2 (8.4)	18.0 (8.8)
Letter 'S'	18 (9.5)	18.5 (11.2)

Table 4. shows mean values (and standard deviations) for the patient and control groups. NART estimated verbal IQ was calculated by 129- (0.92 x error number). Each verbal fluency test (semantic/phonetic) was tested for 1 min.

Stimuli and Design

The stimuli and task was identical with the previous one for the pilot study experiment 1 (see chapter 3).

Procedures

Before the experimental session, both patients and controls were invited to a short interview with research nurse in the office. For the screening test such as MMSE, BDI was conducted by the research nurse while I was observing the interview. They also did the verbal fluency (semantic/phonetic fluency) test, NART (National Adult Reading Test), and UPDRS (Unified Parkinson's Disease Rate Scale) for the patients group only. For patients group, they also asked their specific medical conditions and the length of illness. These took about 50 min before the experiment, thus they were allowed to have enough break for the next session. All the participants[3] were guided to the other room and instructed about the purpose of task and procedure verbally and encouraged to ask any question. In order to make them feel supported and safe, I myself stayed all the way through until they finished. It took approximately two hours for each participant to finish the interview and experimental session. This experiment was ethically approved by the school of psychology committee.

RESULTS

On Reaction Time (RT)

- **For switch/ repeat trials**

Analysis of the 4-way repeated measured ANOVA with factors CTI (100, 1200), trial type (switch, repeat), task (arrow, location, word), and congruency (congruent, single incongruent 1, single incongruent 2[4], double incongruent) between group revealed the main effect of group, **[F (1, 32) =320, p <.001]** *(see the Appendix, page 393 table a)* because PD patients demonstrated the slower RT than controls (PD M= 1727 [SE: 131] vs. controls M= 1592 [SE: 130]). However, there was no group effect in any factors. Although PD patients showed bigger switch costs *(108ms of switch cost, switch M= 1780 [SE: 135], repeat M = 1672 [SE: 128])* compared to the controls *(75ms of switch cost. Switch M= 1634 [SE: 135],*

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[3] Among the healthy volunteers, six participants from desford, Leicester conducted the experiment in the church hall, for their convenience.

[4] Distinction between single incongruent 1 and single incongruent 2 lies in the previous N-1 trials. Precisely, if the current task is *congruent* to the previous task on the N-1 trials, this is the current condition of the single incongruent 1.
If the current task is incongruent to the previous task on the N-1 trials, this is the current condition of the single incongruent 2.

repeat M= 1549 [SE: 128]) but the group difference was not significant: F (1, 32) =.34, p=.57.

The Effect of Previous Congruency *(see the Appendix, page 394 table c)*

Analysis of the one way repeated measured ANOVA with factors of previous congruency (between single incongruent 1 and single incongruent 2) with group revealed the effect of previous congruency on each task at the two different trial types (switch/repeat) both CTI=100 and CTI=1200.

Switch trials at CTI=100

Arrow task showed no significant previous congruency effect, [F (1, 32)= 1.4, p=.24] and there was no interaction with group, [F (1, 32)= 2.5, p =.12] although PD only showed the big size of previous congruency effect (266ms, M= 2165 [SE: 181] vs. M= 2431 [SE: 176]) whereas old control showed the reversed previous congruency effect (-29ms, M= 2190 [SE: 181] vs. M= 2070 [SE: 170]). There was no main effect of group, [F (1, 32)= .79, p=.40].

Location task showed marginally significant previous congruency effect, [F (1, 32)= 3.5, p=.07]and there was no interaction with group, [F (1, 32)= .00, p= 1.0]. Both group showed reversed previous congruency effect (controls: -143ms, single incongruent 1 M= 1974 [SE: 235] vs. single incongruent 2 M= 1831 [SE: 182], PD: -143ms, M= 2304 [SE: 235] vs. M=2161 [SE: 182]). There was no main effect of group, [F (1, 32)= 1.3, p=.26].

Word task showed the significant effect of previous congruency overall, [F (1, 32)= 20, p <.001] but there was no interaction with group, [F (1, 32)=

.001, p=.97]. The separate t-test for the previous congruency effect in each group revealed that it was significant in both old control, t (16)= 4.2, p=.04 (227ms, single incongruent 1 M= 1511 [SE: 95] vs. single incongruent 2 M=1738 [SE: 135]) and PD group, t (16)= 3.8, p=.045 (223ms, M= 1686 [SE: 95] vs. M= 1909 [SE: 135]). There was no main effect of group, F (1, 32)= 1.2, p=.22.

Repeat trials at CTI=100

Arrow task showed the previous congruency effect, [F (1, 32)= 6.9, p=.012] and there was a marginal interaction group, [F (1, 32)= 3.4, p =.07]. Both groups did not show any previous congruency effect (Old controls: 2ms of previous congruency effect, single incongruent 1 M= 2183 [SE: 176] vs. single incongruent 2 M= 2085 [SE: 234], PD:-572ms of previous congruency effect, M=2420 [SE: 176] vs. M= 1848 [SE: 234]). There was no main effect of group, [F (1, 32)= .00, p=1.0].

Location task showed non-significant previous congruency effect, [F (1, 32)= 1.3, p=.25] and it there was no interaction with group, [F (1, 32)= 2.4, p=.13]. There was no main effect of group, [F (1, 32)= 2.4, p=.13] although old controls only showed the significant previous congruency effect, t (16)= - 3.4, p=.002 (222ms of previous congruency effect, single incongruent 1 M= 1700 [SE: 218], single incongruent 2 M= 1921 [SE: 211]) not PD, t (16)= -.55, p=.49.

Word task showed the marginally significant effect of previous congruency overall, [F (1, 32)= 3.3, p =.08] but there was no interaction with group, [F (1, 32)= .18, p=.67]. The separate t-test for the previous congruency effect in each group revealed that it was significant in both old control, t (16)= 2.2, p=.04 (138ms, single incongruent 1 M= 1426 [SE: 95] vs.

single incongruent 2 M=1564 [SE:178]) and PD group, t (16)= 3.9, p=.001 (222ms, M= 1623 [SE: 95] vs. M= 1845 [SE: 179]). There was no main effect of group, [F (1, 32)= 1.8, p=.19].

Switch trials at CTI=1200

Arrow task showed significant previous congruency effect, [F (1, 32)= 16, p<.001] and there was no interaction with group, [F (1, 32)= .87, p =.36]. Both groups demonstrated large size of previous congruency effect (Old controls: 447ms, single incongruent 1 M= 1232 [SE:127] vs. single incongruent 2 M= 1679 [SE: 207], PD:277 ms, M= 1431 [SE: 127] vs. M= 1708 [SE: 207]). There was no main effect of group, [F (1, 32)= .25, p=.62].

Location task showed non-significant previous congruency effect, [F (1, 32)= .26, p=.62] and there was no interaction with group, [F (1, 32)= .01, p=.92]. Both group showed reversed previous congruency effect (controls: -32ms, single incongruent 1 M= 1464 [SE: 182] vs. single incongruent 2 M= 1432 [SE: 221], PD: -48ms, M= 1673 [SE: 182] vs. M=1625 [SE: 221]). There was no main effect of group, F (1, 32)= .53, p=.47.

Word task showed non-significant effect of previous congruency, [F (1, 32)= 2.9, p =.09] and there was no interaction with group, [F (1, 32)= .12, p=.74]. The separate t-test for the previous congruency effect in each group revealed that it was non-significant in old control, t (16)= .62, p=.19 (36ms, single incongruent 1 M= 1174 [SE: 79] vs. single incongruent 2 M=1212 [SE: 67]) and marginally significant in PD group, t (16)= 2, p=.06 (58ms, M= 1316 [SE: 79] vs. M= 1374 [SE: 67]). There was no main effect of group, [F (1, 32)= 2.2, p=.14].

Repeat trials at CTI=1200

Arrow task showed no significant previous congruency effect, F (1, 32)= .19, p=.66 and there was no interaction with group, F (1, 32)= .98, p =.33. Both groups did not show any previous congruency effect (Old controls: 2ms of previous congruency effect, single incongruent 1 M= 2183 [SE:176] vs. single incongruent 2 M= 2085 [SE: 234], PD:-572ms of previous congruency effect, M=2420 [SE: 176] vs. M= 1848 [SE: 234]). There was no main effect of group, F (1, 32)= .53, p=.47 although PD only showed the previous congruency effect (95ms, single incongruent 1 M= 1617 [SE: 201] vs. single incongruent 2 M= 1532 [SE: 158]) , however post-hoc t-test revealed that it was not significant, t (16)= .32, p=.60.

Location task showed significant previous congruency effect, F (1, 32)= 19, p<.001 and there was no interaction with group, F (1, 32)= .12, p=.73. Both group showed reversed previous congruency effect (controls: -321ms, single incongruent 1 M= 1550 [SE: 221] vs. single incongruent 2 M= 1229 [SE: 156], PD: -377ms, M= 1662 [SE: 221] vs. M=1285 [SE: 157]). There was no main effect of group, F (1, 32)= .10, p=.75.

Word task showed the significant effect of previous congruency overall, F (1, 32)= 9.5, p =.004 but there was no interaction with group, F (1, 32)= 1.6, p=.21. The separate t-test for the previous congruency effect in each group revealed that it was significant in both old control, t (16)= 4.5, p=.02 (299ms, single incongruent 1 M= 1035 [SE: 82] vs. single incongruent 2 M=1384 [SE: 139]) and PD group, t (16)= 3.9, p=.001 (222ms, M= 1623 [SE: 95] vs. M= 1845 [SE: 179]). There was no main effect of group, F (1, 32)= .61, p=.44.

• **For alternating switch/ double trials**

Analysis of the 4-way repeated measured ANOVA with factors CTI (100, 1200), switch type (alternating switch, double switch), task (arrow, location, word), and congruency (congruent, single incongruent 1, single incongruent 2[5], double incongruent) between group revealed no main effect of group, **[F (1, 31) =1.9, p =.18]** and there was no further interaction between group in any factors (*see the Appendix, page 393 table a*). Patient group showed a little bigger alternating switch cost *(83ms alternating switch cost, alternating switch, M= 1848 [SE: 124] vs. double switch, M= 1765 [SE: 120]) than controls (66ms alternating switch cost, alternating switch M= 1602 [SE: 128] vs. M= 1436 [SE: 123]),* however the difference was not statistically significant, [F (1, 31) = .61 p=.44].

The Effect of Previous Congruency *(see the Appendix, page 395 table c)*

Analysis of the one way repeated measured ANOVA with factors of previous congruency (between single incongruent 1 and single incongruent 2) with group revealed the effect of previous congruency on each task at the two different switch types (alternating switch/double switch) both CTI=100 and CTI=1200.

Alternating trials at CTI=100

Arrow task showed a significant previous congruency effect, [F (1, 32)= 6.5, p=.015] and the interaction with group was non-significant, [F (1,

[5] Distinction between single incongruent 1 and single incongruent 2 lies in the previous N-1 trials. Precisely, if the current task is *congruent* to the previous task on the N-1 trials, this is the current condition of the single incongruent 1.
If the current task is incongruent to the previous task on the N-1 trials, this is the current condition of the single incongruent 2.

32)= 1.0, p =.32]. There was no main effect of group, [F (1, 32)= 2, p=.16]. Both group revealed a large size of previous congruency effect (controls: 415ms, M=1965 [SE: 160] vs. M= 2380 [SE: 410] and PD: 944ms, M= 2206 [SE: 160] vs. M= 3150 [SE: 416]).

Location task showed a non- significant previous congruency effect, [F (1, 32)= 2.6, p=.11]and the interaction with group was non-significant, [F (1, 32)= 1.1, p= .29]. Both group showed a reversed previous congruency effect (controls: -447ms, single incongruent 1 M= 2169 [SE: 337] vs. single incongruent 2 M= 1722 [SE: 155], PD: -91ms, M= 2028 [SE: 337] vs. M=1937 [SE: 155]). There was no main effect of group, [F (1, 32)= .01, p=.91].

Word task showed significant previous congruency effect, [F (1, 32)= 4.2, p =.05] but the interaction with group was non-significant, [F (1, 32)= .03, p=.87]. The separate t-test for the previous congruency effect in each group revealed that it was significant in both control, t (16)= 4.3, p=.025 (190ms, single incongruent 1 M= 1580 [SE: 128] vs. single incongruent 2 M=1770 [SE: 160]) and PD group, t (16)= 5.3, p=.01 (224ms, M= 1739 [SE: 128] vs. M= 1963 [SE: 160]). There was no main effect of group, [F (1, 32)= .96, p=.34].

Double switch trials at CTI=100

Arrow task showed a significant previous congruency effect, [F (1, 31)= 7.7, p=.009] and the interaction with group was non-significant, [F (1, 31)= 1.1, p =.30]. Both groups revealed a reversed previous congruency effect (controls:-516ms, single incongruent 1 M= 2269 [SE:239] vs. single incongruent 2 M= 1763 [SE: 198], PD:-228ms, M= 2339[SE: 232] vs. M=

2111 [SE: 192]). There was no main effect of group, [F (1, 31)= .57, p=.45].

Location task showed a non-significant previous congruency effect, [F (1, 32)= 1.5, p=.22 and the interaction with group was non-significant, [F (1, 32)= 1.0, p=.32]. Both group showed a reversed previous congruency effect (controls: -23ms, single incongruent 1 M= 1992 [SE: 269] vs. single incongruent 2 M= 1969 [SE: 221], PD: -243ms, M= 2640 [SE: 269] vs. M=2397 [SE: 221]). There was no main effect of group, [F (1, 32)= 2.6, p=.11].

Word task showed a non-significant effect of previous congruency, [F (1, 32)= 2.5, p =.12 and the interaction with group was non-significant, [F (1, 32)= .70, p=.41]. The separate t-test for the previous congruency effect in each group revealed that it was significant in control, t (16)= 5.8, p=.01 (217ms, single incongruent 1 M= 1500 [SE: 100] vs. single incongruent 2 M=1717 [SE: 147]) but not in PD group, t (16)= .64 p=.51 (32ms, M= 1450 [SE: 129] vs. M= 1718 [SE: 200]). There was no main effect of group, [F (1, 32)= .39, p=.54].

Alternating switch trials at CTI=1200

Arrow task showed a marginal effect of previous congruency, [F (1, 32)= 3.3, p=.08] and the interaction with group was non-significant, [F (1, 32)= 1.8, p =.18]. Control group only revealed a significant previous congruency effect, t (16)= 3.9, p=.001 whereas PD group did not show the significant previous congruency effect, t (16)=1.2, p=2.6, (48ms, M= 1412 [SE: 141] vs. M= 1460 [SE: 209]). However, there was no main effect of group, [F (1, 32)=.07, p=.79].

Location task showed a significant previous congruency effect, [F (1, 32)= 8.1, p=.007] and the interaction with group was non-significant, [F (1, 32)= .19, p=.67]. There was no main effect of group, [F (1, 32)= 2.4, p=.13] although old controls only showed a significant previous congruency effect, t (16)= - 3.4, p=.002 (222ms of previous congruency effect, single incongruent 1 M= 1700 [SE: 218], single incongruent 2 M= 1921 [SE: 211]) not PD, t (16)= -.55, p=.49. There was no main effect of group, [F (1, 32)= .00, p=.99]. Both group showed a reversed previous congruency effect (controls: -411ms, M= 2013 [SE:308] vs. M= 1502 [SE: 238], PD:-375ms, M= 1949 [SE: 308] vs. M= 1574 [SE: 238]).

Word task showed a non- significant effect of previous congruency, [F (1, 32)= .96, p =.36] and the interaction with group was non-significant, [F (1, 32)= .85, p=.36]. The separate t-test for the previous congruency effect in each group revealed that it was non-significant in control, t (16)= -1.5, p=.15 (3ms, single incongruent 1 M= 1199 [SE: 97] vs. single incongruent 2 M=1202 [SE:69]) but it was significant in PD group, t (16)= 2.7, p=.013 (104ms, M= 1318 [SE: 97] vs. M= 1422 [SE: 69]). There was no main effect of group, [F (1, 32)= 2.5, p=.12].

Double switch trials at CTI=1200

Arrow task showed a significant previous congruency effect, [F (1, 32)= 15, p=.001 and the interaction with group was non-significant, [F (1, 32)= .70, p =.41]. Both group revealed a significant previous congruency effect (controls 418ms, single incongruent 1 M= 1237 [SE:129] vs. single incongruent 2 M= 1655 [SE: 200], t (16)= 4.3, p= 0.25 PD: 268ms, M=1450 [SE: 129] vs. M= 1728 [SE: 200], t (16)= 2.1, p=.04). There was no main effect of group, F (1, 32)= .39, p=.54.

Location task showed a non-significant previous congruency effect, [F (1, 32)= 1.1, p=.28] and the interaction with group was non-significant, [F (1, 32)= .23, p=.63]. Both group showed a significant previous congruency effect (controls: 142ms, single incongruent 1 M= 1346 [SE: 199] vs. single incongruent 2 M= 1588 [SE: 302], t (16)= 2.7, p=.04, PD: 93ms, M= 1983 [SE: 302] vs. M=1890 [SE: 199], t (16)= 1.9, p=.05). There was no main effect of group, [F (1, 32)= 2.0, p=.16].

Word task showed a non-significant effect of previous congruency, [F (1, 32)= .02, p =.88] and the interaction with group was non-significant, [F (1, 32)= 2.5, p=.12]. The separate t-test for the previous congruency effect in each group revealed that it was non-significant in both control, t (16)= 1.3, p=.20 (81ms, single incongruent 1 M= 1166 [SE: 84] vs. single incongruent 2 M=1247 [SE: 101]) and PD group, t (16)= 56, p=.41 (-36ms, M= 1352 [SE: 84] vs. M= 1284 [SE: 101]). There was no main effect of group, F (1, 32)= .83, p=.37.

On Error (%)

- **For switch/ repeat trials**

There was no main effect of group, **[F (1, 32)= .74, p=.40]** and no interaction with any factors (*see the Appendix, page 394 table b*).

The effect of Previous congruency

Analysis of the one way repeated measured ANOVA with factors of previous congruency (between single incongruent 1 and single incongruent 2) for each task at both CTI=100 and CTI=1200 with group revealed no main effect of group on each task and all three tasks did not show any interaction with group except the word task on the switch trials at CTI=100, [F (1, 32)= 4.3, p=.05].

- **For alternating switch/ double trials**

There was no main effect of group, **[F (1, 32)= .39, p=.53]** and no interaction in any factors (*see the Appendix, page 394 table b*).

The effect of Previous congruency

Analysis of the one way repeated measured ANOVA with factors of previous congruency (between single incongruent 1 and single incongruent 2) for each task at both CTI=100 and CTI=1200 with group revealed no main effect of group on each task and all three tasks did not show any interaction with group.

Discussion

The current experiment aimed to see if the early stage of PD patients showed any impairment or enhancement of cognitive control by comparing the switch cost and alternating switch cost as well as the congruency effect in the experiment which has been previously used (chapter 3). The results showed that there was no significant group difference in performing switching tasks except for the fact that PD patients demonstrated slower RT and more errors overall. However, all participants showed evidence of costs associated with alternating task switches. These costs were apparent only for reaction time. There was no alternating switch cost in both groups for errors. Patients with early stage PD and controls showed a similar pattern of performance as measured by reaction time, resulting in no group difference in the analysis. In addition, patients showed bigger switch cost than controls but the group difference was not significant for both reaction time and errors.

It is noteworthy that all patients were receiving treatment affecting the dopaminergic system. There have been three studies demonstrating a significant alleviation of task switching/shifting deficits in PD following L-dopa administration (Cools et al., 2001a; Cools et al., 2003; Hayes et al., 1998). These cognitive operation relied on the integrity of strialtal-dorsolateral prefrontal cortext circuits (Brass et al., 2003; Cools et al., 2001a, 2001b, 2003).

Cools et al (2001, 2003) have reported that chronic L-dopa administration relieves the motor systems of PD, but also induce cognitive changes. For example, Cools et al. (2003) demonstrated that L-dopa medication may increase cognitive flexibility in PD (improving switching performance by reducing switch costs), while increasing impulsivity. Contrasting effects on operations medicated by ventral frontial-striatal circuitry have been reported in PD patients in impulsive control (Cools et al., 2003) were similar to those seen in non-medicated patients with first episode Schizophrenia (Hutton et al., 2002). Thus, determining the properties of cognitive tasks that are influenced by either positively or negatively with administration of L-dopa provides a very valuable method to further define the operations of the basal ganglia circuitry, as well as the influence of dopamine innervation (Shook et al., 2005).

Due to these contrasting effects from dopaminergic medication, it is unclear to conclude that bigger switch costs in PD patients in the present study is the sign of the mild executive dysfunction.

If the influence of dopamine medication was beneficial and enhancing the cognitive function in PD, such as smaller switch cost and alternating switch cost compared to the control group in the present study. Therefore, it remains possible to run the current experiment when PD patients are off-medication. Shook et al. (2005) reported that regular dopamine medication was interrupted temporarily, the patients suffered much worse switch deficits on both cognitive switch task and the simple version of response switching. In addition, the interaction of response switching and cognitive switching revealed significant response effect, particularly for PD patients in the off-medication state in their study (2005). Although the relation between dopamine and inhibitory process is not yet fully understood, given the on- versus off-medication differences found in a number of studies using that tasks that require some form of inhibition (Rogers and Monsell, 1995; Schuch & Koch, 2003; Filoteo et al, 2002; Franz & Miller, 2002; Aron et al., 2003a). Studies using task implicate inhibitory processes have demonstrated evidence in support of abnormal response inhibition in PD (e.g., Filoteo et al., 2002; Franz & Miller, 2002) and Huntington's disease (Aron et al., 2003a) patients. Hence, it is possible to argue that general deficits in activation and inhibition that are associated with PD patients and level of dopaminergic medication, yet the design of the task, and medication has to be more carefully restricted for the future.

Apart from the dopaminergic medication issue, the lack of group difference in the present study might be due to the 4-way ANOVA design with different levels for each factor. Thus, it is reasonable to run the simple one -way ANOVA between switch and repeat trials as well as between alternating and double switch trials. Tentatively, it is assumed that the lack of group difference in backward inhibition was due to the fact that participants in both groups showed the alternating switch cost; yet again it was not statistically different. Both group showed the similar pattern of performance in terms of reaction time but PD showed more errors than controls. However, there was no group difference in errors. It is interesting to note that PD patients showed the benefit of alternating switch when the current task was the location task. In other words, there was a reversed alternating switch cost[6] in the location task for PD group, suggesting that PD patients might have difficulties selecting the location task set especially when they have to switch from the other tasks. Alternatively, they might fail to overcome the inhibition for the location task, suggesting that spatial information processing in PD patients is different from controls.

Congruency effect between two groups did not show any differences. In other words, they showed the strong congruency effect in task switching regardless of preparation interval, suggesting that the interference from the irrelevant task set was quite strong and dominant so that the switching performance in both groups are equally influenced by the congruency.

Lastly, the effect of previous congruency in task switching and alternating tasks were significant in all three tasks and it appears that PD patients were more influenced by the residual activation of the task set on the N-1 trials which is no-longer-use on N trials as they showed significantly stronger previous congruency effect than controls. Note that location task in trial type (switch/repeat) and switch type (alternating switch/double switch) revealed the reversed previous congruency effect in most conditions when the one-way ANOVA for each task at the each CTI

[6] PD patients were much slower in the double switch trials when the current N trials are location tasks compared to in the alternating switch trials, causing the facilitation from alternating switch trials.

condition was run. In other words, when the location task on the current trial N was congruent to the previous task on the trial N-1, the mean reaction time was significantly slower than when the current location task was incongruent to the previous task on the trial N-1. PD patients also showed the facilitation (reversed alternating switch cost) in the location task on the current trials. It is still not certain why the location task has the facilitation effect when the level of congruency are supposed to be less difficult and when the residual inhibition from the task you had just abandoned (e.g., Location task-→ Word task-→ Location task AB**A**) are supposed to be strongly dominant compared to the double switch trials (e.g., Arrow task→ Word task-→ Location task, CB**A**). This result might suggest that PD patient would not use backward inhibition necessarily only for the location task. Further study has to be established in order to examine if the visual/perceptual processing in patients are directly linked to the result. Previous studies (Brown and Marsden, 1988, 1991; Woodward et al, 2002; Pollux and Robertson, 2001) have studied the visual spatial shifts of attention in PD patients and their impaired ability to maintain attention. Thus, it is worthwhile to run the location task separately with different cue (e.g., peripheral/ central) and target (spatially located) to see the change of alternating switch cost and previous congruency effect in the near future.

In summary, the absence of impairment in PD group for the current experiment in the present study would be directly to the dopamingergic medication and their less severity of disease (early stage).

Chapter 5

Experiment 3: Effect of the verbal cues on switch cost and backward inhibition

INTRODUCTION

Typically, studies of backward inhibition involve three different tasks, and task precues are presented in the intertrial interval to enable random sequencing of the three tasks (Arbuthnott, 2005). Obviously, the role of the cues is to inform subjects what task they have to perform and the interval between cue and target/stimulus (CTI: cue-target interval/ CSI: cue-stimulus interval) is important since it affects the time available for advance preparation. The issue of advanced preparation is one of topics that researchers have been debating over the last decade as discussed in chapter 1 (ref. see *page 11-20* in the chapter 1).

Apart from discussing different views on interpreting the effect of preparation intervals and residual switch costs, recent studies suggested that a considerable portion of switch cost is actually related to switching cues rather than switching the task itself (Arrington & Logan, 2004; Logan & Bundesen, 2003; Mayr & Kliegl, 2003; Miyake et al, 2004). For instance, Mayr & Kliegl (2003) used two cues: 1) G or S for colour judgement 2) B or W for shape judgement thus, trials involves cue switch without changing task as well as the typical cue-task switch and the results was that considerable switch costs were observed when cue changed, even when the task remained the same. They concluded that switch costs were not actually due to a change in task per se but rather due to a change in cue-associated processes.

Undoubtedly, it is obvious that cue processing in task switching plays an important role in task switching which influences directly on the size of switch costs although cue switch costs (: the cost caused by cue changes, not task changes) in Mayr and Kliegl (2003)'s experiment have shown that cue is not only helping for the advance preparation for task set configuration but also for initiating the retrieval from Long-Term Memory (LTM) prior to task performance. However, in the same study of Mayr and Kliegl (2003) demonstrated that alternating-switch cost was not influenced by switching cues but was observed only when the task switched. In their experiment 3, three different tasks were used: participants had to judge an object's colour (red vs. blue), shape (circle vs. square) or size (small vs. large). Task cues were letters (i.e., D and R for the colour task, M and V for the shape task, and T and K for the size task). For the backward inhibition effect, they compared between task C-B-A sequence and task A-B-A sequences that one is repetition of cues (e.g., A_1- B_x - A_1) and the other is change of cues (e.g., A_1- B_x – A_2). For the cue repeat condition, there was no backward inhibition effect between CBA sequence and ABA sequence.

On the other hand, there was significant backward inhibition between CBA sequence and ABA sequence for the cue change condition (e.g., 51 ms of BI effect). Their results supported their idea that backward inhibition affect the task-set application stage rather than the retrieval stage as they hypothesised that there are two stages of processing that are critical during changes of task configurations and thus for the emergence of switch costs.

Arguably, Arburthnott (2005) questioned that if backward inhibition occurs during this phrase, then alternating switch cost should not be directly influenced by factors that affect the efficiency of task set retrieval. In line with the evidence from her previous study (Arbuthnott & Woodward, 2002) which the size of switch cost was influenced by the strength of association between cues and tasks, alternating switch cost was not, she still suggested that cue might also have a more subtle influence on activation of the retrieved set (e.g., category-response rules or stimulus-response association), especially if cue processing differed substantially from the target processing (e.g., spatial vs. object processing).

She believed that these aspects could potentially influence alternating-switch cost independent of set retrieval. In order to answer these questions, she used three digit-judgment tasks: digits were judged for magnitude (greater or less than 5), parity (odd or even), and prime status (prime number or multiple). For the cues, there were verbal cues named the relevant response options for each judgement (i.e., Odd/Even, Less/More, or Prime/Multiple) as well as spatial cues indicated the appropriate task by the position of the stimulus on the screen.

The results replicated the finding of her previous study (Arbuthnott & Woodward, 2002) by showing that backward inhibition effect was eliminated when spatial location was used as a cue. Precisely, backward inhibition effect (a.k.a. alternating switch costs) was only found in the verbal cue condition (e.g., 85ms of BI effect) not in the spatial cue condition (e.g., -73 ms of reversed BI effect or facilitation effect). However, switch cost was larger for spatial cues (276ms vs. 500ms for verbal and spatial cues respectively) thus, this data supported the idea that switch cost and alternating switch cost are separable processes, at least with respect to

cue processing (Arbuthnott, 2005). Furthermore, she suggested that spatially isolated tasks may shift the relative balance of activation in favour of the relevant task set, reducing the need for inhibition of competing set, resulting in the facilitation[1] for alternating tasks in this condition which means that competing sets were not inhibited due to the absence of backward inhibition (sequential inhibition).
However, if this difference between spatial localization of the task and verbal cues cannot be entirely due to greater activation accruing with verbal cue during the cue-target-interval because of easier retrieval, as alternating switch cost has also been observed for weakly associated shape cues (Arbuthnott & Woodward, 2002). Thus, Arbuthnott (2005) reasoned that some aspect of the different alternating switch costs between cues must relate to the retrieved set itself, such as discriminable location-category-response representations for spatially isolated tasks versus less discriminable category-response representations for verbal cues.

Furthermore, if including verbal cues in retrieval path might influence the characteristics of a retrieved set in a way that increase the relative activation of competitors. She speculated that including a verbal task representation by naming during set retrieval might increase backward inhibition despite the spatial discrimination. If verbal retrieval supports greater activation of competing task sets, alternating switch costs would be observed even when tasks are spatially isolated. In order to explore this possibility, participants had to vocally name the upcoming task following

[1] Alternating switch costs in the spatial cue condition in her all three experiments were -72ms (experiment 1), -44ms (experiment 2), -88ms (experiment3), suggesting that when participants had benefits of recently abandoned tasks in the alternating switch trials (e.g. task A- B-**A**).

the presentation of the cue in her experiment 3 because this manipulation would add the process in both spatial and verbal cues for the retrieval of the task name as well as retrieval of the task set itself.

Judging from her recent study about the influence of cue type on backward inhibition (Arbuthnott, 2005), it seems that cue manipulation, in other words, having all verbal cue in the present study might produce the backward inhibition.

On the other hand, the verbal cue might reduce the size of switch cost according to the previous studies (Arbuthontt & Woodward, 2002, Miyake et al., 2004)'s strong cue-task association argument.

Moreover, in some of the cases when no backward inhibition (alternating switch cost) was observed, a non-verbal cue (i.e., non-text based information for the task) was used (see *Table 5*). *Table 5* summarises previous studies on backward inhibition and its observation depending on the type of cues they used.

Literature	**Cue type**	**Backward inhibition (Task-set inhibition)**
Arbuthnott (2005)	Spatial	No
	Verbal	Yes
Arbuthnott & Woodward (2002)	Spatial	No
	Verbal	Yes
	Symbolic	Yes
Gade and Koch (2005)	Form	Yes
Hübner et al. (2003)	Colour	Yes
	Colour	No
	None	No
Lien et al. (2006)	Task sequence	No
Mayr and Keele (2000)	Verbal	Yes
Mayr & Kliegl (2003)	Symbolic	No
Schoch & Koch (2003)	Form	No

Table 5. A summary of backward inhibition studies showing what type of cue was used and whether backward inhibition (task-set inhibition) was observed.

In the previous experiment, the verbal cue was used only for the word task as it was mainly designed for the task-associated feature, e.g., the two-sided pointed horizontal arrow for the arrow task and two separate squares for the location task for that reason. Therefore, having the verbal cues for the all three tasks in this experiment might give the evidence if the verbal cue is another important factor to have BI effect and the strength of the cue-task association is essential for task switching.

I predict that backward inhibition measured by alternating switch costs might be observed in all tasks whereas switch costs would be decreased in the arrow and location task because the verbal cue for the arrow and location task is directly giving the information about the task and this strong cue-task association will help participants perform the task switching. For the congruency effect, it is not clear if the verbal cue is crucial to change the size of the effect. However, it is hypothesised that the congruency effect would be occurred regardless of the cue change because the congruency is more related to the stimulus itself.

The purpose of the present study was to examine the verbal cue influence on the size of switch costs and alternating switch costs by comparing the result with experiment 1 and to investigate the role of different cue type in switch tasks.

METHODS

Participants

Twenty participants (11 women) were recruited from the University of Nottingham through advert and 12 of them were undergraduates and the rest of them were postgraduate in the psychology department. The participants ranged age from 18 and 32 years (M= 25.4, SD=7), reported normal and corrected-to-normal vision and were all right-handed except two participants. They received £4 as an inconvenience allowance after completion of the experiment. The study took approximately 50 min to complete including the instruction and practice session.

Stimuli and Procedures

The task, stimuli and study procedures were identical to the previous experiment 1 (ref. chapter 3) except for the cue type. The cue for the word task was the same as before but the cue for the location and arrow task was verbally presented in the centre of the screen (Arial font with capital letter, size 20): ARROW for the arrow task, LOCATION for the location task, and WORD for the word task In all other respects the procedures was identical to that of Experiment 2.

The cue for each task was presented first and then it was visually displayed directly either above or below the arrow target until a response was made. In other words, the cue remained on the screen and was joined by the target.

RESULTS

1) Effect of task switching

Four research questions for the effect of task switching were raised.

They are as follows.

a. *Is there any switch cost?*

b. *Is there a main effect of congruency?*

c. *Does congruency interact with switch/repeat trials (trial type)?*

d. *Is there any previous congruency effect?*

On Reaction Time (RT)

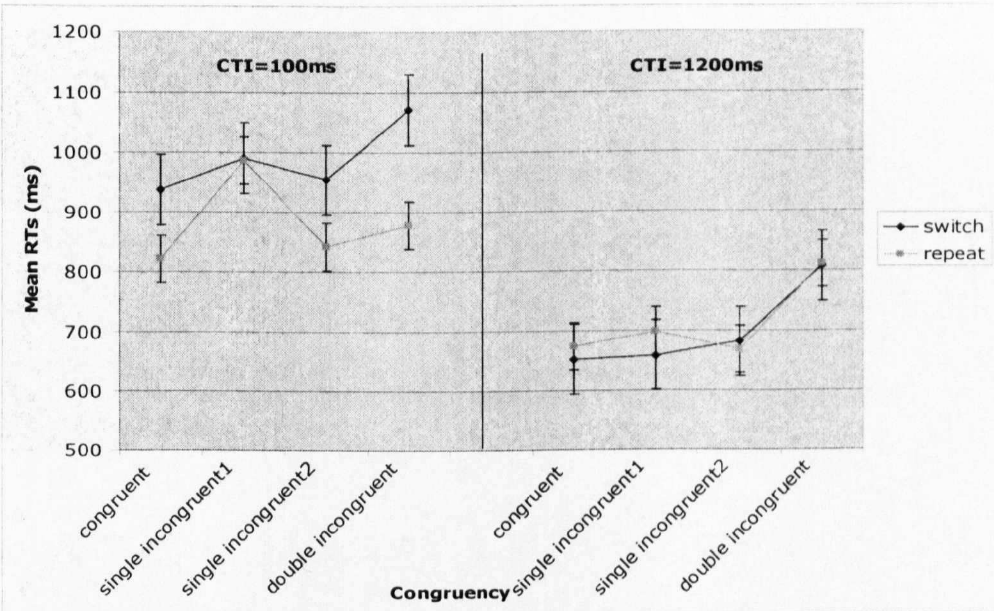
Analysis of the 4-way repeated measured ANOVA with factors CTI (100, 1200), trial type (switch, repeat), task (arrows, location, word), and congruency (congruent, single incongruent 1, single incongruent 2, double incongruent) revealed two significant 3-way interaction (trial type, task and congruency), **[F (4, 81) =2.6, p =.04]**, (CTI, trial type and task), **[F (1, 30) =4.6, p =.03]** and a marginally significant 3-way interaction (CTI, task and congruency), **[F (4, 88) =2.2, p =.07]** (see the Appendix, page 399 table 1a). This interaction was explored by conducting three separate 3-way (factors CTI, trial type, and congruency) repeated measures ANOVAs for each task. These are reported below.

On Errors (%)

Analysis of the 4-way repeated measured ANOVA with factors CTI (100, 1200), trial type (switch, repeat), task (arrow, location, word), and congruency (congruent, single incongruent 1, single incongruent 2, double incongruent) revealed a non-significant 4-way interaction: [F (4, 77) = 1.0, p =.38] (see the Appendix, page 399 table 1b). There were only a significant 3-way interaction (CTI, trial type and congruency), **[F (2, 44) =3.4, p=.04]**. In order to interpret this 3-way interaction involving task, 3 separate figures by each task were presented with the reaction time (RT) figures. Each figure is reported below.

Arrow task

a. RT (ms)



b. Error (%)

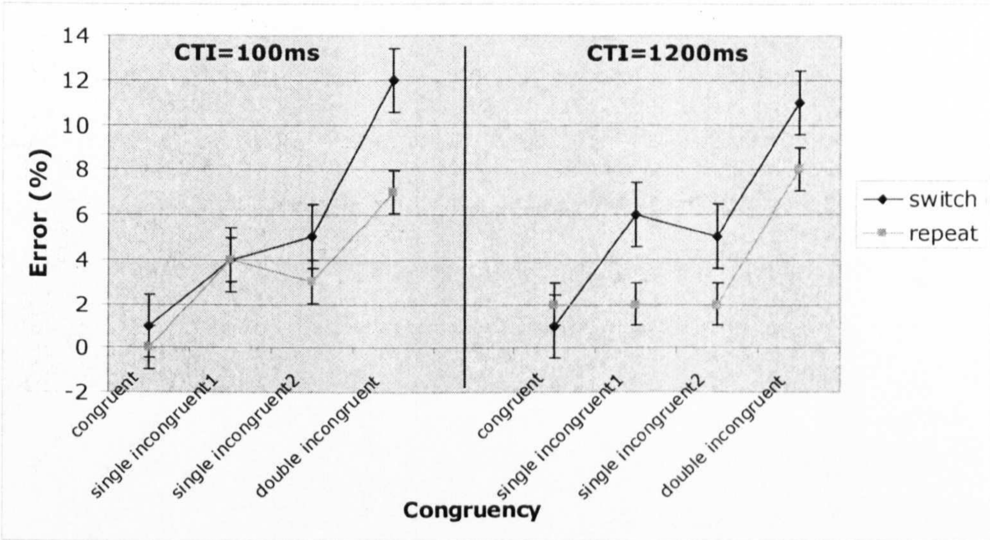


Figure 12. Mean RTs (and standard errors) (figure 12 a) and percent error scores (figure 12 b) in congruency and trial type in two CTI conditions for the arrow task.

RT (ms)

A significant difference between switch and repeat trials was found at CTI =100, **[F (1, 20) = 30, p <.001]** *(107ms of switch cost, switch M = 989 [SE: 44] vs. repeat M= 882 [SE: 34]: vs.)* but not at CTI=1200, [F (1, 20) =.40, p =.53] (See figure 12a).

There was a significant 2-way interaction between trial type and congruency at the CTI= 100, **[F (2, 42) = 4.1, p=.02]** but not the CTI=1200, [F (3, 54) = .40, p= .73]. As is clear from an examination of Figure 4, this was as a result of dramatic RT increase from congruent to single incongruent 1 during the repeat trials, resulting in no switch cost in the single incongruent 1 condition at CTI=100.

When congruency was examined by each trials to see if the interaction between trial type and congruency at the CTI=100 was caused by the different congruency effect on the trial type or not, it shows that

Congruency effect was significant at both switch, **[F (2, 45)= 6.5, p=.002]** *(68ms congruency effect, congruent M= 937 [SE: 39], single incongruent 1 M= 991 [SE: 43], single incongruent 2 M= 954 [SE: 43], double incongruent M= 1070 [SE: 45])* and repeat trials, **[F (2, 44)= 5.3, p=.007]** *(81ms congruency effect, M= 821 [SE: 41], M= 987 [SE: 58], M= 842 [SE: 32], M= 878 [SE: 41])* during the CTI=100.

In both CTI conditions, the effect of congruency was significant at the CTI=100, **[F (2, 48) = 7, p <.001]** *(78ms of congruency effect, M= 879 [SE: 38] vs. M= 989 [SE: 44] vs. M= 898 [SE: 33] vs. M= 974 [SE: 39]: congruent vs. single incongruent 1 vs. single incongruent 2. vs. double incongruent)* and at the CTI=1200, **[F (2, 45) =8.5, p <.001]** *(57ms of congruency effect, M= 664 [SE: 39] vs. M= 679 [SE: 50] vs. M= 674 [SE: 35] vs. M= 809 [SE: 53])*.

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (20)= 2.6, p =.015** but not on the switch trials, t (20)= 1.2, p=.26.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was not significant either on the repeat trials, t (20)= .52, p < .61 or on the switch trials, t (20)= -.78, p=.44.

Error (%)

A significant difference between switch and repeat trials was found, **[F (1, 19) = 7.3, p=.014]**, indicating that switch trials made more errors than repeat trials (switch M= 6 % vs. repeat M= 3 %). A significant effect of congruency was also found, **[F (1, 30) = 19. p<.001].** The rest of 3-way ANOVA result will be shown in the Appendix.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (19)= -.63, p =.53 and on the switch trials, t (19)= .18, p=.86.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (19)= .38, p =.70 and on the switch trials, t (19)= -.85, p=.40.

Summary

a. A main effect of switch costs for the arrow task only occurred at the short preparation interval condition for reaction time whereas there was a main effect of switch costs in both short and long preparation interval condition on the error.

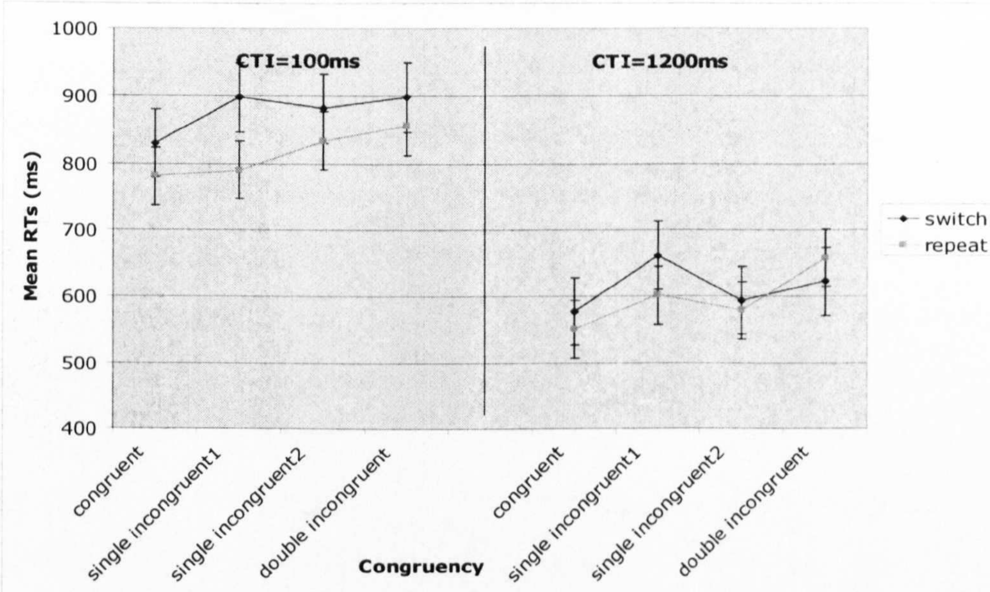
b. A main effect of congruency for the arrow task was observed for reaction time and error consistently for both short and long preparation interval.

c. The interaction between congruency and trial type (switch/repeat trials) was only significant during the short preparation interval on reaction time.

d. The effect of previous congruency for the arrow task was only occurred during the repeat trials for the short preparation interval on reaction time.

Location task

a. RT (ms)



b. Error (%)

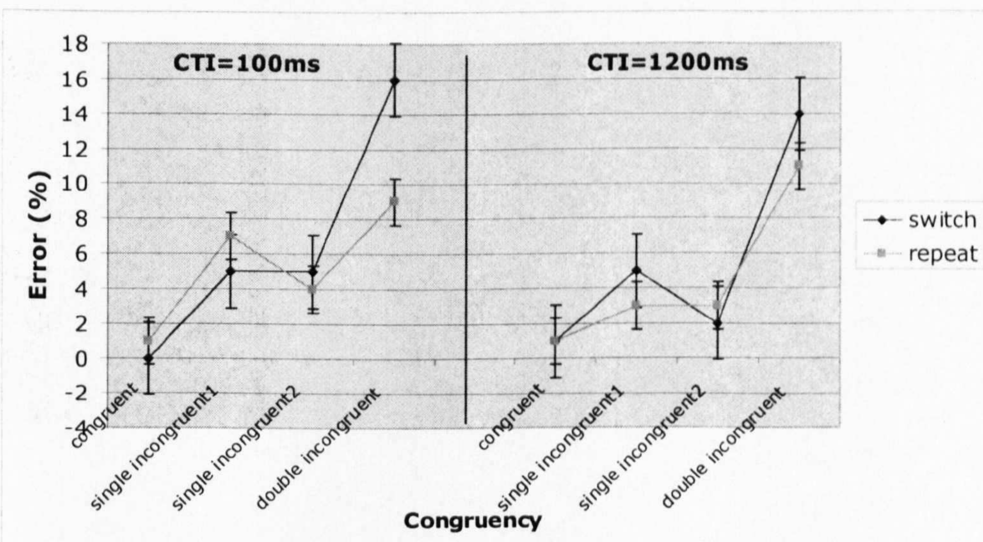


Figure 13. Mean RTs (and standard errors) (figure 13 a) and percent error scores (figure 13 b) in congruency and trial type in two CTI conditions for the location task.

RT (ms)

A significant difference between switch and repeat trials was found at the CTI= 100, **[F (1, 20)= 10, p =.005]** *(62ms of switch cost, switch M = 877 [SE: 30] vs. repeat M= 815 [SE: 38].)* but not at the CTI=1200, [F (1, 20) = 1.8, p =.19] (see Figure 13a).

A 2-way interaction between trial type and congruency was non-significant at the CTI=100, [F (2, 43) = .52, p =.61] and at the CTI=1200, [F (2, 53) = 1.3, p =.26].

The effect of congruency was only marginally significant at the CTI=1200, **[F (3, 52) = 2.6, p=.07]** *(55ms of congruency effect, M= 586 [SE: 47] vs. M= 631 [SE: 47] vs. M= 586 [SE: 52] vs. M= 640 [SE: 56])* not at CTI=100, [F (2, 41) =2, p=.17].

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (20)= -.65, p =.52 and on the switch trials, t (20)= .54, p=.59.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the switch trials, **t (20)= 2, p=.05** but not on the repeat trials, t (20)= .59, p =.56.

Error (%)

A significant 2-way interaction (trial type and congruency) was found, **[F (2, 45)= 5, p=.008]**. When this interaction was examined separately by CTI, it reveals that interaction in trial type and congruency was only significant at the CTI=100, **[F (2, 41)= 7, p=.002]** not the CTI=1200 [F (1, 30) =.96, p =.38].

A difference between switch and repeat trials was non- significant both at the CTI=100, [F (1, 19) = 77, p =.39] and at the CTI=1200, [F (1, 19) =.42, p =.52].

A significant congruency effect was found at the CTI= 100, **[F (2, 43) = 11.3, p <.001]** and at the CTI=1200, **[F (2, 38) =17, p <.001]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non- significant on the repeat trials, t (19)= -.82, p =.42 and on the switch trials, t (19)= -.73, p=.47.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the switch trials, **t (19)= -2.4, p=.025** but not on the repeat trials, t (19)= -.17, p =.86.

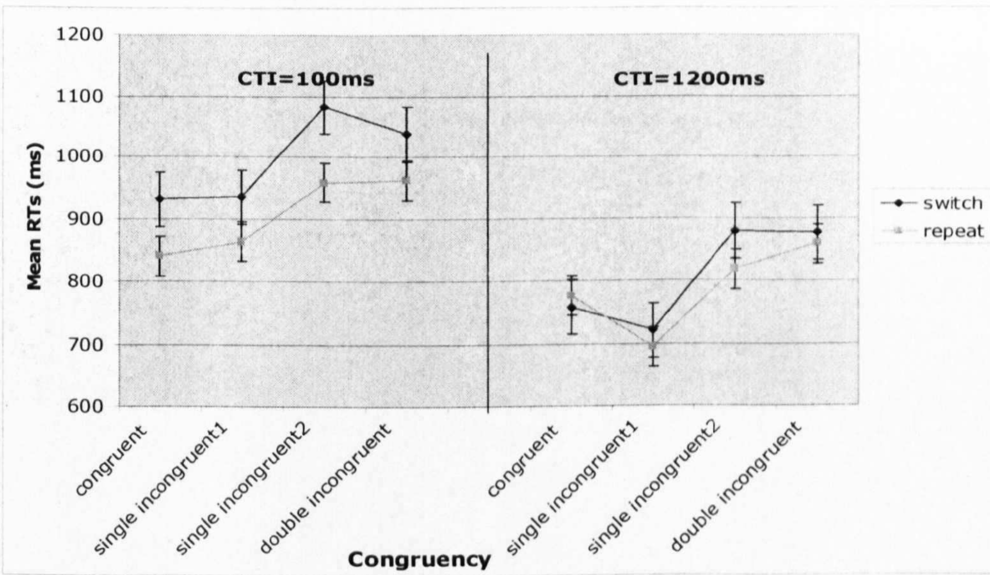
Summary

a. A main effect of switch costs for the location task only occurred at the short preparation interval condition for reaction time whereas there was no main effect of switch costs on the error in both short and long preparation intervals.
b. The effect of congruency for the location task was marginally significant for reaction time during the long preparation interval and it was significant on error during the both preparation interval.
c. An interaction between congruency and trial type only occurred for errors during the short preparation interval.

d. The effect of previous congruency for the location task was only significant for the switch trials for the long preparation interval for both reaction time and error.

Word task

a. RT (ms)



b. Error (%)

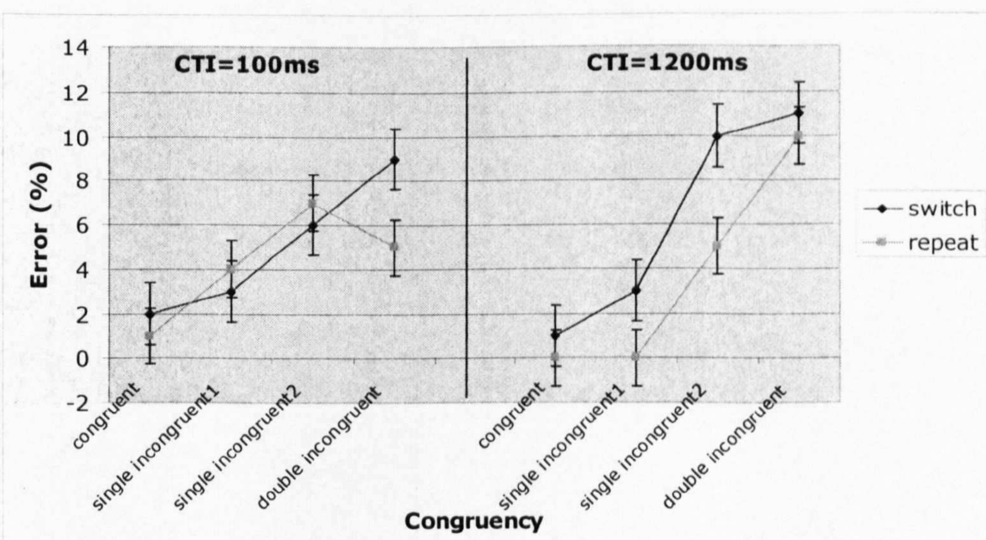


Figure 14. Mean RTs (and standard errors) (figure 14 a) and percent error scores (figure 14b) in congruency and trial type in two CTI conditions for the word task.

RT (ms)

A significant difference between switch and repeat trials was found at the CTI= 100, **[F (1, 20)= 47, p <.001]** *(91ms of switch cost, switch M = 997 [SE: 30] vs. repeat M= 906 [SE: 31])* and a marginally significant difference at the CTI=1200, **[F (1, 20) = 3.3, p =.08]** *(22ms of switch cost, switch M = 808 [SE: 34] vs. repeat M = 786 [SE: 38])* (see Figure 14a).

A 2-way interaction in trial type and congruency was non-significant both at the CTI=100, [F (3, 57) =.10 p =.95] and CTI=1200, [F (2, 39) =.63, p =.53].

For both CTI conditions, the effect of congruency was significant at CTI=100, **[F (2, 36)= 14, p<.001]** *(85ms of congruency effect, congruent M= 885 [SE:32] vs. single incongruent 1M= 890 [SE: 28] vs. single incongruent 2 M= 1020 [SE: 39] vs. double incongruent M= 1000 [SE:34])* and CTI= 1200, **[F(2, 51)= 22, p <.001]** *(40ms of congruency effect, M= 767 [SE:44] vs. M= 707 [SE: 34] vs. M= 848 [SE: 33] vs. M= 867 [SE: 40]).*

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (20)= -2.5, p =.02** and on the switch trials, **t (20)= -4.3, p <.001**.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (20)= -3.1, p = .007** and on the switch trials, **t (20)= -6.9, p<.001**.

Errors (%)

A significant 3 way interaction (CTI, trial type and congruency), **[F (2, 32)= 3.7, p=.04]** was examined by two separate 2-way interaction for each CTI. At the CTI=100, the interaction in trial type and congruency was not significant, [F (2, 35)= 1.7, p=.20]. A difference in switch and repeat trials was not significant, [F (1, 19)= .34, p=.56] during the CTI=100 whereas it was significant during the CTI=1200, **[F (1, 19)= 7.3, p=.02]**.

A significant effect of congruency was found at both CTI=100, **[F (2, 39) =5.6, p=.007]** and CTI=1200, **[F (2, 35)= 17, p <.001]**.

At CTI=1200, switch and repeat trials were equally and significantly affected by the factor congruency, **[F (2, 39) = 16, p <.001]** (switch trials) and **[F (2, 32)= 13, p <.001]** (repeat trials).

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (19)= 1.4, p =.16 and on the switch trials, t (19)= 1.1, p=.28.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the switch trials, **t (19)= 3.2, p=.005** but on the repeat trials, t (19)= 2.7, p =.014.

Summary

a. A main effect of switch costs for the word task only occurred at the short preparation interval and was marginally significant the long preparation interval for reaction time whereas there was a main effect of switch costs in the long preparation interval on error.

b. A main effect of congruency for the word task was observed on reaction time and error consistently for both short and long preparation interval.

c. The interaction between trial type and congruency was not observed for both reaction time and error.

d. The effect of previous congruency for the word task was observed for both switch and repeat trials during the both preparation interval for reaction time. It was only significant for the switch trials during the long preparation interval for errors.

2) Effect of alternating task

Four research questions for the effect of alternating tasks were as follows.

a. Is there any main effect of alternating switch cost?

b. Is there a main effect of congruency?

c. Does congruency interact with alternating switch/double switch trials (switch type)?

d. Is there any previous congruency effect?

On Reaction Time (ms)

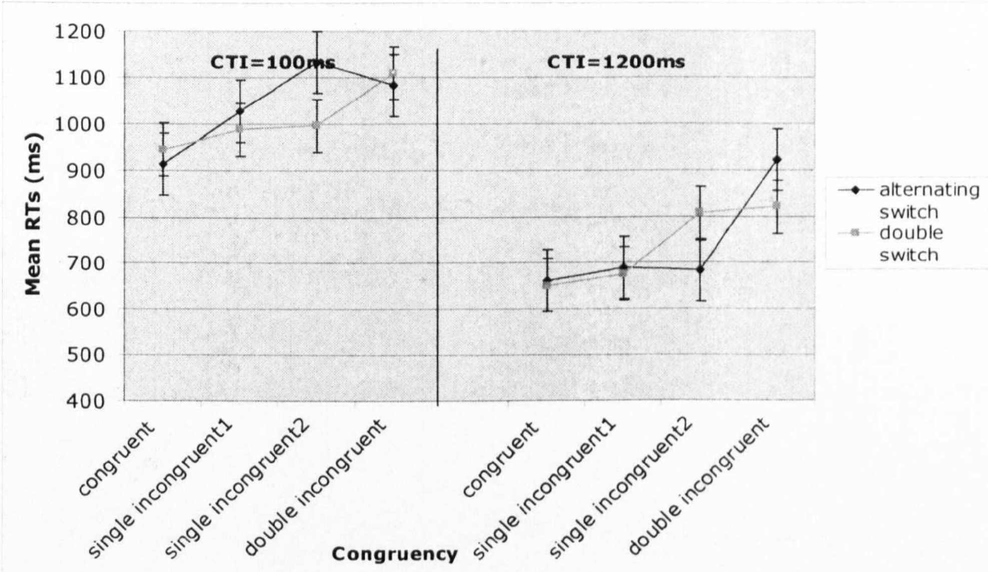
The repeated measures ANOVA with the factors CTI, switch type, task, and congruency revealed a significant 4-way interaction, **[F (4, 92) =3.5, p =.007]** (*see the Appendix, page 400 table 2a*). This interaction was explored by conducting three separate 3-way repeated measures ANOVA for each task. Each of these is reported below.

On Errors (%)

Analysis of the 4-way repeated measured ANOVA with factors CTI, switch type, task and congruency revealed a non-significant 4-way interaction, **[F (4, 75)= .37, p=.82]** (*see the Appendix, page 400 table 2b*). There was only a significant 3-way interaction (CTI, switch type and congruency), **[F (2, 45)= 3.1, p=.05]** and a marginally significant 3-way interaction (CTI, task, congruency), **[F (3, 63)= 23, p=.08]**. This marginal 3-way interaction was explored by presenting three separate figures by each task as these figures were previously presented on the reaction time (RT).
Each figure is reported below.

Arrow task

a. RT (ms)



b. Error (%)

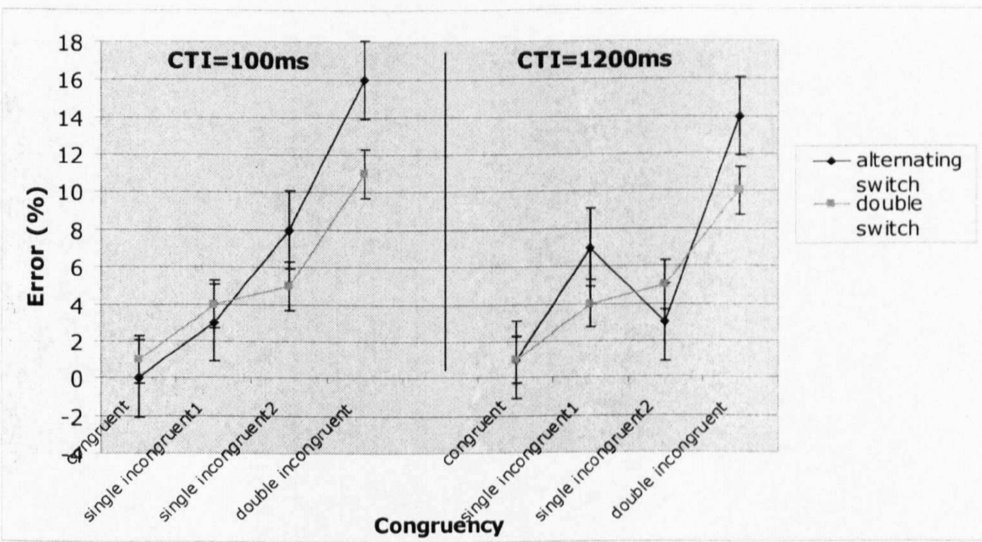


Figure 15. Mean RTs (and standard errors) (figure 15a) and percent error scores (figure 15b) in congruency and switch type in two CTI conditions for the arrow task.

RT (ms)

There was a significant 3-way interaction between CTI, switch type and congruency, **[F (2, 41) = 7.9, p =.001].** The simple effects of this interaction were explored by examining each of the CTIs separately.

The effect of alternating switch was non-significant, [F (1, 20) =1.4, p =.24] *(30ms of alternating switch cost, alternating switch M= 1039 [SE: 43] vs. double switch M= 1009 [SE: 40])* both at the CTI= 100 and at the CTI=1200, [F (1, 20) =.00, p=.99] *(1ms of alternating switch cost, alternating switch M= 739 [SE: 37] vs. double switch M= 738 [SE: 48]*) (see Figure 7). However, there a big alternating switch cost in the second single incongruent condition in the CTI= 100 *(136ms of alternating switch cost, alternating switch M=1133 [SE: 61] vs. double switch M= 997 [SE: 67])* and this difference was confirmed as significant by a Paired-Samples T-test: **t (20) = 2.3, p =.05**.

A 2-way interaction between switch type and congruency was only significant at the CTI=1200, **[F (3, 58) = 3.8, p=.015]** but not at CTI=100, [F (2, 50) =1.6, p=.20]. As is clear from an examination of Figure 15a, this was a result of a large difference in RT between alternating and double switch comparison in the single incongruent 2 condition only *(-122ms of alternating switch cost, M= 684 [SE: 30] vs. M= 806 [SE: 49])* which was confirmed by a Paired-Samples T-test: **t (20)= -3.05, p=.006**. During the CTI=1200, alternating switch and double switch trials were equally and significantly affected by the factor congruency: a significant congruency effect was found at the alternating switch trials, **[F (2, 48)= 14, p <.001]** *(103ms of congruency effect, M= 662 [SE: 47], M= 689 [SE: 44], M= 684 [SE: 30], M= 921 [SE: 60])* and at the double switch trials, **[F (3, 53)= 7, p=.001]** *(116ms of congruency effect, M= 52 [SE: 49], M= 677 [SE: 62], M= 806 [SE: 49], M= 820 [SE: 60])*.

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was not significant either on the alternating switch trials, t (20)= -1.2, p =.23 or on the double switch trials, t (20)= -.19, p=.85.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the double switch trials, **t (20)= -2.4, p=.03** but not on the alternating switch trials, t (20)=.12, p = .90.

Error (%)

There was a non-significant 3-way interaction (CTI, switch type and congruency) for the arrow task, [F (2, 48)= .72, p=.52]. The interaction between switch type and congruency was non-significant at CTI=100, [F (2, 43) = .52, p=.62] and at CTI=1200, [F (2, 40)= 1.1, p=.35].

A difference in alternating switch and double switch trials was not significant either at CTI=100, [F (1, 19) =.43, p=.52] and CTI=1200, [F (1, 19)= .43, p=.52]. A significant effect of congruency was found in both CTI=100, **[F (2, 40) = 10.3, p <.001]** and CTI=1200, **[F (2, 32) = 10, p <.001]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was not significant either on the alternating switch trials, t (19)= 1.5, p =.16 or on the double switch trials, t (19)= .28, p=.78.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was marginally significant on the alternating switch trials, **t (19)= -1.8, p =.08** but not on the double switch trials, t (19)= .21, p=.84.

Summary

a. A main effect of alternating switch costs for the arrow task was non-significant on the reaction time and on the error. However, there was a big alternating switch cost (136ms; see *Page 154, Figure15a*) at the single incongruent 2 condition which was significant.

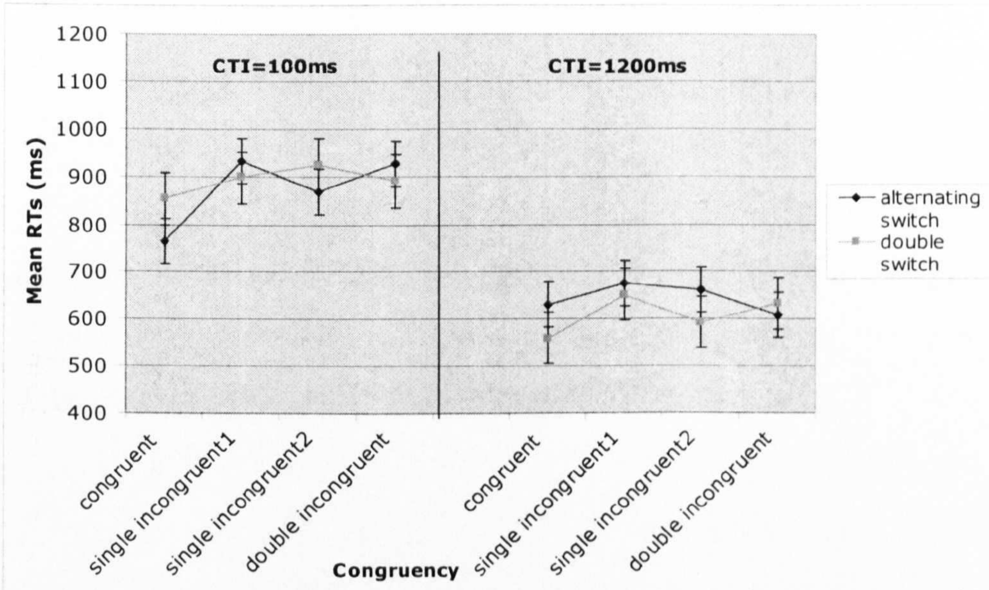
b. A main effect of congruency was observed on reaction time and for short preparation interval and on error for both preparation intervals, showing that congruency affected both alternating switch and double switching trials.

c. The interaction between congruency and switch type (alternating switch/double switch trials) only occurred on reaction time for the long preparation interval but not on error.

d. The effect of previous congruency for the arrow task did not occur on reaction time whereas it occurred on error only during the alternating switch trials for the long preparation interval which was marginally significant.

Location task

a. RT (ms)



b. Error (%)

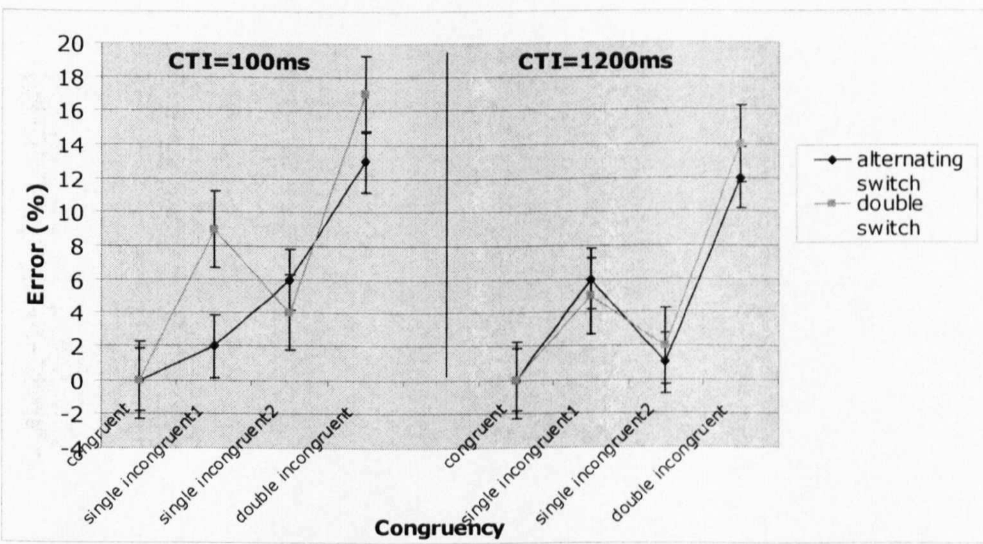


Figure 16. Mean RTs (and standard errors) (figure 16 a) and percent error scores (figure 16 b) in congruency and switch type in two CTI conditions for the location task.

RT (ms)

The effect of alternating tasks was non-significant, [F (1, 20) = .78, p =.39] at the CTI= 100 and at CTI =1200, [F (1, 20) =2.8 p=.11] (See the figure 16). As can be seen in Figure 16, there was substantial alternating switch costs at the congruent condition *(71ms alternating switch cost, alternating switch M= 631 [SE: 54] vs. double switch M= 560 [SE: 55])* and at the single incongruent condition *(69ms alternating switch cost, alternating switch M= 662 [SE: 67] vs. double switch M= 594 [SE: 223])* during the CTI=1200. However, Paired-Samples T-test shows that these alternating switch costs were non-significant: t (20) = 1.4, p=.16 at the congruent and t (20)= 1.6, p=.13 at the single incongruent 2 condition.

There was a significant 3-way interaction between CTI, switch type and congruency, **[F (3, 56) = 3.5, p =.03]**. The simple effects of this interaction were explored by examining each of the CTIs separately.

A significant 2-way interaction between switch type and congruency was only significant at CTI=100, **[F (2, 48)= 4.5, p=.011]** not at CTI=1200, [F (2, 48) = .87, p=.44].

The interaction between switch type and congruency at CTI=100 was caused by a significant congruency effect at the alternating switch trials, **[F (3, 55) =8.4, p<.001]** *(142ms of congruency effect, congruent M= 766 [SE: 39], single incongruent 1 M= 932 [SE: 43], single incongruent 2 M= 868 [SE: 39], double incongruent M= 926 [SE: 34])* and a non-significant congruency effect at the double switch trials, [F (3, 58)= 1.4, p=.25].

The effect of congruency was only significant at CTI=100, **[F (2, 53) = 5.5, p =.003]** *(96ms of congruency effect, congruent M= 810 [SE:34], single incongruent 1 M= 915 [SE:37], single incongruent 2 M= 897 [SE:38], double incongruent M= 908 [SE:29])* but not at CTI=1200, [F (2, 50) = .95, p=.41] .

During the CTI=100, alternating and double switch trials were equally and significantly affected by the factor congruency, **[F (2, 48) = 4.5, p=.01]**.

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (20)= 1.7, p =.098 and on the double switch trials, t (20)= .71, p=.49.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (20)=.31 , p = .76 and on the double switch trials, t (20)= 1.3, p=.22.

Error (%)

There was a significant 3-way interaction (CTI, switch type and congruency) for the location task, **[F (2, 38)= 3.4, p=.04].** The interaction between switch type and congruency was significant at CTI=100, **[F (2, 36) = 7, p=.003]** but not at CTI=1200, [F (2, 33)= .43, p=.62].

A significant difference in alternating switch and double switch trials was found at the CTI= 100, **[F (1, 19)= 7.2, p=.01]** (which was reversed alternating switch cost) but not at the CTI=1200, [F (1, 19)= .66, p=.43]. A significant effect of congruency was found at both CTI=100, **[F (2, 32)= 24, p <.001]** and CTI=1200, **[F (2, 31)=12, p <.001]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (19)= 3.9, p =.001** and on the double switch trials, **t (19)= -2.1, p=.04**.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (19)= -2.4, p =.03** but not on the double switch trials, t (19)= -1.7, p=.11.

Summary

a. There was no main effect of alternating switch costs for the location task for reaction time or errors.

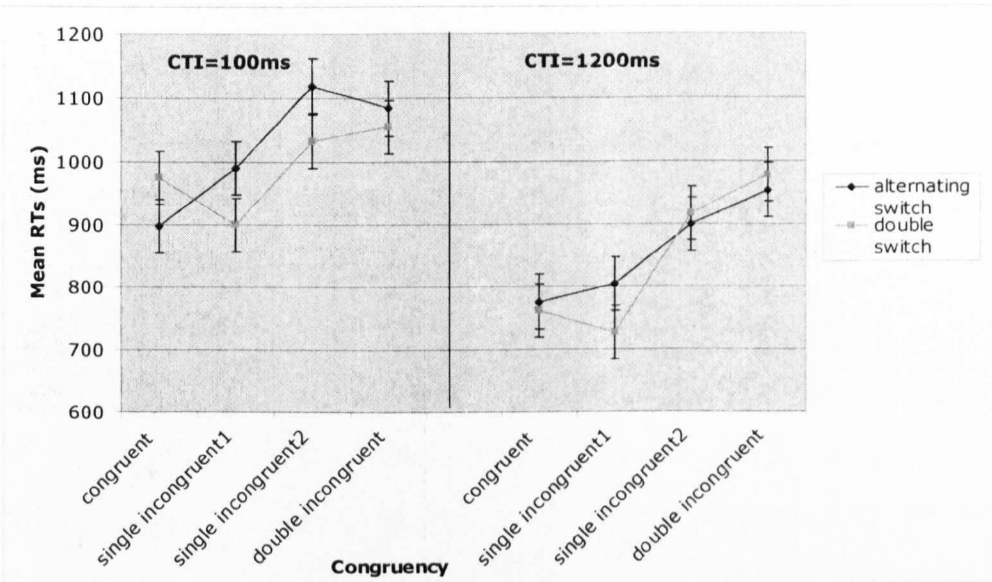
b. A main effect of congruency was observed on reaction time for short preparation interval and on error for both preparation intervals.

c. The interaction between congruency and switch type (alternating switch/double switch trials) occurred on reaction time for the short preparation interval not in error. This interaction was caused by the big congruency effect on the alternating switch trials, not double switch trials, suggesting that congruency only affected the alternating switch trials.

d. The effect of previous congruency for the location task occurred on error only during both the alternating switch trials for the short preparation interval. There was a significant previous congruency effect at the double switch trials for the short preparation interval and at the alternating switch trials for the long preparation interval; however, they were all reversed previous congruency effect. It was not occurred on reaction time.

Word task

a. RT (ms)



b. Error (%)

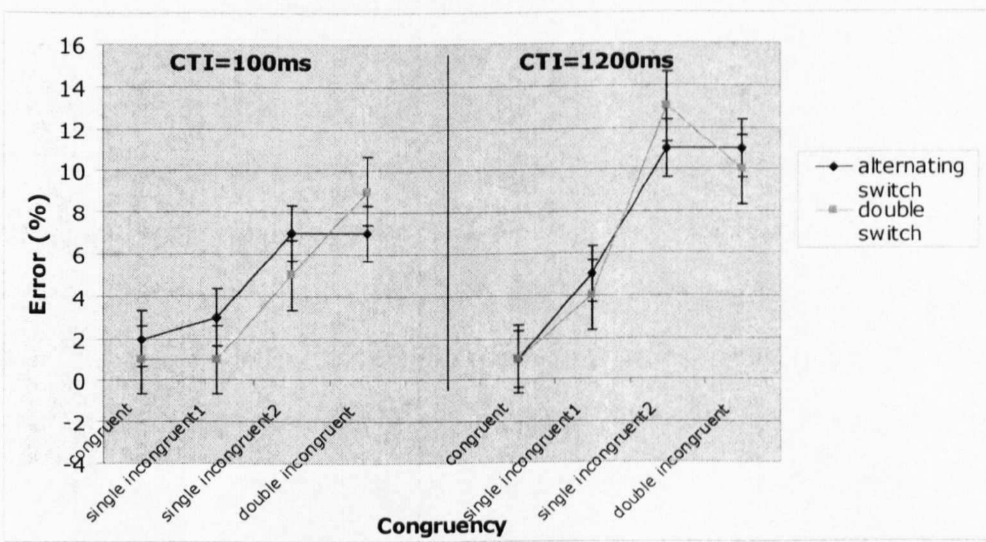


Figure 17. Mean RTs (and standard errors) (figure 17 a) and percent error scores (figure 17 b) in congruency and switch type in two CTI conditions for the word task.

RT (ms)

There was a non-significant 3-way interaction (CTI, switch type and congruency) for the word task, [F (2, 54) = 1.8, p=.15]. A significant interaction (switch type and congruency), **[F (2, 50) = 3.1, p=.04]** was found (*see Figure* 17a). This interaction was as a result from a significant interaction in switch type and congruency at CTI=100, **[F (3, 54) = 4.4, p=.009]** but not at the CTI=1200, [F (2, 45)= 1.0, p=.37].

The effect of alternating task was non-significant both at the CTI= 100, [F (1, 20)= 1.6, p =.21] *(32ms of alternating switch cost, alternating switch M = 1022 [SE: 40] vs. double switch M= 990 [SE: 32])* and at the CTI=1200, [F (1, 20) = .26, p =.61] *(13ms of alternating switch cost, alternating switch M = 858 [SE: 38] vs. double switch M = 846 [SE: 45])* (see Figure 9).

The effect of congruency was significant both at the CTI=100, **[F (2, 37) = 9.9, p <.001]** *(95 ms of congruency effect, M= 935 [SE: 51] vs. M= 945 [SE: 47] vs. M= 1076 [SE: 73] vs. M= 1069 [SE: 52])* and at the CTI=1200, **[F (2, 50)= 18, p <.001]** *(111ms of congruency effect, M= 769 [SE: 40] vs. M= 766 [SE: 35] vs. M= 907 [SE: 47] vs. M= 966[SE: 53])*. At CTI=100, congruency more strongly affected on the alternating switch trials, **[F (2, 51)= 12, p<.001]** *(167ms of congruency effect, M= 897 [SE: 42], M= 990 [SE: 48], M= 1119 [SE: 48], M= 1083[SE: 50])* than double switch trials, **[F (1, 31)= 4.6, p=.025]** *(22ms of congruency effect, M= 769 [SE: 40], M= 900 [SE:28], M= 1032 [SE: 54], M= 1055 [SE:45])*.

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (20)= -2.7, p =.01 a**nd on the double switch trials, **t (20)= -2.4, p=.024**.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (20)= -2.5, p = .02** and on the double switch trials, **t (20)= .-5.1, p <.001**.

Error (%)

The interaction in switch type and congruency was non-significant at CTI=100, [F (2, 31) = .40, p= .63] and CTI=1200, [F (2, 44) = .37, p= .73].

A difference in alternating switch and double switch trials was not significant at CTI=100, [F (1, 19) = 1, p =.32] and CTI=1200, [F (1, 19) = .004, p <.95]. A significant effect of congruency was found at both CTI=100, **[F (2, 36) = 36, p=.04]** and CTI=1200, **[F (2, 41) = 10, p <.001]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (19)= 1.5, p =.15 and on the double switch trials, t (19)= 1.6, p=.13.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the double switch trials, **t (19)= 3.0, p=.007** but not on the alternating switch trials, t (19)= 1.3, p =.19.

Summary

a. A main effect of alternating switch costs for the word task did not occur on the reaction time and on the error.

b. A main effect of congruency was observed on reaction time and on error for both short and long preparation interval, showing that congruency affected both alternating switch and double switching trials.

c. The interaction between congruency and switch type (alternating switch/double switch trials) occurred on the reaction time for the short preparation interval but not on error.

d. The effect of previous congruency for the word task occurred on reaction time for both preparation intervals whereas it was only occurred on error during the alternating switch trials for the long preparation interval.

3) Effect of cues (comparing exp 1 vs. exp 3)

On Reaction Time (ms)

- **For switch/ repeat trials**

There was an interaction between group (exp 1, exp 3) CTI, trial type and task, **[F (2, 75)= 4.8, p =.01]** and group effect by task and congruency, **[F (4, 17)= 2.8, p=.03]** and in a group by trial type and task, **[F (2, 76)= 3.2, p=.05]** *(see the Appendix, page 387-388, table2).* These group effects were caused by the bigger switch costs in for the arrow task and location task in the experiment 1 at CTI=100 *(148ms switch cost: switch M= 1044 [SE: 52] vs. repeat M= 896 [SE: 41] for the arrow task and 168ms switch cost: switch M= 913 [SE: 40] vs. repeat M= 745 [SE: 36] for* *the location task)* compared to their switch costs in the current experiment at CTI=100 *(106ms switch cost: switch M= 988 [SE: 52] vs. repeat M= 882 [SE: 41] for the arrow task and 62ms switch cost: switch M= 877 [SE: 40] vs. repeat M= 815 [SE: 36] for the location task)* (see *Figure 18*).

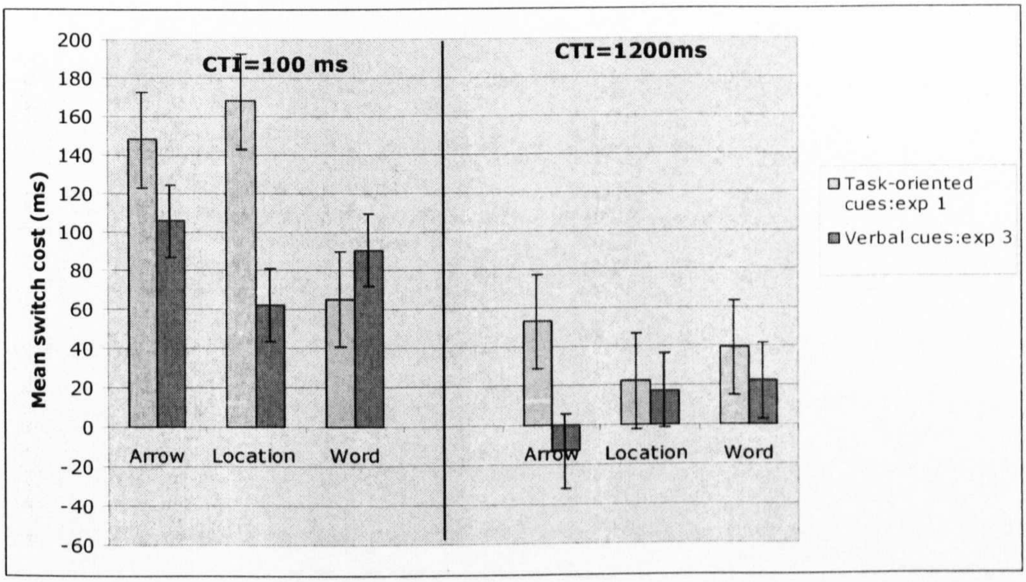


Figure18. Mean switch cost (and standard error) in three tasks with two preparation intervals between experiment 1 (task-oriented cue) and experiment 3 (verbal cue)

The dramatic reduction of switch cost in the location task from the current experiment (106ms of reduction) also caused the group effect in the trial type and task. On the other hand, word task showed the smallest switch cost among three tasks and had less benefit from long preparation interval in experiment 1. In other words, the reduction of switch cost from CTI=100 *(65ms switch cost, switch M= 985 [SE: 37] vs. repeat M= 920 [SE: 43])* to CTI=1200 *(39ms switch cost, switch M= 791 [SE: 34] vs. repeat M= 763 [SE: 35]*) was only 26ms in the experiment 1, resulting in group effect in trial type, CTI and task. The group effect in task and congruency was caused by the bigger congruency effect for the arrow task in the experiment

1 compared to the current experiment (100ms congruency effect in the experiment 1 vs. 66ms congruency effect in the current experiment) whereas the other two tasks showed the similar size of congruency effect in both experiments (63ms congruency effect: exp 1 vs. 54ms congruency effect: exp 3 for the location task, 50ms congruency effect: exp 1 vs. 64ms congruency effect: exp 3 for the word task). Overall, there was no main effect of group, [F (1, 40)= .08, p=.78] (see the Appendix).

- **For alternating and double switch trials**

There was no main effect of group, [F (1, 40) = .08, p= .77] (*see the Appendix, page 387-388, table 2*) and there was only an interaction between group and CTI, **[F (1, 40)= 5.5, p=.02]**, indicating that participants had more benefit of having long preparation interval *(302ms of mean RT reduction, CTI=100 M= 1023 [SE: 43] vs. CTI=1200 M= 721 [SE: 41])* in the experiment 1 than in the current experiment *(232ms of mean RT reduction, CTI=100 M= 971 [SE: 43] vs. M= 739 [SE: 41]).*

On Error (%)

- **For switch and repeat trials**

There was an interaction between group (exp 1, exp 3) in CTI, trial type and congruency, **[F (2, 89)= 3.7, p=.02]**. The main effect of group was non-significant, [F (1, 39)= .87, p=.36].

- **For alternating and double switch trials**

There was no main effect of group, [F (1, 39)= .64, p=.43] or any other interaction with group for this analysis.

DISCUSSION

The main aim of this experiment was to see whether having verbal cues for all three tasks would cause the backward inhibition since the experiment 1 (see chapter 3) demonstrated no backward inhibition apart from the switch cost and congruency effect.

1) Effect of task switching

- ***Switch costs*** for the long preparation interval in all three tasks were dramatically reduced in terms of reaction time compared with the short preparation interval, suggesting that participants used long preparation interval for advanced configuration process based on the hypothesis that preparation effect indicates the time required to establish a task set. In all three tasks, main effect of switch cost was only significant in the short preparation interval for the reaction time whereas it was significant for both preparation interval for the error except for the word task (only significant at the long CTI for the error), suggesting that participants still made errors while making a fast response (cf. speed-accuracy trade-off). This pattern was similar to the previous experiment 1.
- ***Congruency effect on the current trials*** shows how active the other task sets remains. In all three tasks, they demonstrated big congruency effect in reaction time and error, suggesting that participants made slower response and more errors when it was incongruent regardless of the preparation interval. Note that significant congruency effects were observed in both switch and repeat trials. Having congruency effects during the repeat trials for all three tasks

suggests that the persistent activation of the irrelevant task set indeed interfere with the current task set because there is no need to suppress the irrelevant task set during the repeat trials, causing the other task set to be persistently activated.

- ***The interaction between congruency and trial type (switch/repeat)*** shows whether switch trials are more influenced by the repeat trials. If so, the bigger congruency effect on the switch trials suggests that switching different tasks are influenced by the level of activation from the other task sets on the current trials. In the current experiment, there was only significant interaction for the arrow task during the short preparation interval which was as a result from the lack of switch cost at the single incongruent 1 condition and the significant switch cost at the rest of congruent condition (congruent, single incongruent 2 and double incongruent). At this stage, it is not clear why single incongruent 1 condition caused no switch cost during the short preparation interval for the arrow task.
- ***Previous congruency*** shows that the task set from the previous N-1 trials remains in a state of residual activation. In other words, the persisting activation of previous task set interfered with a subsequent task switch, depending on whether it activates a response that is the same as or different from the response by the new task set on the current trials. In the arrow task, the repeat trials were only influenced by the previous congruency during the short preparation interval on reaction time. However, in the location task, the switch trials were only influenced by the previous congruency during the long preparation interval on reaction time and error. In the word task, both switch and repeat trials in any preparation interval (short and long) were influenced

by previous congruency on reaction time. It is noteworthy that word task in the experiment 1 (chapter 3) was only task that showed the significant effect of previous congruency. In the current experiment, the other two tasks also showed the previous congruency effect, yet it was not consistently observed in any type of trials or preparation interval unlike the word task.

2) Effect of alternating task

- ***Alternating switch costs*** was only observed in the arrow task during the short preparation interval at the single incongruent 2 condition (136ms) whereas the rest of tasks did not show any significant alternating switch cost on reaction time and error. Note that there were 68ms alternating switch cost at the single incongruent 2 and 71ms alternating switch cost at the congruent condition for the location task during the long preparation interval.
- ***Congruency effect on the current trials*** shows how active the other task sets remain. In all three tasks, they demonstrated big congruency effect in reaction time and error, suggesting that participants made slower response and more errors when it was incongruent regardless of the preparation interval. Although the congruency affected both alternating and double switch trials in all three tasks, the size of effect on reaction time was different among tasks. For example, the arrow task showed larger congruency effect on the alternating switch trials (see *Page 149*) whereas the location task showed larger congruency effect on the double switch trials (see *Page 153*). For the word task, it did not show any interaction between alternating switch and double switch trials.

- ***The interaction between congruency and switch type (alternating switch/double switch)*** occurred only on reaction time not on error in all three tasks. In the arrow task, the interaction was only significant at the long preparation interval which was as a result from a huge reversed alternating switch cost (-122ms) at the single incongruent 2 condition. In the location task, the interaction was only significant at the short preparation interval which was as a result from the significant congruency effect on the alternating switch trials and a non-significant congruency effect on the double switch trials. In the word task, the interaction was significant in both preparation intervals as the current congruency had more impact on the alternating switch trials than double switch trials.
- ***Previous congruency*** marginally affected the alternating switch trials during the long preparation interval on error for the arrow task. As for the location task, it only occurred on error but the previous congruency on the double switch trials at the short preparation interval and on the alternating switch trials at the long preparation interval were opposite direction. In other words, the error was larger on the current location task when the previous trials were congruent compared to when the previous trials were incongruent. This suggests that participants had more difficulties performing the location task when it was congruent to the previous task. The word task was also affected by the previous congruency in both switch trials during the both preparation intervals on reaction time. The significant previous congruency on error was only observed in the alternating switch trials during the long preparation interval.

3) Effect of cues

The cue type effect between task-oriented cue and verbal cue was examined by group comparison between exp 1 and exp 3 (current experiment). The result demonstrated that having verbal cues in the current experiment reduced the switch cost significantly compared to having task-oriented cue in the experiment 1, however it did not change the appearance of alternating switch cost in the current experiment. Note that the cue for the word task was not changed in both experiments. The results support the hypothesis that strong cue-target association helped the switching performance. However, it did not affect the size of backward inhibition in the tasks unlike the previous studies (see the *Table 5, page 133* in the current chapter).

CONCLUSIONS

The present experiment in this chapter demonstrated the substantial amount of switch costs and congruency effect on the current trials whereas the alternating switch costs were not observed except the arrow task at the single incongruent 2 condition during the short preparation interval.

The results showed that having verbal cues for all three tasks was not influence the occurrence of backward inhibition unlike the previous literature. Comparing the result with exp1, the current experiment revealed the smaller switch cost in the arrow and location task, indicating that strong cue-target association which was instructed by verbal cues might reduce the additional extra process for upcoming task set while switching task.

Strong congruency effect in both exp1 and the current experiment suggest that interference from the irrelevant task sets is immune to the strength of the cue-target association. It suggests that the irrelevant task information on the stimulus is highly activated and this high activation of the other task sets are interfering with the current task. These results clearly demonstrate that task set reconfiguration process is limited to overcome the passive dissipation from the other tasks.

Chapter 6

Experiment 4: The effect of arbitrary cues on switch cost and backward inhibition

INTRODUCTION

Task switching performance is strongly influenced by whether the imperative stimulus uniquely specifies which task to perform (Arbuthnott and Woodward, 2002). Normally, the function of the cue is to set up the cognitive system for the upcoming actions. It is already known that switching takes more time compared to repeating a task because it involves the additional process of changing the task set. The general idea of switching costs is that they reflect an underlying process that 'reconfigures' this cognitive system to perform one or the other task, and that this reconfiguration can be achieved prior to the presentation of the stimulus (Koch, 2003). The evidence for this notion is mainly based on studies that vary task preparation time such as Cue-Target-Interval (CTI) or Response-Cue-Interval (RTI).

Apart from the manipulation of changing the preparation interval to study the concept of reconfiguration, presenting different types of cues (Merian, 1996) have been also a major method for studying task switching. The rationale of this method is that task reconfiguration in the cuing paradigm is triggered by an external task cue; otherwise, it is impossible for participants to know which task to perform just based on the stimulus (Koch, 2003). Hence, there has been ample amount of efforts on the role of the cues in task switching in order to see how effectively they aid task switching as demonstrated by their influence on the size of the switch costs. Despite the importance of cues in task switching, the study of the cue type or the role of the cue was not the main interest until researchers discovered that difference cue types influence the task switching performance especially by giving the explicit cues (Arbuthnott, 2005).

This explicit-cuing paradigm was simply to present the cue before the target so that participants had information in advance which task to perform. However, there were different ways of giving information for the task without presenting an explicit cue.

For example, in the alternating-runs paradigm, in which the task alternates every N trials, where N is constant and predictable, so that one can compare task-switch and task repetition within a block without an explicit cue (Monsell, 2003). Alternatively, by using a prespecified task sequence (e.g. colour-shape-colour) participants have the short sequence of trials they can prepare for the upcoming task. However, these methods had limitation as they only allowed us to understand the passive dissipation of the previous task-set by varying the stimulus-response interval (SRI). In order to overcome this limitation, an explicit task-cueing paradigm was developed by Meiran (1996). Since then, this procedure has been widely used as it enabled us to manipulate independently the cue-stimulus interval (allowing active preparation) and the response-cue interval (allowing passive dissipation) (Monsell, 2003). In the explicit task-cueing procedure, the task is unpredictable and a task cue appears either with or before the stimulus. Especially, the interval between the cue and the target is manipulated to control the time at which the participants can begin to reprogram their cognitive systems for the upcoming task before the target appears (Meiran, 1996). The decrease in switch costs as the time available for preparation between cue and stimulus has been taken to index a process of endogenous task-set reconfiguration (Monsell & Mizon, 2006). Moreover, they also found that the presence of contextual cues as to the currently appropriate task set was an important factor: When Task A and B are unambiguously associated with different stimuli, switch costs are much smaller than when one stimulus type is associated with both tasks (Allport et al, 1994; Rogers & Monsell, 1995). For example, Rogers and Monsell (1995) had a letter and digit task in crosstalk and no-crosstalk conditions. In the crosstalk condition, the irrelevant character was drawn from the neutral set on one third of the trials and this irrelevant character was sometimes associated with the response for the currently inappropriate as well as the appropriate task. In the no-crosstalk condition, the irrelevant character (#,?,*, and %) was always drawn from a set of neutral, non-alphabetic characters. When the stimulus display included both a letter and digit character (i.e. bivalent stimuli), switch cost was 289 ms, as compared with 161 ms for stimulus displays with a nonalphanumeric (e.g., #) distractor (i.e., univalent stimuli; Rogers and Monsell, 1995). This is likely because bivalent stimuli are associated with both task sets, and thus encoding such stimuli would activate competing stimulus-response associations in a bottom-up fashion (Allport & Wylie, 1999). Arbuthnott and Woodward (2002) proposed that greater switch cost with bivalent stimuli would thus reflect the time necessary to select between competing processing options, which presumably requires the executive control. Conversely, univalent stimuli would activate only the relevant stimulus-response association, resulting in much less switch costs because the need to recruit executive processes to resolve competition would be reduced (Arbuthnott and Woodward, 2002).

In the context of bivalent stimuli, Meiran (1996, 2000) included the cues to indicate the relevant task (Arbuthnott, 2002). The presence of such cues could potentially reduce the time necessary to select between competing response options by providing an additional source of biased activation for the relevant task set, especially when the association between the cue and the relevant task was well established (Arbuthnott, 2002).

In the current experiment, the stimulus had three task-set information as the target is the always the same regardless of the task. This trivalent stimulus had to be directly guided which task participants had to perform. Thus, without giving an explicit cue for the each task, it was not simply possible to make a response. For the pilot experiment (chapter 3), cues which represent key characteristics of the task were selected. For the experiment 3, verbal cues to the task were presented. In both experiments, the information for the task was straightforward without any ambiguity.

In particular, semantic and associative relations between the cues and tasks were strong by using the verbal cues for the tasks in the experiment 3. The result from the experiment 3 supported the idea that strong association between the cue and task reduced the switch cost.[1] However, it remains unclear why backward inhibition was not observed in the previous chapters except for the arrow task only when it was single incongruent 2 condition (e.g, exp 1: 310ms alternating switch cost, exp 3: 136ms

[1] Switch costs for the arrow and location tasks from the exp 3 was decreased compared to the arrow and location tasks from the exp 1. Note that the cue for the word task in exp 1 and 3 was the same (verbal cue: WORD). See the page166 in the chapter 5.

alternating switch cost). Presumably, it is possible to interpret that the presence of a pair of arrows pointing up and down would bias the appropriate response options to a greater degree than the location and word task as the arrow has a long-standing association with direction. According to the result from the experiment 3, it is unlikely to conclude that verbal cue is an important factor to obtain the backward inhibition despite the previous studies showed BI effect by using the verbal cues (ref. see the table 5, page 133 in the chapter 5). In order to distinguish any cue type effect on switch cost and backward inhibition, the present experiment was developed. By using the arbitrary cues for all tasks, the cue-task association is now weak and furthermore, the working memory demand is crucial to learn the meaning of the cue in order to perform the task. It is also possible that using the random symbol cues were sufficiently resource-demanding to require some task-set reconfiguration, whereas the verbal cues of the experiment 3, there is no need to learn and interpret the meaning of the cue, causing the less effort for the task-set reconfiguration. The core assumption lies that the requirement to interpret the symbolic cues may cause the task more difficult, resulting in slower performance overall and the magnitude of the switch costs would be increased due to the weak cue-task association. However, it is not certain whether the weak cue-task association by having the arbitrary cues would result in the appearance of backward inhibition.

The goal of the present experiment was to test the hypothesis that the strength of the cue-task association is crucial to change the size of the switch cost and alternating switch cost. By using the arbitrary cues, it is possible to eliminate the hypothesis from the previous literature (see the page 138, chapter 5 page) that the verbal cue is the important factor for backward inhibition depending on the presence and magnitude of the alternating switch costs. Additionally, another goal for this experiment was to examine the congruency effect whether the congruency effect is found regardless of the cue type. If so, it would give the strong evidence that interference from the irrelevant task sets remains dominant and congruency effect occurs on the level of stimulus representation, indicating that the cue information for the task would not help to reduce the interference from the irrelevant task sets.

METHODS

Participants

Twenty participants (9 women) were recruited from the University of Nottingham through the advert and 12 of them were undergraduates and the rest of them were postgraduate in the psychology department. The participants ranged age from 19 and 30 years (M= 25, SD=7), reported normal and corrected-to-normal vision and were all right-handed except two participants. They received £4 as an inconvenience allowance after completion of the experiment. The study took approximately 50 min to complete including the instruction and practice session.

Stimuli and Procedures

The task, stimuli and study procedures were identical to the previous experiment 1 (ref. chapter 3) except for the fact that the cues in this experiment were all arbitrary: the cue for the arrow task was &&&&&, the cue for the location task was %%%%%, and the cue for the word task was

#####. These cues were chosen from the keyboard symbol in order to replace the letters for the verbal cues from experiment 3. The reason why I chose the random symbols in the keyboard rather than the object image was to remove the possibility that participants could use the visual representation of the cue. For example, imagine if the arrow cue was the shape of a clock, then they would learn the meaning that 'the clock is the arrow cue' quickly and this meaning of the clock would strengthen the cue-task association because the visual representation of the clock would be easily retrieved from the Long-Term Memory (LTM) once the new meaning of the clock as an arrow task cue is translated. On the other hand, the series of the symbol & (&&&&&&) from the task does not have any meaning itself nor any typical visual representation that participants would come across. In this case, they have to develop their own strategy to interpret the symbols into the meaning of the cues. Therefore, the working memory load of the participants is high and it is now demanding to interpret the meaning of the cue itself because the meaning of the cue is neither pre-existed nor context-based. The cues were presented in the centre of the screen (Arial font, size 20).

In all other respects the procedures was identical to that of Experiment 1. However, the practice session for the task was lengthened as the participants found it harder to learn which task they had to perform. Thus, the trials for the each task was 24 trials (cf. originally, the trials for the each task was 16 trials) and then 48 trials for the switch trials (cf. the trials for the switching between tasks was 36 trials in the experiment 1) during the practice session. Figure 19 demonstrates the example of current experiment.

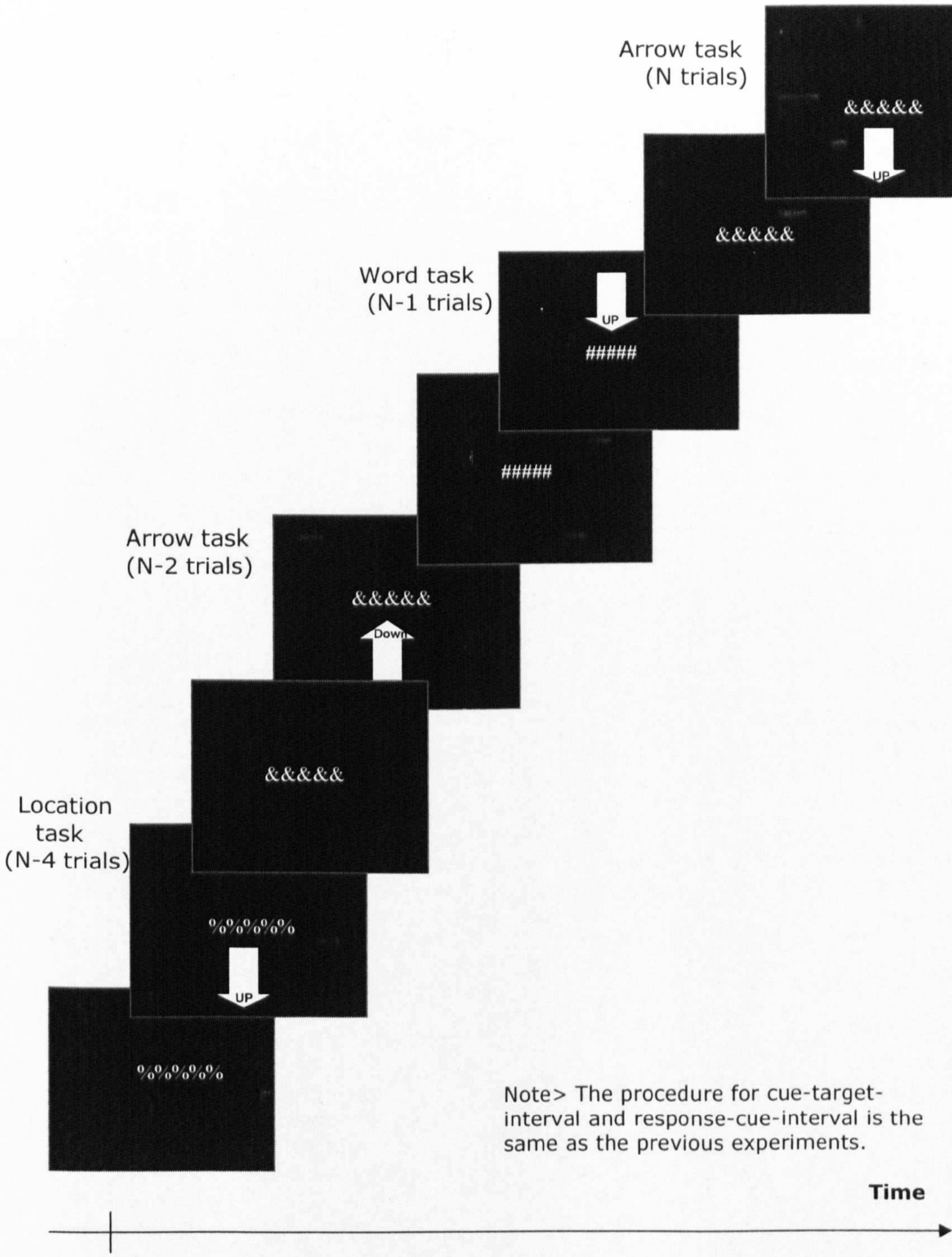


Figure 19. shows an example of the time course of task presentation in Experiment 4. Tasks were described here were three tasks: arrow, location and word task.

RESULTS

1) Effect of task switching

Four research questions for the effect of task switching were raised. They are as follows.

a. *Is there any switch cost?*

b. *Is there a main effect of congruency?*

c. *Does congruency interact with switch/repeat trials (trial type)?*

d. *Is there any previous congruency effect?*

On Reaction Time (RT)

Analysis of the 4-way repeated measured ANOVA with factors CTI (100, 1200), trial type (switch, repeat), task (arrows, location, word), and congruency (congruent, single incongruent 1, single incongruent 2, double incongruent) revealed a significant 4-way interaction (CTI, trial type, task and congruency), **[F (3, 65) =3.9, p =.008].** (see the Appendix, page 401 table 1a). This interaction was explored by conducting three separate 3-way (factors CTI, trial type, and congruency) repeated measures ANOVAs for each task. These are reported below.

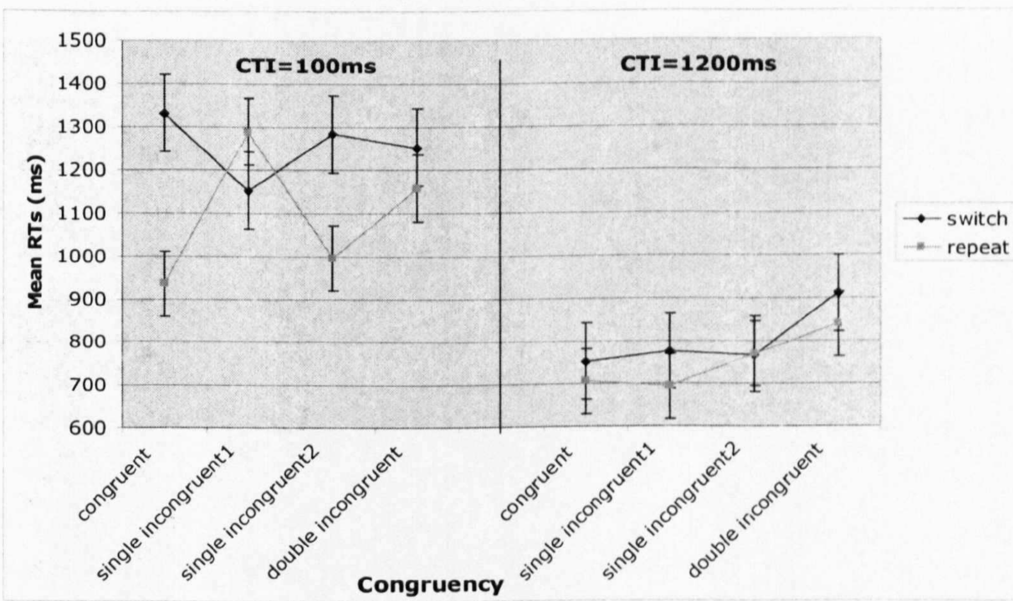
On Errors (%)

Analysis of the 4-way repeated measured ANOVA revealed a non-significant 4-way interaction: [F (4, 66)= 1.3, p=.29] (see the Appendix, page 402 table 1b). There was only a significant 3-way interaction: **[F (2, 32)= 3.1, p=.06]**. This 3-way interaction was explored by presenting three separate figures by each task as these figures were previously presented on the reaction time (RT). Each figure is reported below.

Arrow task

A significant difference between switch and repeat trials was found at CTI =100, **[F (1, 18) = 13, p =.002]** *(159ms of switch cost, switch M = 1255 [SE: 79] vs. repeat M= 1096 [SE: 51])* and at CTI=1200, **[F (1, 18) = 4.4, p =.05]** *(50 ms of switch cost, M = 802 [SE: 69] vs. M = 752 [SE: 58])* (See *Figure 20*).

a. RT(ms)



b. Error (%)

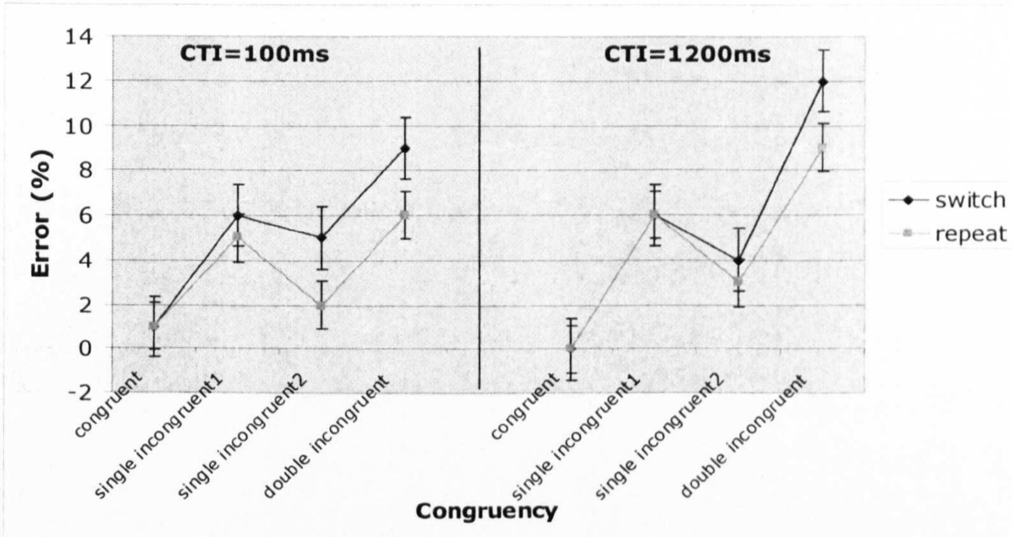


Figure 20. Mean RTs (and standard errors) (figure 20 a) and mean percentage (figure 20 b) in congruency and trial type in two CTI conditions for the arrow task.

RT (ms)

There was a significant 3-way interaction (CTI, trial type and congruency) for the arrow task, **[F (2, 38)= 6.3, p=.004]** which resulted from two effect which impacted CTI =100, **[F (2, 39) = 134, p <.001]** but not CTI= 1200, [F (2, 42) = .32, p= .76]. Both of these effects can be clearly seen in Figure 20 and were confirmed by an analysis of the simple effect (the factors trial type and congruency were examined at each CTI separately).

As is clear from an examination of Figure 20 a, this was as a result of dramatic RT increase from congruent to single incongruent 1 during the repeat trials, resulting in no switch cost in the single incongruent 1 condition at CTI=100. The interaction between trial type and congruency at CTI=100 was caused by a significant congruency effect on the repeat trials, **[F (2, 42) = 11, p <.001]** *(211ms of congruency effect, congruent M= 937 [SE: 59], single incongruent 1 M= 1289 [SE: 89], single incongruent 2 M= 997*

[SE: 55], double incongruent 2 M= 1159 [SE: 54],) and a reversed congruency effect on the switch trials which was marginally significant, **[F (2, 30)= 2.8, p=.08]** *(-101ms of congruency effect, congruent M= 1331 [SE: 92], single incongruent 1 M= 1152 [SE: 69], single incongruent 2 M= 1284 [SE: 116], double incongruent M= 1253 [SE: 65]).*

In both CTI conditions, the effect of congruency was only significant at the CTI=1200, **[F (2, 45)= 4.8, p= .008]** *(64ms of congruency effect, congruent M= 729 [SE: 64], single incongruent 1 M= 735 [SE: 78], single incongruent 2 M= 768 [SE: 49], double incongruent, M= 875[SE: 79])* but not at the CTI=100, [F (2, 40) = 1.8, p =.17].

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (18)= 3.6, p =.002** but not on the switch trials, t (18)= -1.5, p=.15.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the switch trials, **t (18)= -2.5, p=.02** but noton the repeat trials, t (18)= -1.2, p = .25.

Error (%)

There was a non-significant 2-way interaction (trial type and congruency) at both CTI=100, [F (2, 30)= .34, p=.68] and CTI=1200, [F (2, 37) =1.3, p=.28].

A significant difference in error percentage between switch and repeat trials for the arrow task was found only at the CTI=100, **[F (1, 18)= 6.9, p=.02]** but not at the CTI=1200, [F (1, 18)= 1.2, p=.29].

The effect of congruency was non-significant for both the CTI=100, [F (1, 19)= 1.3, p=.28] and the CTI=1200, [F (1, 21)= 2.6, p=.12].

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (18)= -9.4, p =.36 and on the switch trials, t (18)= -.34, p=.74.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (18)= -.55, p =.59 but it was significant on the switch trials, **t (18)= -.33, p=.02**.

Summary

a. A main effect of switch costs for the arrow task occurred on reaction time for both preparation interval condition whereas only for short preparation interval condition on the error.

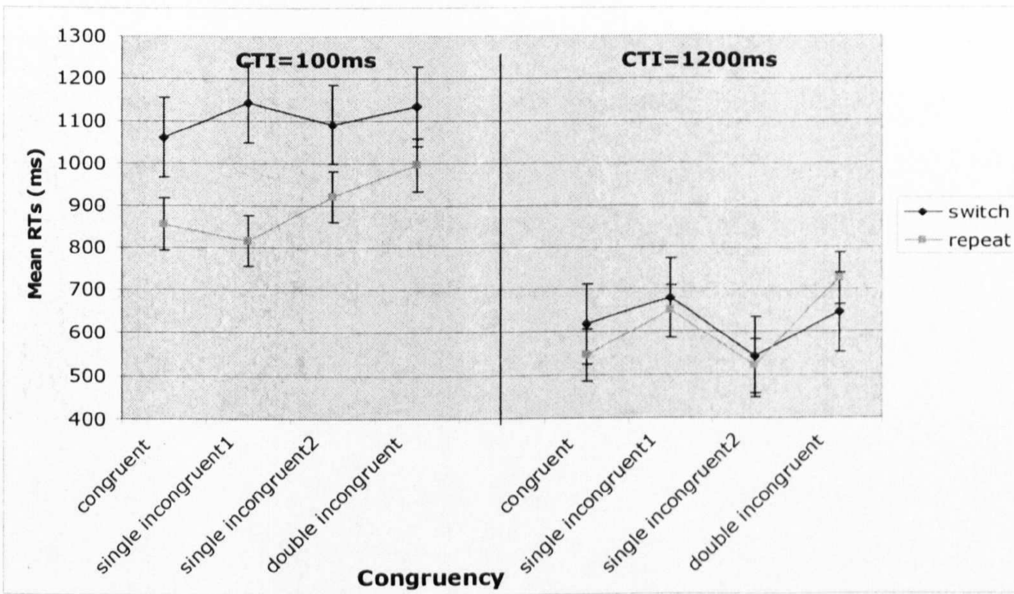
b. A main effect of congruency for the arrow task was observed on reaction for both short and long preparation interval but it was not observed on error.

c. The interaction between congruency and trial type (switch/repeat trials) was only significant on reaction time for the short preparation interval and it was caused by the significant congruency effect on the repeat trials and reversed effect on the switch trials. There was no significant interaction on error.

d. The effect of previous congruency for the arrow task was only occurred during the repeat trials for the short preparation interval and during the switch trials for the long preparation interval on reaction time. It was also observed on error during the switch trials for the long preparation interval.

Location task

a. RT (ms)



b. Error (%)

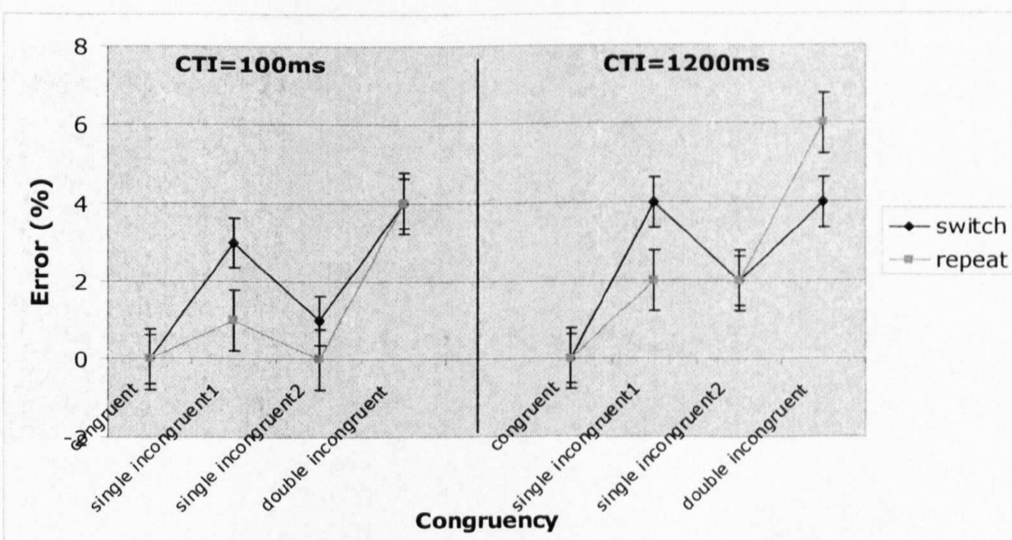


Figure 21. Mean RTs (and standard errors) (figure 21 a) and mean percentage (figure 21 b) in congruency and trial type in two CTI conditions for the location task.

RT (ms)

A significant difference between switch and repeat trials was found at the CTI= 100, **[F (1, 18)= 39, p <.001]** *(210ms of switch cost, switch M = 1107 [SE: 69] vs. repeat M= 897 [SE: 56])* but not at the CTI=1200, [F (1, 18) = .19, p =.66] (see Figure 21).

There was a non-significant 3-way interaction (CTI, trial type and congruency) for the location task, [F (2, 39)= .78, p=.47].
However, a marginally significant effect of congruency for both switch and repeat trials was found at the CTI=100, **[F (3, 52) = 2.6, p=.07]** *(59ms of congruency effect, M= 958 [SE: 63] vs. M= 979 [SE: 57] vs. M= 1007 [SE: 64] vs. M= 1065 [SE: 70])* and a significant effect of congruency for both switch and repeat trials at the CTI=1200, **[F (2, 40)= 6.5, p=.003]** *(45ms of congruency effect, M= 582 [SE: 64], M= 663 [SE: 38], M= 531 [SE: 31], M= 686 [SE: 47])*.

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was marginally significant on the repeat trials, **t (18)= -1.9, p =.06** but not on the switch trials, t (18)= 1.5, p=.14.
At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (18)= 2.2, p = .04** and on the switch trials, **t (18)= 3.4, p=.003**.

Error (%)

There was a non-significant 2-way interaction (trial type and congruency) in both at CTI=100, [F (1, 27)=.75, p=.45] and CTI=1200, [F (1, 24)= 1.0, p=.34]. A significant difference in error percentage between switch and repeat trials for the location task was not found either at the CTI=100, [F (1, 18)= 2.4, p=.14] or at the CTI=1200, [F (1, 18)=.005, p=.94].

The significant effect of congruency was found at both CTI=100, **[F (2, 32)= 13, p <.001]** and CTI=1200, **[F (2, 35)=5.4, p=.009]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the switch trials, **t (18)= -2.3, p=.03** but not on the repeat trials, t (18)= -1, p =.33.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the switch trials, **t (18)= -2.4, p=.024** but not on the repeat trials, t (18)= -.49, p =.63.

Summary

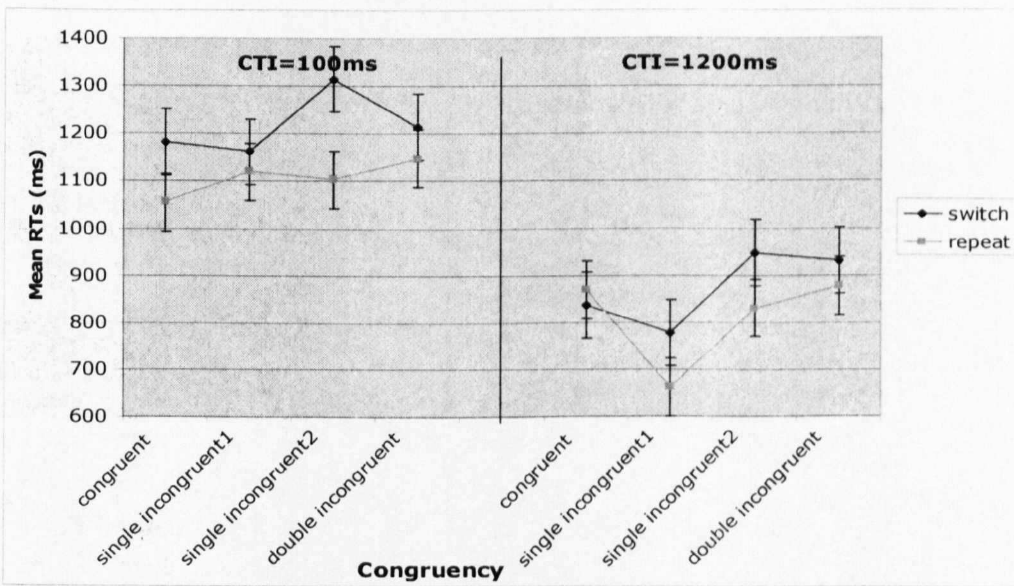
a. A main effect of switch costs for the location task occurred for reaction time only at the short preparation interval and there were no significant switch costs in the error data in either short or long preparation interval.
b. A main effect of congruency for the arrow task was observed on the reaction time and error consistently for both short and long preparation interval.

c. The interaction between congruency and trial type (switch/repeat trials) was non-significant on reaction time and error.

d. The effect of previous congruency for the location task only occurred on reaction time during both switch and repeat trials for the long preparation interval and on error for during the switch trials for short and long preparation interval. This previous congruency effect was opposite direction. In other words, the single incongruent 2 condition was faster/less error than single incongruent 1 condition.

Word task

a. RT (ms)



b. Error (%)

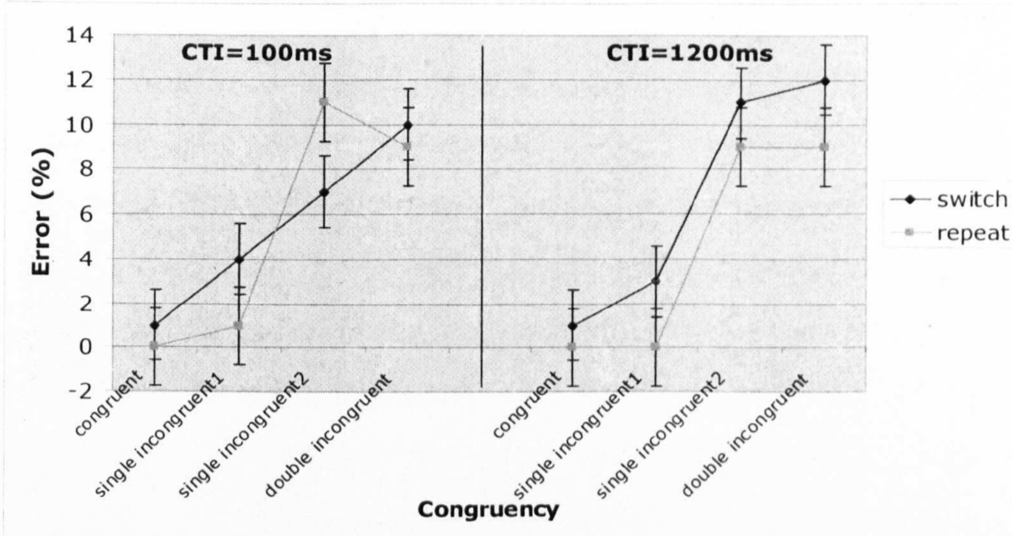


Figure 22. Mean RTs (and standard errors) (figure 22 a) and mean percentage (figure 22 b) in congruency and trial type in two CTI conditions for the word task.

RT (ms)

A significant difference between switch and repeat trials was found at the CTI= 100, **[F (1, 18)= 22, p <.001]** *(112ms of switch cost, switch M = 1218 [SE: 64] vs, repeat M= 1106 [SE: 59])* and at the CTI=1200, **[F (1, 20) = 7.5, p =.02]** *(64ms of switch cost, switch M = 874 [SE: 57],vs. repeat M = 810 [SE: 41])* (see Figure 22 a).

A 2-way interaction in trial type and congruency was marginally significant at the CTI=100, **[F (2, 43) = 26, p =.07]** but not at the CTI=1200, [F (2, 36) =2.3, p =.11]. This marginal interaction between trial type and congruency at the CTI=100 was resulted from a significant effect of congruency at the switch trials, **[F (2, 42) = 6.2, p=.003]** *(48ms of congruency effect, congruent M= 1182 [SE: 75], single incongruent 1 M= 1162 [SE: 67], single incongruent 2 M= 1315 [SE: 76], double incongruent*

M=1214 [SE: 53]) and a non-significant effect of congruency at the repeat trials, [F (2, 42)= .98, p=.39].

In both CTI conditions, the effect of congruency was marginally significant at the CTI=100, **[F (2, 46)=2.7, p=.06]** *(59ms of congruency effect, congruent M= 1118 [SE: 70], single incongruent 1 M= 1141 [SE: 76], single incongruent 2 M= 1209 [SE: 59], double incongruent M= 1181 [SE:49])* and it was significant at the CTI= 1200, **[F(2, 51)= 22, p <.001]** *(40ms of congruency effect, M= 767 [SE:44] vs. M= 707 [SE: 34] vs. M= 848 [SE: 33] vs. M= 867 [SE: 40]).*

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the switch trials, **t (18)= -3.2, p=.004** but not on the repeat trials, t (18)= .26, p =.80.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (18)= -4.2, p = .001** and on the switch trials, **t (18)= -2.5, p=.02**.

Error (%)

There was a significant 2-way interaction (trial type and congruency) at CTI=100, **[F (2, 35)= 4.2, p=.02]** but not at the CTI=1200, [F (2, 36)= .50, p=.61]. This interaction was as a result from a marginally significant effect of congruency at the repeat trials, **[F (1, 21)= 3.8, p =.06]** but not at the switch trials, [F (1, 21)= 1.8, p=.20].

A significant difference in error percentage between switch and repeat trials for the word task was found only at the CTI=100, **[F (1, 18)= 6.5, p=.02]** but not at the CTI=1200, [F (1, 18)=.034, p=.85].

The significant effect of congruency was not only found at the CTI=1200, **[F (1, 20)= 4.2, p=.05]** but not at the CTI=100, [F (1, 20)= 2.6, p =.12].

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (18)= 2.1, p =.05** but not on the switch trials, t (18)= .64, p=.53.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (18)= 2.1, p =.05** and it was marginally significant on the switch trials, **t (18)= 1.9, p=.07.**

Summary

a. A main effect of switch costs for the word task only occurred on reaction time for both preparation interval whereas for the long preparation interval on error.

b. A main effect of congruency for the word task was observed on reaction time for both short (marginal) and long preparation interval and it was only significant for the long preparation interval on error.

c. The interaction between congruency and trial type (switch/repeat trials) was only marginal on reaction time and error for short preparation interval.

d. The effect of previous congruency for the word task only occurred during the switch trials for the short preparation interval and both switch and repeat trials for the long preparation interval on reaction time. It was also observed during the repeat trials for the short preparation interval and both switch (marginal) and repeat trials for the long preparation interval.

2) Effect of alternating task

Four research questions for the effect of alternating tasks were as follows.

a. *Is there any main effect of alternating switch cost?*
b. *Is there a main effect of congruency?*
c. *Does congruency interact with alternating switch/double switch trials (switch type)?*
d. *Is there any previous congruency effect?*

<u>On Reaction Time (ms)</u>

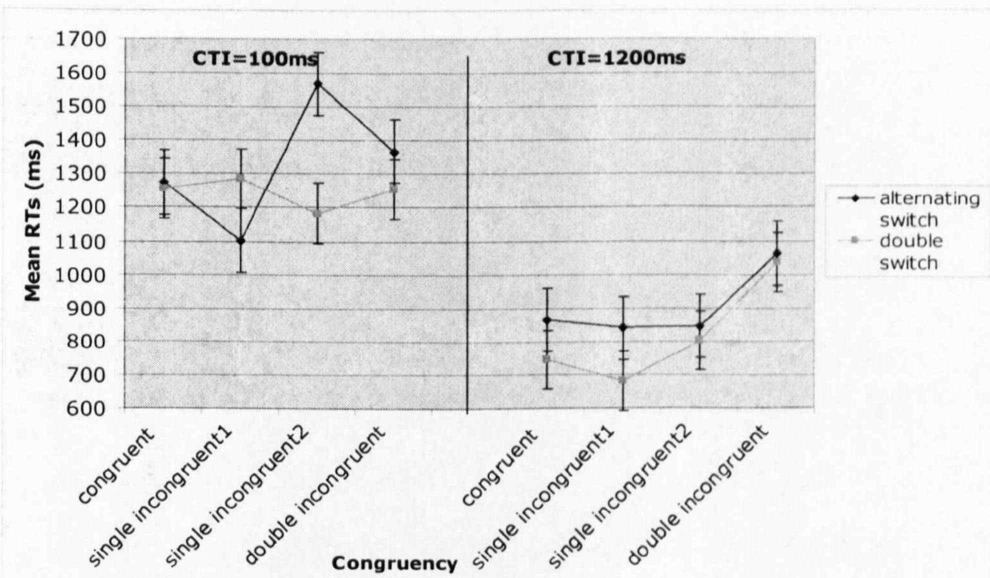
The repeated measures ANOVA with the factors CTI, switch type, task, and congruency revealed a significant 2-way interaction between task and congruency, **[F (3, 50) = 6.1, p =.002]** and between CTI and task, **[F (2, 31)= 4.9, p=.02]**. There was a main effect of all the factors except for the switch type which was marginally significant, **[F (1, 18)= 3.8, p=.07]**. (*see the Appendix, page 402 table 2a*). This interaction was explored by conducting three separate 2-way repeated measures ANOVA for each task. Each of these is reported below.

On Error (%)

Analysis of the 4-way repeated measured ANOVA with factors CTI, switch type, task and congruency revealed a non-significant 4-way interaction, [F (4, 75)= .37, p=.82] (*see the Appendix, page 402 table 2b*). There was only a significant 3-way interaction (CTI, switch type, congruency), **[F (2, 42)= 3.4, p=.03].** This marginal 3-way interaction was explored by presenting three separate figures by each task previously presented for the reaction time (RT).

Arrow task

a. RT (ms)



b. Error (%)

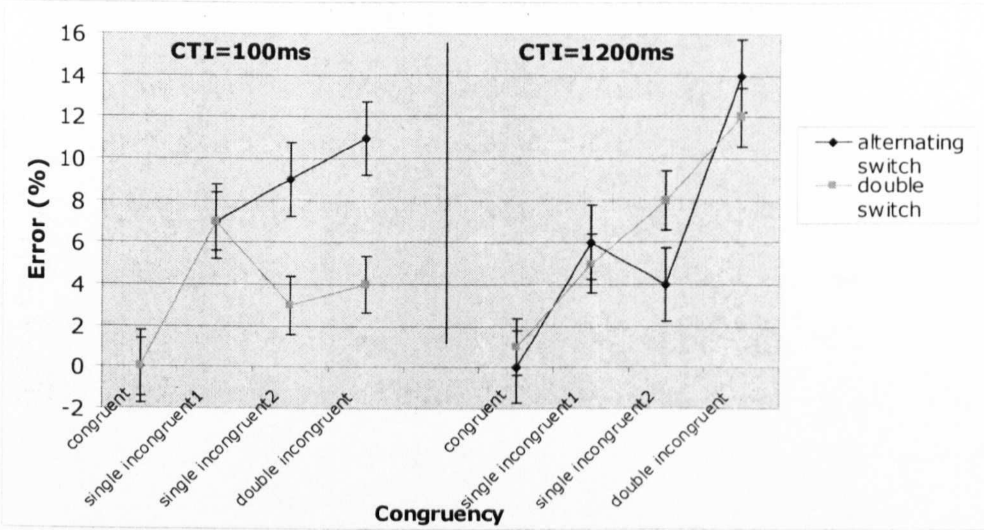


Figure 23. Mean RTs (and standard errors) (figure 23a) and mean error percentage (figure 23 b) in congruency and switch type in two CTI conditions for the location task.

RT (ms)

The effect of alternating switch was non-significant, [F (1, 18) = 2.3, p =.15] *(84ms of alternating switch cost, alternating switch M= 1329 [SE: 74] vs. double switch M= 1245 [SE: 99])* both at the CTI= 100 and at the CTI=1200, [F (1, 18) = 2.7, p=.11] *(87ms of alternating switch cost, alternating switch M= 904 [SE: 90] vs. double switch M= 817 [SE: 53]*) (see Figure 23 a).

2-way interaction between switch type and congruency was only significant at the CTI=100, **[F (3, 48) = 4.9, p=.007]** but not at the CTI=1200, [F (1, 27) = .31, p=.67]. This interaction between switch type and congruency at the CTI=100 was resulted from a significant effect of congruency at the alternating switch trials, **[F (2, 36)= 7.3, p=.002]** *(72ms of congruency effect, congruent M = 1275 [SE: 97], single incongruent 1 M=1103 [SE: 60], single incongruent 2 M= 1559 [SE: 114], double incongruent M= 1368 [SE: 106])* and no significant effect of congruency at the double switch trials, [F (2, 35)= .23, p=.79]. In addition, this interaction was also caused by the huge alternating switch cost *(385ms alternating switch cost, alternating switch M= 1568 [SE: 114] vs. double switch M= 1184 [SE: 157])* only at the single incongruent 2 condition, which was confirmed as significant by a Paired-Samples T-test: **t (18)= 3.4, p=.003**. During the CTI=100, big alternating switch cost (113ms alternating switch cost, M= 1368 [SE: 105] vs. M= 1255 [SE: 78]) also occurred at the double incongruent condition, however, Paired-Samples T-test revealed that it was non-significant: t (18)= 1.5, p=.14.

The effect of congruency was only significant at CTI=1200, **[F (2, 46) = 8.6, p <.001]** *(73ms of congruency effect, M= 806 [SE: 78], M= 761 [SE: 72], M= 825 [SE: 75], M= 1050 [SE: 89])* but not at the CTI=100, [F (2, 31)= 1.5, p=.23].

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (18)= -4.1, p =.001** but not on the double switch trials, t (18)= .57, p=.57.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was marginally significant on the double switch trials, **t (18)= -2.0, p=.06** but not on the alternating switch trials, t (18)= -.09, p = .92.

Error (%)

There was a significant 2-way interaction (switch type and congruency) at the CTI=100, **[F (2, 38)= 5.5, p=.007]** but not at the CTI=1200, [F (2, 36)= 1.6, p=.21]. The interaction in switch type and congruency at the CTI=100 was as a result from a significant difference between alternating switch and double switch trials at the single incongruent 2: **t (18)= -3.2, p=.005** and at the double incongruent: **t (18)=-2.7, p=.015**. A difference in alternating switch and double switch trials was significant at CTI=100, **[F (1, 18) = 9.1, p=.007]** but not at the CTI=1200, [F (1, 18)= .49, p=.49]. The effect of congruency was marginally significant at the CTI=1200, **[F (1, 25)= 3.3, p =.07]** but not at the CTI=100, [F (1, 21)= 1.5, p=.24].

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= .39, p =.70 and on the double switch trials, t (18)= -1.3, p=.20.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= -.39, p =.70 and on the double switch trials, t (18)= .61, p=.55.

Summary

a. A main effect of alternating switch costs for the arrow task did not occur on reaction time but on error only for the short preparation interval. However, there was a huge alternating switch cost (for RT: 385ms) only at the single incongruent condition during the short preparation interval. Although the size of mean reaction time for the alternating switch costs was quite big in both preparation interval *(i.e., 84ms at the CTI=100 and 87ms at the CTI=1200),* the lack of statistical power might cause the non-significant main effect on reaction time.

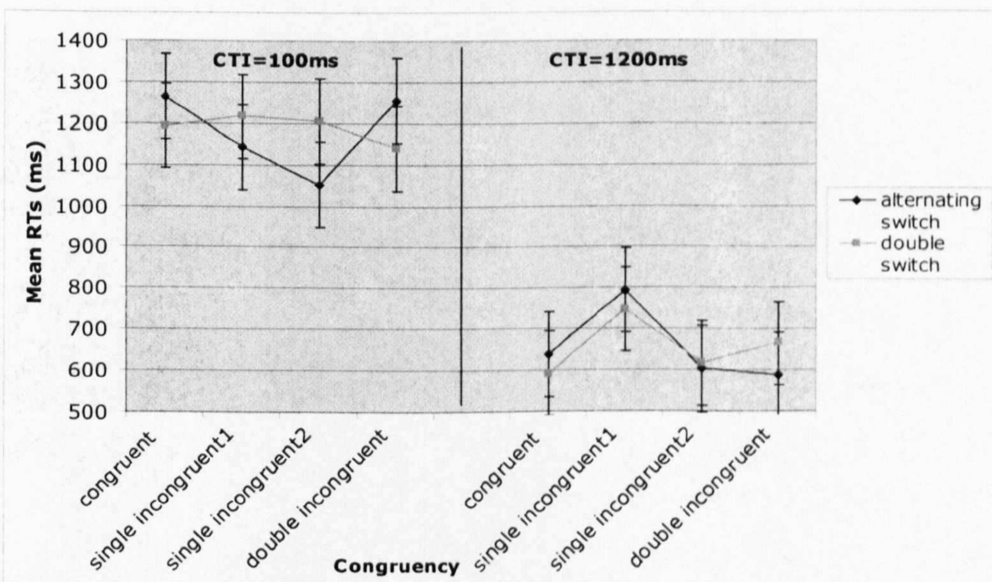
b. A main effect of congruency occurred on reaction time and on error only for the long preparation interval.

c. The interaction between congruency and switch type (alternating switch/double switch trials) occurred on reaction time and on error for the short preparation interval.

d. The effect of previous congruency for the arrow task occurred on reaction time during the alternating switch trials for the short preparation interval and during the double switch trials (marginal) for the long preparation interval. It did not occur on error.

Location task

a. RT (ms)



b. Error (%)

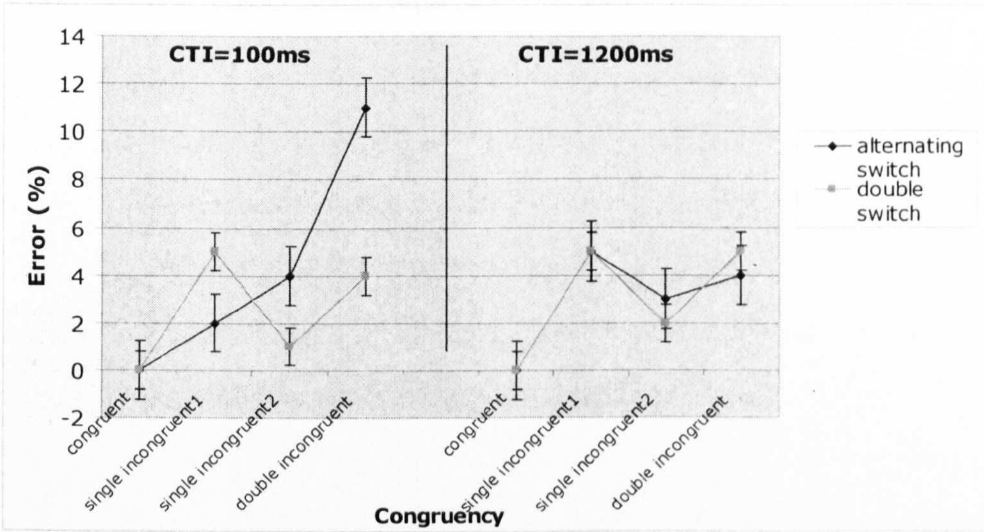


Figure 24. Mean RTs (and standard errors) (figure 24 a) and mean error percentage (figure 24 b) in congruency and switch type in two CTI conditions for the location task.

RT (ms)

The effect of alternating switch was non-significant, [F (1, 18) =.02, p =.89] both at the CTI= 100 and at the CTI=1200, **[F (1, 20) =.00, p=.99]** (see Figure 24 a).

2-way interaction between switch type and congruency was non- significant at the CTI=100, [F (1, 25) = .87, p=.40] and at the CTI=1200, [F (2, 35) =.55, p=.58].

The effect of congruency was only significant at CTI=1200, **[F (2, 44) = 5.4, p =.005]** *(55ms of congruency effect, M= 614 [SE: 61], M= 771 [SE: 58], M= 609 [SE: 42], M= 627 [SE: 45])* but not at the CTI=100, [F (1, 27)=.58, p=.52].

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= 1.6, p =.12 and on the double switch trials, t (18)= .22, p=.82.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (18)= 3.1, p = .006** but not on the double switch trials, t (18)= 1.7, p=.09.

Error (%)

A difference in alternating switch and double switch trials was non-significant at CTI=100, [F (1, 18) = 39, p=.54] and at the CTI=1200, [F (1, 18)=.04, p=.84]. The effect of congruency was significant at the CTI=100 **[F (2, 31)= 6.3, p =.007]** and at the CTI=1200, **[F (2, 38)= 4.5, p=.02]**.

There was a non-significant 2-way interaction (switch type and congruency) at the CTI=100, [F (2, 41)= 1, p=.38] and at the CTI=1200, [F (2, 38)= .35, p=.72].

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the double switch trials, **t (18)= -2.5, p=.02** but not on the alternating switch trials, t (18)= -.87, p =.39.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= -1.4, p =.17 and on the double switch trials, t (18)= -1.8, p=.09.

Summary

a. A main effect of alternating switch costs for the location task did not occur on the reaction time and on the error.

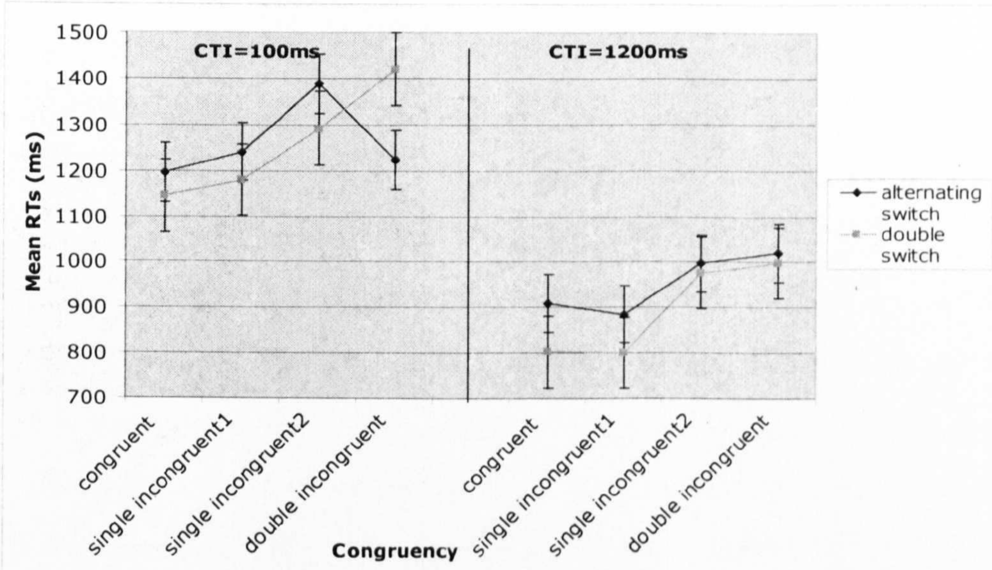
b. A main effect of congruency was observed on reaction time for the long preparation interval and on error in both short and long preparation interval, showing that congruency affected both alternating switch and double switching trials.

c. The interaction between congruency and switch type (alternating switch/double switch trials) did not occur on the reaction time and on error.

d. The effect of previous congruency for the location task occurred on reaction time during the alternating switch trials for the short preparation interval. There was also significant previous congruency on error during the double switch trials for the short preparation interval but it was reversed.

Word task

a. RT (ms)



b. Error (%)

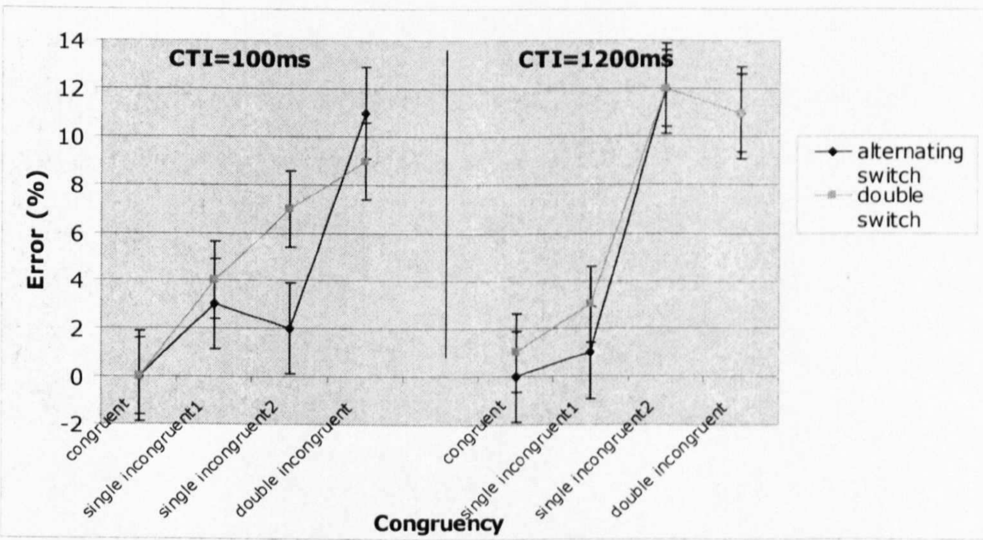


Figure 25. Mean RTs (and standard errors) (figure 25 a) and mean error percentage (figure 25 b) in congruency and switch type in two CTI conditions for the word task.

RT (ms)

A significant 2-way interaction between switch type and congruency was non-significant at CTI=100, [F (1, 25)= 1.7, p=.20] and at CTI=1200, [F (2, 39) = .24, p=.82].

The effect of alternating task was non-significant both at the CTI= 100, [F (1, 18)= .01, p =.92] *(4ms of alternating switch cost, alternating switch M = 1263 [SE: 85] vs. double switch M= 1259 [SE: 92])* and at the CTI=1200, [F (1, 18) = 1.3, p =.26] *(58ms of alternating switch cost, alternating switch M = 1953 [SE: 63] vs. double switch M = 895 [SE: 42])* *(see Figure 25 a)*.

The effect of congruency was significant at CTI=100, **[F (2, 36) = 5.6, p =.007]** *(120ms of congruency effect, congruent M= 1170 [SE: 79], single incongruent 1 M= 1210 [SE: 88], single incongruent 2 M= 1340 [SE: 88], double incongruent M= 1322 [SE: 110])* and at CTI=1200, **[F (2, 43) = 5, p =.007]** *(91ms of congruency effect, M= 855 [SE: 69], M= 842 [SE: 44], M= 987 [SE: 66], M= 1009 [SE: 49])*.

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (18)= -2.9, p =.01** but not on the double switch trials, t (18)= -1.5, p=.15.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the double switch trials, **t (18)= -2.6, p=.02** but not on the alternating switch trials, t (18)= -1.2, p = .22.

Error (%)

There was a non-significant 2-way interaction (switch type and congruency) at the CTI=100; [F (2, 38)=.56, p=.58] and at the CTI=1200, [F (2, 41)= .26, p=.80].

A difference in alternating switch and double switch trials was non-significant at CTI=100, [F (1, 18) = .32, p=.58] and at the CTI=1200, [F (1, 18)= .39, p=.54]. The effect of congruency was significant at the CTI=1200 **[F (1, 23)= 4.7, p =.03]** but not at the CTI=100, [F (1, 20)= 1.7, p=.20].

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= 1.1, p =.29 and on the double switch trials, t (18)= .44, p=.66.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (18)= 2.3, p =.03** and it was marginally significant on the double switch trials, **t (18)= 1.9, p=.07**.

Summary

a. A main effect of alternating switch costs for the word task did not occur on the reaction time and on the error.

b. A main effect of congruency was observed on reaction time for both short and long preparation interval and on error for the long preparation interval, showing that congruency affected both alternating switch and double switching trials.

c. The interaction between congruency and switch type (alternating switch/double switch trials) did not occur on the reaction time and on error.

d. The effect of previous congruency for the word task occurred on reaction time during the alternating switch trials for the short preparation interval and during the double switch trials for long preparation interval. It was also occurred on error during the alternating and double switch trials for the long preparation interval.

3)Effect of cues (exp 3 vs. exp 4)

On Reaction Time (ms)

• For switch and repeat trials

There was an interaction between group (exp 3 vs. exp 4) in CTI, trial type and task and congruency, **[F (4, 163)= 2.5, p =.04]** , group effect in CTI, trial type and task, **[F (2, 66)= 6.4, p=.004], group effect in trial type, [F (1, 38)= 7.5, p=.009]** *(see the Appendix, page 388 table 4).*

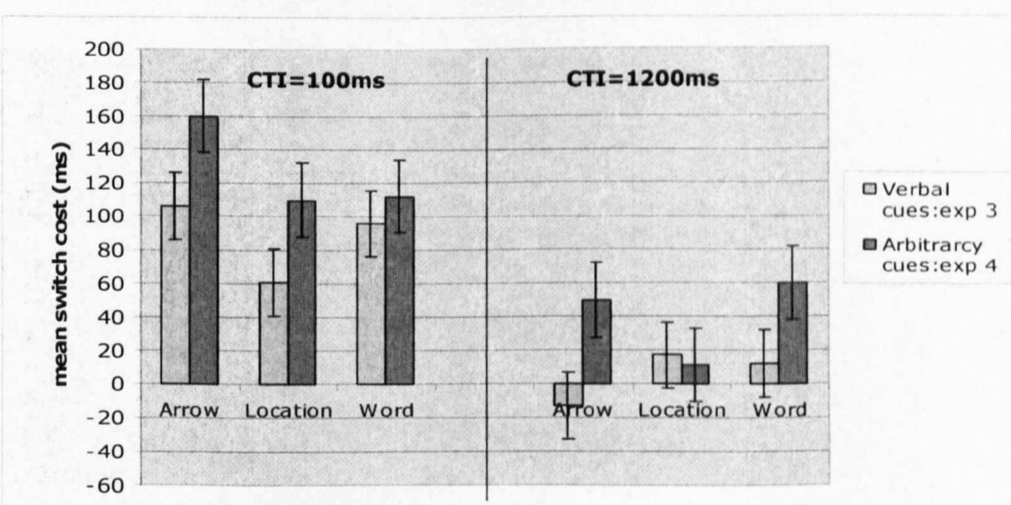


Figure 26. Mean switch cost (and standard error) in three tasks with two preparation intervals between experiment 3 (verbal cue) and experiment 4 (arbitrary cue)

As can be seen in Figure 26, the current experiment with arbitrary cues demonstrated significantly bigger switch costs in all three tasks for both preparation intervals, causing the group interaction in trial type, **[F (1, 38)= 7.5, p=.009]**. In other words, the current experiment showed significantly bigger switch costs *(101ms switch cost, switch M= 975 [SE: 47] vs. repeat M= 878 [SE: 40])* than the experiment 3 with verbal cue *(48ms switch cost, M= 831 [SE: 45] vs. M= 783 [SE: 38])*. The group effect in CTI, trial type and task resulted from the lack of switch cost difference in the location task during the long CTI=1200 and the reversed switch cost in the arrow task during the long CTI=1200 for the experiment 3. On the other hands, the other two tasks showed the significant switch cost difference between two experiments.

Overall, the mean RT in the current experiment *(M= 929 [SE: 44])* was much slower (122ms of RT increase) than experiment 3 with verbal cues *(M= 807 [SE: 41])* resulted in a main effect of group, **[F (1, 38)= 4.1, p=.05]**.

- **For alternating and double switch trials**

There was no main effect of group, [F (1, 40)]= .08, p= .77] and there was only group difference in CTI, **[F (1, 40)= 5.5, p=.02]**, indicating that participants had more benefit of having long preparation interval *(302ms of mean RT reduction, CTI=100 M= 1023 [SE: 43] vs. CTI=1200 M= 721 [SE: 41])* in the experiment 1 than in the current experiment *(232ms of mean RT* *reduction, CTI=100 M= 971 [SE: 43] vs. M= 739 [SE: 41]) (see the Appendix, page 388 table 4).*

On Error (%)

• For switch and repeat trials

There was a group effect in CTI, trial type and congruency, **[F (2, 89)= 3.7, p=.02]**. The main effect of group was non-significant, [F (1, 39)= .87, p=.36].

• For alternating and double switch trials

There was no main effect of group, [F (1, 39)= .64, p=.43] and no any other group effect in this analysis.

DISCUSSION

The main aim of this experiment was to examine the arbitrary cue effect for all three tasks and see if the arbitrary cues change the size of switch cost and alternating switch cost. In order to see the cue type effect between verbal cues and arbitrary cues, the result from the current experiment was compared with the result from the experiment 3.

1) Effect of task switching

- ***Switch costs*** for the CTI=100 ms condition in all three tasks were dramatically reduced in terms of reaction time, suggesting that participants used long preparation interval for advanced configuration process based on the hypothesis that preparation effect indicates the time required to establish a task set. Arrow and word task showed the main effect of switch cost during the both preparation intervals for the reaction time whereas the location showed the main effect of switch cost only during the short preparation interval. For the error, arrow task showed the main effect of switch cost only in the short preparation interval but the word task showed the main effect of switch cost only in the long preparation interval. On the other hand, the location task showed no main effect of switch cost for the error. It remains unclear why three tasks showed the different task switching effect.

- ***Congruency effect on the current trials*** shows how active the other task sets are. More precisely, it is shown that persisting activation of the irrelevant task set really affected the switching performance, depending on whether it activates a response that is the same (congruent) as or different (incongruent) from the response activated by the new upcoming task set (current task set). In other word, task switching performance was not only depended on the currently relevant task-set, but was also influenced by the set of temporary irrelevant task. In all three tasks, they demonstrated the significant congruency effect in reaction time, suggesting that participants made slower response when it was incongruent regardless of the preparation interval. Tentatively, it is regarded that congruency effect indexes the degree to switch the competing task set when it is not suppressed. One might expect that long preparation interval will be effective for reducing congruency effect as much as for the switch costs. However, the results from the previous experiments so far showed the occurrence of congruency effect in both preparation intervals, suggesting that proactive control of interference is an optional extra process, perhaps requiring the recruitment of an additional inhibitory mechanism (Monsell & Mizon, 2006).

• ***The interaction between congruency and trial type (switch/repeat)*** shows whether switch trials are more influenced by the repeat trials. If so, the bigger congruency effect on the switch trials suggests that switching different tasks are influenced by the level of activation from the other task sets on the current trials. The arrow task showed the significant congruency effect (211ms) during the repeat trials and reversed congruency effect (-101ms) during the switch trials at the CTI= 100, causing the significant interaction. Having congruency effects during the repeat trials in the arrow task suggests that the persistent activation of the irrelevant task set indeed interfered with the current task set because there was no need to suppress the irrelevant task set during the repeat trials, causing the other task set to be persistently activated. Interestingly, the reversed congruency effect in the arrow task shows that switching to the arrow task when it was congruent, the RT was slower than switching to the arrow task when it was incongruent, suggesting that participants might have suppressed strongly the irrelevant task sets which were location and word task sets for the incongruent trials whereas they might have not suppressed the irrelevant task sets or their effort to suppress the irrelevant task sets might be small because it was congruent trials during switching tasks. As a result, there was a reversed congruency effect in the arrow task during the switching trials at the CTI=100. On the other hand, location task did not show any interaction between trial type and congruency for reaction time and error and the word task showed the marginal interaction at the CTI=100, caused by the significant congruency effect (48ms) during the switch trials. Note that word task showed the congruency effect during the switch trials not the repeat trials. In summary, there were different impacts on the switch and repeat trials depending on the task and it suggests that task behaves differently on the congruency effect.

- ***Previous congruency*** shows that the task set from the previous trials persisted in a state of residual activation and that previous task set interfered with a subsequent task switch, depending on whether it activates a response that is the same as or different from the response by the new task set on the current trials. In the current experiment, single incongruent 1 and single incongruent 2 were compared because when the current task is incongruent to the previous trials (single incongruent 2), the RT and/or error is slower/larger than when the current task is congruent to the previous trials (single incongruent 1).

All three tasks demonstrated a significant previous congruency effect on reaction time and error. However, location task showed the reversed previous congruency effect on reaction time and error, which means that single incongruent 2 (the current location task is incongruent to the previous task) was less difficult than single incongruent 1 (the current location task is congruent to the previous task). This indicates that task set from the previous trials persisted in a state of residual activation and that previous task set facilitated with the current location task. On the other hand, word task showed the significant previous congruency effect during the switch trials for the short preparation interval and it also occurred during the repeat and switch trials for the long preparation interval on reaction time. It also showed the previous congruency effect in the repeat trials for the short and long preparation interval on error. This strong impact on the word task was previously found in the exp 1 and 3, suggesting that task set from the previous trials persisted in a state of residual activation and that previous task set interfered with the current word task, especially when the previous task set was incongruent to the current word task. At this stage, the only speculation is that the visually-displayed word information for the word task causing the conflict with other task set information. Thus, when the word task is on the current trials, it would be harder to suppress the irrelevant task set information from the other task set when the previous N-1 trials was incongruent to the current word task.

2) Effect of alternating task

- ***Alternating switch costs*** was not observed on reaction time and error in the location and word task, suggesting that participants might not use the backward inhibition or they used another type of inhibition mechanism such as dimensional inhibition (Goschke, 2002) in order to overcome the conflict irrelevant stimulus dimension (e.g., word in the word task). Although the main effect of alternating switch costs was non-significant in all three tasks on reaction time and error, it is interesting to note that arrow task demonstrated the huge alternating switch cost (385ms) during the short preparation interval at the single incongruent 2 condition. Previously, the arrow task showed the huge alternating switch costs in the experiment 1 (310ms) and experiment 3 (136ms) during the CTI=100 when it was only single incongruent 2 condition. Additionally, arrow task also showed the significant alternating switch costs on error: it only occurred at the CTI=100 when the current trials were single incongruent and double incongruent.

It is unclear why the arrow task was sensitive to the single incongruent 2 condition for the short preparation interval, causing the backward inhibition. Presumably, BI was present only when there was sufficient interference from the previous trials (single incongruent 2, double incongruent) and it was necessary to reduce the interference from the previous task set if the current task is the arrow task. However, it is uncertain why the location and word task did not show any alternating switch cost in the experiment.

- ***Congruency effect on the current trials*** shows how active the other task sets remain. In all three tasks, the congruency impacted on the alternating switch and double switch trials and different preparation intervals. However, word task demonstrated a bigger congruency effect (120ms, 90ms: CTI=100, CTI=1200 respectively) compared to the other tasks (73ms for the arrow task, 55ms for the location task) in terms of reaction time, suggesting that word task sets are more influenced by the current level of activation from the other two task sets.
- ***The interaction between congruency and switch type (alternating switch/double switch)*** demonstrates if backward inhibition is interacting with the interference of the irrelevant task sets, depending on the strength of the activation from the irrelevant task sets. For example, arrow task showed the significant congruency effect on the alternating switch trials (72ms congruency effect) not on the double switch trials (-14ms congruency effect) only for the short preparation interval. In addition, the arrow task demonstrated a huge alternating switch cost (385ms alternating switch cost) when it was single incongruent 2 condition during the short preparation interval, resulting in the significant interaction between congruency and switch type at the CTI=100. However, the location and word task did not show any significant interaction between switch type and congruency or any

significant main effect of alternating switch cost, suggesting that these two tasks might use another type of inhibitory control mechanism which is not measured by alternating switch cost.

- ***Previous congruency*** significantly affected the alternating switch trials in the short preparation interval for the arrow task (only RT). The word task was also affected by the previous congruency during the alternating switch trials in the short preparation interval and double switch trials in the long preparation interval on reaction time. Word task also showed the previous congruency effect in the alternating switch trials for the long preparation interval on error. This previous congruency effect in the word task was previously observed in the effect of task switching analysis, indicating that word information is indeed the most conflicting information with the other task features and participants had struggled to suppress the irrelevant task sets when their response was incongruent to the response of the word task on the current trials.

  On the other hand, location task only showed the previous congruency effect for the alternating switch trials in the long preparation interval on reaction time, whereas it showed the reversed previous congruency effect for the double switch trials in the short preparation interval on error. It is assumed that the persistent activation from the previous task sets on N-1 trials showed the different impact on each tasks.

3) Effect of cues

The switch cost in the current experiment was significantly bigger than the experiment 3 with verbal cue, supporting the hypothesis that strength of the cue-target association was important factor for task switching. In other words, the weak cue by using the arbitrary cues required the extra task set reconfiguration process to learn and interpret the meaning of the cues, causing the high working memory load for switching tasks. One could argue that participants might use the inner speech to remind themselves of which task they had to perform. This inner speech is associated with the phonological loop system from the work memory model proposed by Baddeley (1986) and Baddeley & Logie (1999), which is considered to be a peripheral, independent component (or 'slave' system) of working memory. According to this traditional working memory model, this phonological loop specializes for the short term storage and processing of verbal-phonological information, including maintenance rehearsal. In particular, one of its subcomponents, called the articulatory control (or articulatory rehearsal) process, is assumed to underlie the generation of inner speech or internal subvocalisaion (Baddeley & Logie, 1992). Although this phonological loop is not directly related to the executive control processes according to the model, it is likely to assume that inner speech during the preparation interval helped participants to interpret the meaning of arbitrary cues and perform the task correctly. Goshke (2000) actually showed that switch cost was substantially smaller among participants who said the task name than among those who verbalized an irrelevant word. His finding suggests that the opportunity to verbally remind oneself which task to perform next may indeed be an effective strategy to prepare for the forthcoming switch. Although the inner speech which might be self-cuing device that helps participants keep track of which task is to be performed on the upcoming trials (Baddeley et al,, 2001; Emerson & Miyake, 2003), the current result suggests that the effort for retrieving and activating the task goal for the forthcoming task set would cause the increased switch costs compared to the exp 3 with verbal cues. In other words, participants had no need to use the inner speech to remind themselves when the verbally-instructed cues were presented for all three tasks.

The lack of alternating switch costs in both experiments except the arrow task when it was single incongruent 2 condition at the CTI=100 suggests that strength of cue-task association is not crucial factor to cause the backward inhibition, however, it still remains unclear why the cue changes did not influence on the occurrence of backward inhibition.

Lastly, the congruency effect occurred in both experiments (e.g., 61ms in the exp 3, 44ms in the current exp), suggesting that the persistent activation of the irrelevant tasks sets interfered with the level of activation of the current task set regardless of the cue changes as well as the preparation intervals. These results strongly support the idea that congruency effect occurs on the representation of the target-response mapping because there was no pre-instructed information for the congruency and the persistent activation among three tasks had to win the competition to overcome the interference which are dominant on the target information.

CONCLUSION

The present experiment in this chapter demonstrated that a substantial amount of switch costs and strong congruency effects throughout all three tasks whereas alternating switch costs only occurred in the arrow task when it was single incongruent 2 condition during the short preparation interval.

Incongruent trials were slower and more error prone than congruent trials regardless of the trial type (repeat, switch, alternating switch or double switch trials). The previous congruency effect indicates that the task set from the previous trials persisted in a state of residual activation especially when the task set is competing with the other two tasks and that previous task set interfered with a current task set. In the current experiment, word task only demonstrated the significant effect of previous congruency, suggesting that word task set is more prone to be influenced by previous incongruent trials. On the other hand, the location task showed the facilitation from the previous incongruent trials.

Group comparison between verbal cues and arbitrary cues demonstrated larger switch costs for the arbitrary cues compared to the verbal cues, suggesting that participants might use the inner speech for self-cuing device and extra effort for task-set reconfiguration in order to understand the meaning of the arbitrary cues and prepare for the forthcoming task. There was no group difference in alternating switch costs and congruency effect between two experiments.

Chapter 7

Experiment 5: The role of the target features on switch cost and backward inhibition

INTRODUCTION

Previous evidence (Hübner et al, 2003; Mayr & Kliegl, 2003; Arbuthnott, 2008) has indicated that sequential inhibition - a lateral inhibition during the sequential selection of low-level perceptual and motor code- occurs after the target stimulus has appeared, rather than during the preparation interval suggesting that it may be the target, rather than the cue, that is relevant to produce backward inhibition. Furthermore, switching cues even without switching tasks increases switch cost (Logan & Bundesen, 2003) but does not influence backward inhibition (Gade & Koch, 2008; Mayr & Kliegl, 2003). Giving these findings, distinct targets may influence backward inhibition more than do distinct cues.

Since Arbuthnott (2005) argued that the different cue type influenced the effect of switch cost as well as backward inhibition, cue manipulation for the backward inhibition in the previous experiments was the main purpose. However, the results so far demonstrated that different cue type is more influential to switch costs than alternating switch costs. In addition, each task showed the different size of alternating switch costs, yet it was not clear if the backward inhibition depended on the type of task, rather than the cue. In order to find the reason why the tasks behaved differently in the previous experiments, there was an assumption that three tasks have different response selection processing, especially for the word task. For instance, the response selection for the word task is based on reading the word 'up/down' inside the arrow, whereas for the arrow and location the response selection is not based on verbal information inside the arrow but the shape or location of the stimulus. Thus, the shape or location of the 'arrow' stimulus on the screen might struggle to compete with the verbal features in the stimulus in terms of response selection. Furthermore, there is a perceptual filtering process to perform the arrow task. For example, the correct response for the arrow task has to made by looking at the point of the arrow where the word information can be interfering. This fundamental difference would apply for the task-specific effect considering the size of backward inhibition. In contrast, there is no need for perceptual processing during the word task but only need for the reading the word which might lead this linguistic process to overpower the perceptual process for the arrow and location task.

In summary, the characteristics of the work task must be based on the linguistic information and the other two tasks are based on the perceptual information of the target features. In this respect, two different information would get confounded as three tasks are singularly embedded in one stimulus. Consequently, these different task set information and response selection processes might influence the task set reconfiguration processing when participants were about to make a correct response for which task they performed. This idea is much similar to the dual-code theory[1] (Paivio, 1986; Clark & Paivio, 1991) that both visual and verbal information are processed differently by using distinct channels and creating separate

[1] For example, verbal codes are stored as linear sequences of words and visual codes as pictures.

representations for information processed in each channel; 1) a non-verbal representation to handle objects and events, and 2) a verbal imagery system to perceive and generate language. According to the dual-code theory, dual coding increases the likelihood of recall because of dual retrieval routes-on for each code. At this point, one would simply question whether the role of the target features, such as verbal features and visual features is another important factor to influence the task switching performance and cause the different sizes in switch cost and backward inhibition.

In order to answer this question, the current experiment aimed to distinguish two types of different information on target deliberately while having the same task set for three tasks and see whether this manipulation of the target would change the size of the switch costs and alternating switch costs in all three tasks. According to the previous experiments, there was task-specific effect on switch cost, previous congruency effect and alternating switch cost. For example, word task showed the robust previous congruency effect whereas it was the arrow task that demonstrated only backward inhibition when it was single incongruent 2 condition at the CTI=100. Based on the hypothesis that the different task set information has different level of activation and thus different impact on the switch cost, previous congruency, alternating switch cost, it was reasonable to argue that different task set information on the target is an important factor to influence the task switching performance.

By teasing apart the word 'up/down' information inside the target and putting this 'up/down' outside of the arrowhead containing the features relevant to the other tasks, it was now possible to see whether the effect of separate information between linguistic and visual (perceptual) on the target would change the size of switch costs and alternating switch costs. However, the location and arrow task still share the single visual information and the degree of the perceptual and visual processing in those two is not quite separable. Thus, it is uncertain whether the location and the arrow task would show any difference from the previous experiments in terms of switch cost, previous congruency and the alternating switch cost.

METHODS

Participants

Twenty participants (11 women) were recruited from the University of Nottingham through the advert and seven of them were undergraduates and the rest of them were postgraduate in the psychology department. The participants ranged age from 18 and 31 years (M= 24.4, SD=7), reported normal and corrected-to-normal vision and were all right-handed except two participants. They received £4 as an inconvenience allowance after completion of the experiment. The study took approximately 50 min to complete including the instruction and practice session.

Stimulus and Design

The task, stimuli and study procedures were identical to the previous experiment 3 (ref. chapter 5) except that the word information inside the arrow target was removed and shown to the right side of the target stimuli. The task cues were all verbal cues as in Experiment 3 (chapter 5).

The reason for the verbal cues in this experiment was to give the direct information for the task in order to minimise the time for the cue processing and maximise it for the target processing. Figure 27 shows the example of the tasks in the current experiment.

Figure 27. An example of the time course of task presentation in Experiment 5.
* The procedure for the CTI and RCI is the same as the previous Exps.

RESULTS

1) Effect of task switching

Four research questions for the effect of task switching were raised. They are as follows.

a. *Is there any switch cost?*

b. *Is there a main effect of congruency?*

c. *Does congruency interact with switch/repeat trials (trial type)?*

d. *Is there any previous congruency effect?*

On Reaction Time (RT)

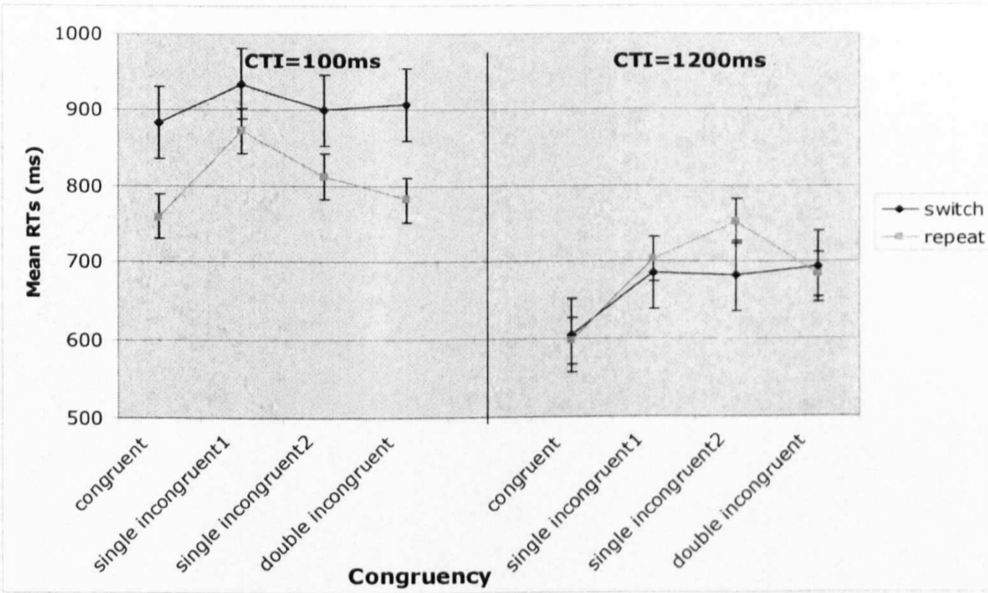
Analysis of the 4-way repeated measured ANOVA with factors CTI (100, 1200), trial type (switch, repeat), task (arrows, location, word), and congruency (congruent, single incongruent 1, single incongruent 2, double incongruent) revealed a significant 4-way interaction (trial type, task and congruency), **[F (4, 83) =2.8, p =.03]** (*see the Appendix, page 403 table 1a*). This interaction was explored by conducting three separate 3-way (factors CTI, trial type, and congruency) repeated measures ANOVAs for each task. These are reported below.

On Error (%)

Analysis of the 4-way repeated measured ANOVA with factors CTI (100, 1200), trial type (switch, repeat), task (arrow, location, word), and congruency (congruent, single incongruent 1, single incongruent 2, double incongruent) revealed a non-significant 4-way interaction: [F (4, 77)= .59, p= .68] (*see the Appendix, page 403 table 1b*) and a significant 3-way interaction (CTI, task and congruency): **[F (3, 48)= 3.6, p=.02]**.

Arrow task

a. RT (ms)



b. Error (%)

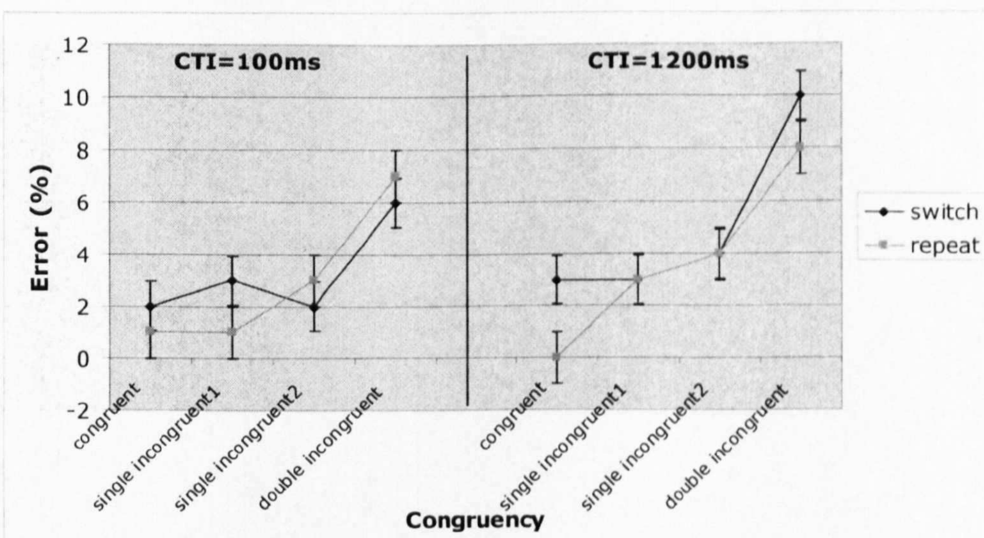


Figure 28. Mean RTs (and standard errors) (figure 28 a) and percent error scores (figure 28 b) in congruency and trial type in two CTI conditions for the arrow task.

RT (ms)

A significant difference between switch and repeat trials was found at CTI =100, **[F (1, 18) = 33, p <.001]** *(99ms switch cost, switch M = 906 [SE: 46] vs. repeat M= 807 [SE: 43])* but not at CTI=1200, [F (1, 18) =.55, p =.47] (See figure 28 a).

In both CTI conditions, the effect of congruency was marginally significant at the CTI=100, **[F (2, 43) = 2.5, p =.08]** *(46ms of congruency effect, M= 822 [SE: 43] vs. M= 904 [SE: 47] vs. M= 857 [SE: 54] vs. M= 844 [SE: 45]: congruent vs. single incongruent 1 vs. single incongruent 2. vs. double incongruent)* and it was significant at the CTI=1200, **[F (3, 48) =4.4, p =.01]** *(100ms of congruency effect, M= 600 [SE: 47] vs. M= 694 [SE: 64] vs. M= 717 [SE: 70] vs. M= 688 [SE: 51]).*

The interaction in trial type and congruency was non-significant at both CTI=100, [F (2, 42)= .86, p=.45] and CTI=1200, [F (2, 40)= 1.1, p=.33].

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (18)= 1.5, p =.16 and on the switch trials, t (18)= .82, p=.42.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (18)= -8.1, p = .43 and on the switch trials, t (18)= .13, p=.90.

Error (%)

There was a non-significant 2-way interaction (trial type and congruency) in both at CTI=100, [F (2, 38)= 1.1, p=.36] and at the CTI=1200, [F (2, 42)=.79, p=.47].

RT difference between switch and repeat trials in error percentage was non-significant at the CTI=100 [F (1, 18)= .21, p= .65] and at the CTI=1200, [F (1, 18) =1.1, p=.30].

The effect of congruency was significant both at CTI=100, **[F (2, 30)= 6.3, p=.008]** and at the CTI=1200, **[F (3, 49) = 7.2, p=.001]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (18)= .84, p =.41 and on the switch trials, t (18)= -.67, p=.51.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (18)= 2.6, p =.02** but not on the switch trials, t (18)= -.11, p=.91.

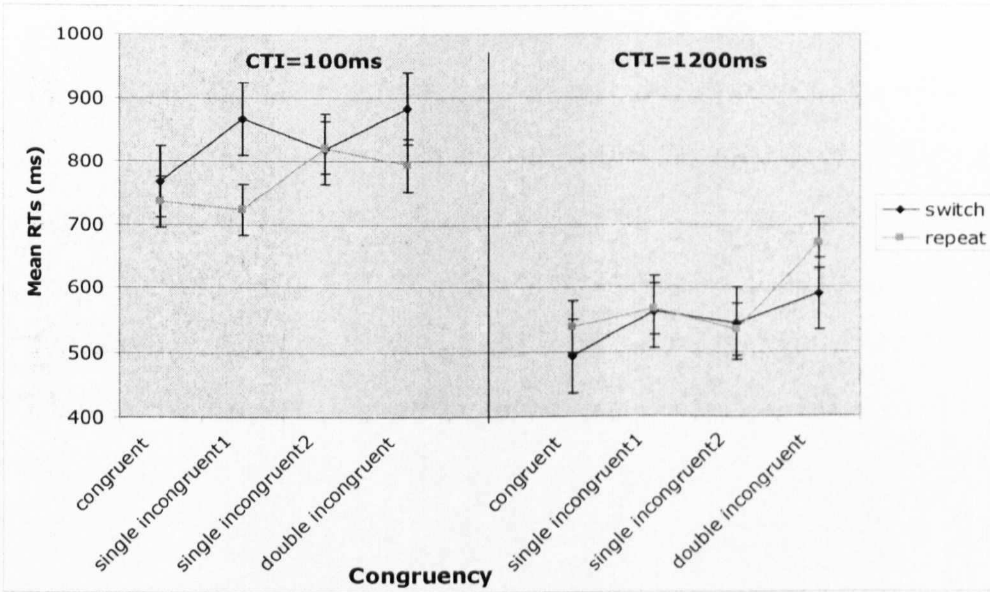
Summary

a. A main effect of switch costs for the arrow task only occurred on reaction time for the short preparation interval and not on error.
b. A main effect of congruency for the arrow task was observed on reaction time and error for both short and long preparation interval.
c. The interaction between congruency and trial type (switch/repeat trials) was non-significant on reaction time and error.

d. The effect of previous congruency for the arrow task only occurred on error during the repeat trials for the long preparation interval.

Location task

a. RT (ms)



b. Error (%)

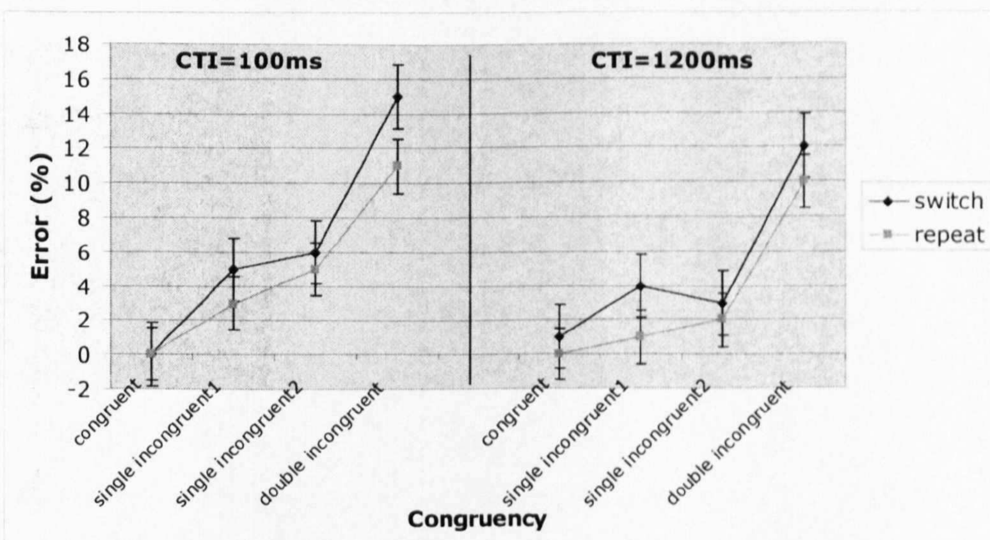


Figure 29. Mean RTs (and standard errors) (figure 29 a) and percent error scores (figure 29 b) in congruency and trial type in two CTI conditions for the location task.

RT (ms)

A significant difference between switch and repeat trials was found at the CTI= 100, **[F (1, 18)= 10, p =.004]** *(62ms switch cost, switch M = 834 [SE: 33], repeat M= 769 [SE: 35])* but not at the CTI=1200, [F (1, 18) = 1.8, p =.19] (see *Figure 29 a*).

A 2-way interaction between trial type and congruency was significant at the CTI=100, **[F (2, 44) = 3.8, p =. 02]** but not at the CTI=1200, [F (2, 44) = 1.9, p =.15]. This interaction was caused by the significant congruency effect on the switch trials, **[F (3, 48)= 6.7, p=.001]** *(111ms of congruency effect, congruent M= 767 [SE: 35], single incongruent 1 M= 866 [SE: 35], single incongruent 2 M= 819 [SE: 35], double incongruent M= 883 [SE: 43])* and the marginal congruency effect on the repeat trials, **[F (3, 50)= 2.4, p=.08]** *(43ms of congruency effect, M= 736 [SE: 41], M= 724 [SE: 39], M= 821 [SE: 55], M= 793 [SE: 38])*.
The effect of congruency was significant at the CTI=100, **[F (2, 40) = 3.6, p=.03]** *(76ms of congruency effect, M= 752 [SE: 35], M= 795 [SE: 32], M= 820 [SE: 42], M= 838 [SE: 37])* and at CTI=1200, **[F (3, 47) =7.0, p=.001]** *(63 ms congruency effect, M= 515 [SE: 36], M= 564 [SE: 40], M= 538 [SE: 46], M= 631 [SE: 50])*.

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was marginally significant on the repeat trials, **t (18)= -2.0, p =.06** but not on the switch trials, t (18)= 1.7, p=.11.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (18)= 1.2, p = .25 and on the switch trials, t (18)= .76, p=.46.

Error (%)

There was a non-significant 2-way interaction (trial type and congruency) in both at CTI=100, [F (2, 41)= .57, p=.59] and CTI=1200, [F (1, 25)=.19, p=.75].

RT difference between switch and repeat trials in error percentage was non-significant at the CTI=100 [F (1, 18)= 2.3, p= .14] and at the CTI=1200, [F (1, 18) =1.4, p=.26].

The effect of congruency was significant both at CTI=100, **[F (1, 27) 10, p=.001]** and at the CTI=1200, **[F (1, 24) = 15, p<.001]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (18)= 1, p =.33 and on the switch trials, t (18)= .81, p=.43.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the switch trials, **t (18)= 2.0, p=.05** but not on the repeat trials, t (18)= 1.4, p =.16.

Summary

a. A main effect of switch costs for the location task only occurred on reaction time for the long preparation interval but not on error.

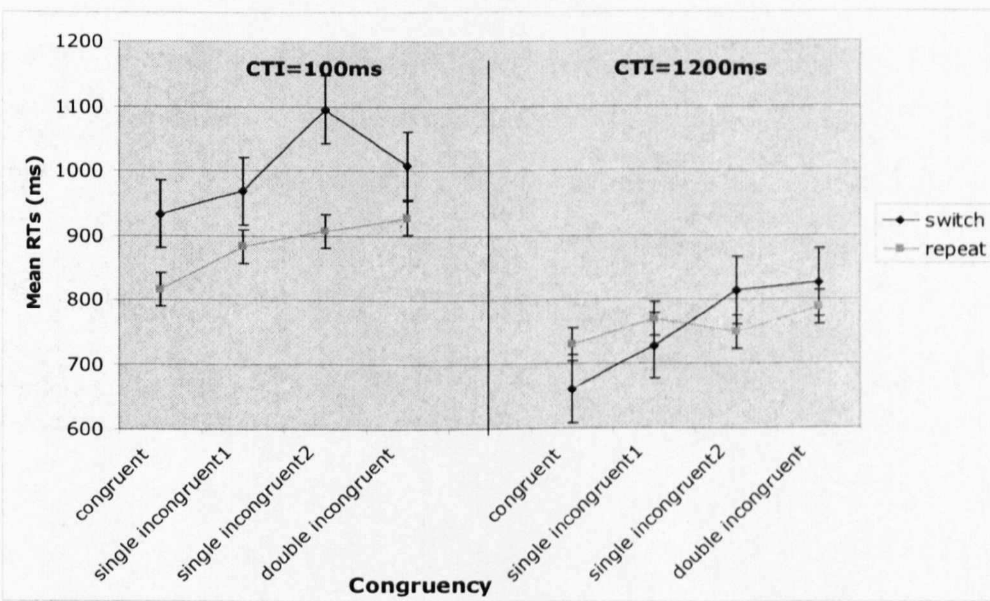
b. A main effect of congruency for the location task was observed on reaction time and error for both short and long preparation interval.

c. The interaction between congruency and trial type (switch/repeat trials) was only significant on reaction time during the short preparation interval but not on error. This interaction was caused by the significant congruency effect on the switch trials and marginal effect on the repeat trials.

d. The effect of previous congruency for the location task only occurred on error during the switch trials for the long preparation interval.

Word task

a. RT (ms)



b. Error (%)

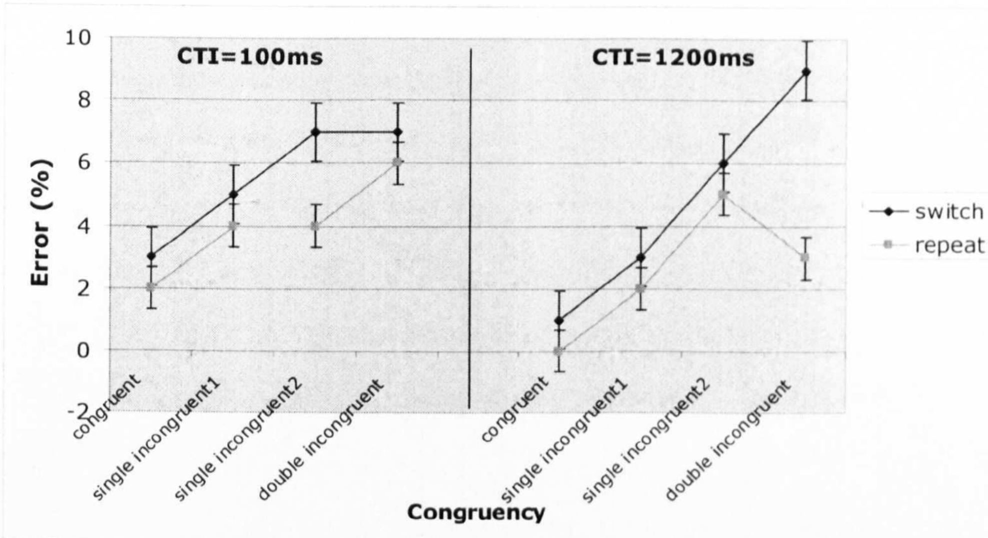


Figure 30. Mean RTs (and standard errors) (figure 30 a) and percent error scores (figure 30 b) in congruency and trial type in two CTI conditions for the word task.

RT (ms)

A significant difference between switch and repeat trials was found at the CTI= 100, **[F (1, 18)= 10, p =.004]** *(117ms switch cost, switch M = 1001 [SE: 46] vs. repeat M= 884 [SE: 38])* and it was non-significant at the CTI=1200, [F (1, 18) = 1.4, p =.24] (see Figure 30 a).

There was a marginally significant 3-way interaction (CTI, trial type and congruency) for the arrow task, **[F (2, 42)= 2.8, p=.06]** which resulted from two effects which impacted CTI=100 but not CTI=1200. Both of these effects can be clearly seen in Figure 30 and were confirmed an analysis of the simple effects (the factors trial type and congruency were examined at each CTI separately).

A 2-way interaction in trial type and congruency was significant both at the CTI=100, **[F (2, 46) = 3.9 p =.02]** and CTI=1200, **[F (2, 44) = 3.1, p =.05]**. The interaction in trial type and congruency at the CTI=100 was as a result from a big switch cost *(187ms, switch M= 1095 [SE: 54], repeat M= 907 [SE: 48])* at the single incongruent 2 condition which was confirmed by Paired- Samples T-test: **t (19) = -6.7, p <.001**.

The interaction in trial type and congruency at the CTI=1200 was as a result from a significant effect of congruency on the switch trials, **[F (2, 34)= 10, p<.001]** *(62ms congruency effect, M= 661 [SE: 32], M= 728 [SE: 50], M= 814 [SE: 59], M= 826 [SE: 52])* but a non-significant effect of congruency on the repeat trials, [F (1, 26)= 1.5, p=.23].

In both CTI conditions, the effect of congruency was significant at the CTI=100, **[F (2, 33)= 9.3, p=.001]** *(72ms of congruency effect, congruent M= 875 [SE:40], single incongruent 1M= 926 [SE: 43], single incongruent 2 M= 1001[SE: 49], double incongruent M= 968 [SE:43])* and CTI= 1200, **[F(1, 24)= 4.2, p =.04]** *(64ms of congruency effect, M= 696 [SE:43], M= 699 [SE: 45], M= 782 [SE: 48] , M= 807 [SE: 55]).*

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the switch trials, **t (18)= -3.3, p=.004** but not on the repeat trials, t (18)= -.57, p =.58.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (18)= -2.6, p = .02** and on the switch trials, **t (18)= -3.3, p=.004**.

Error (%)

There was a non-significant 2-way interaction (trial type and congruency) in both at CTI=100, [F (2, 42)= .45, p=.67] and CTI=1200, [F (2, 33)= 2.1, p=.14].

A significant difference between switch and repeat trials in error percentage was found at the CTI=100 **[F (1, 18)=7.6, p=.013]** and at the CTI=1200, **[F (1, 18) =6.7, p=.02]**.

The effect of congruency was non-significant at CTI=100, [F (2, 33)= 2.5, p=.10] and it was significant at CTI=1200, **[F (2, 31) = 6.6, p=.006]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (18)= .19, p =.85 and on the switch trials, t (18)= 1.1, p=.28.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the switch trials, **t (18)= 3.8, p=.001** but not on the repeat trials, t (18)= 1.4, p =.19.

Summary

a. A main effect of switch costs for the word task only occurred on reaction time for the short preparation interval and for the both preparation interval on error.
b. A main effect of congruency for the word task was observed on reaction time for both preparation interval and on error for the short preparation interval.

c. The interaction between congruency and trial type (switch/repeat trials) was only observed on reaction time for both preparation interval. The interaction was caused by the big switch cost (187ms) at the single incongruent 2 condition during the short preparation. It was also caused by the significant congruency effect on the switch trials and non-significant effect on the repeat trials during the long preparation interval.

d. The effect of previous congruency for the word task occurred on reaction time during the switch trials for the short preparation interval and during the switch and repeat trials for the long preparation interval. It only occurred on error during the switch trials for the long preparation interval.

2) Effect of alternating task

Four research questions for the effect of alternating tasks were as follows.

a. *Is there any main effect of alternating switch cost?*
b. *Is there a main effect of congruency?*
c. *Does congruency interact with alternating switch/double switch trials (switch type)?*
d. *Is there any previous congruency effect?*

On Reaction Time (ms)

The repeated measures ANOVA with the factors CTI, switch type, task, and congruency revealed a non-significant 4-way interaction, [F (3, 61) =1.1, p =.34] (*see the Appendix, page 404 table 2a*). There was a significant 2-way interactions in task and congruency, **[F (3, 58)= 3.3, p=.04]** and a marginally significant 2-way interaction in CTI and task, **[F (2, 34)= 2.8,**

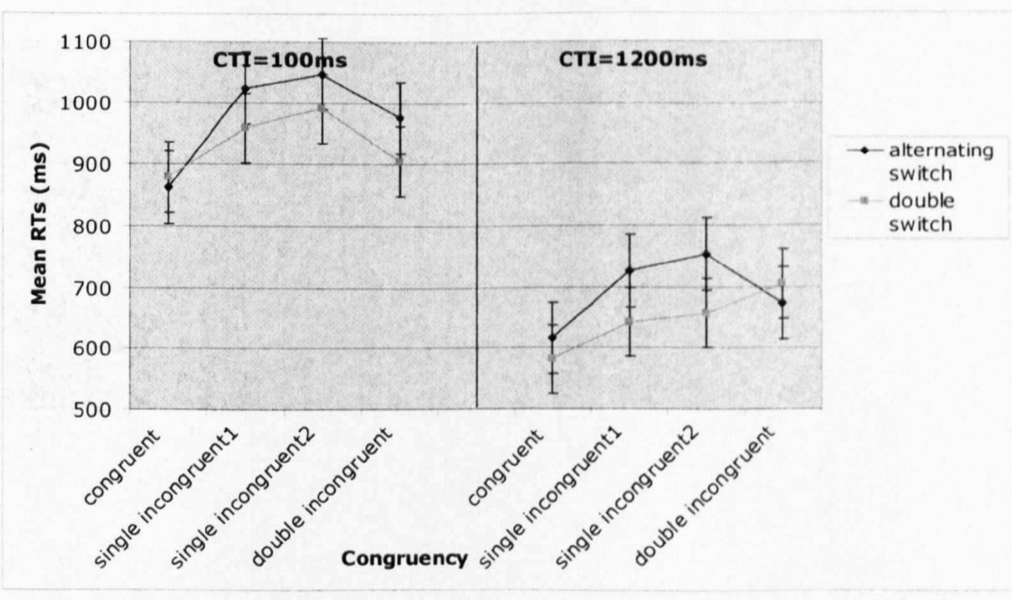
p=.07]. The effect of alternating task for each task was presented separately in order to compare with the previous results. Each of these is reported below.

On Errors (%)

Analysis of the 4-way repeated measured ANOVA with factors CTI (100, 1200), switch type (alternating switch, double switch), task (arrow, location, word), and congruency (congruent, single incongruent 1, single incongruent 2, double incongruent) revealed a non-significant 4-way interaction: [F (4, 69)= .74, p= .56] (*see the Appendix, page 404 table 2b*) but a marginally significant 3-way interaction (CTI, switch type and task): **[F (2, 34)= 2.8, p=.08]**.

Arrow task

a. RT (ms)



b. Error (%)

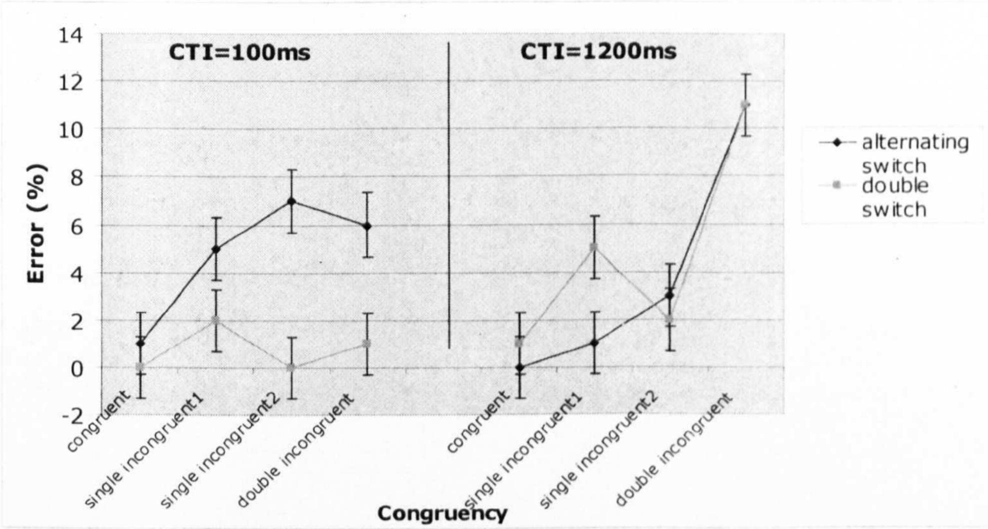


Figure 31. Mean RTs (and standard errors) (figure 31 a) and percent error scores (figure 32 b) in congruency and switch type in two CTI conditions for the arrow task.

RT (ms)

The effect of alternating switch was non-significant, [F (1, 19) =2.6, p =.12] *(34ms of alternating switch cost, alternating switch M= 970 [SE: 55] vs. double switch M= 936 [SE: 53])* both at the CTI= 100 and at the CTI=1200, [F (1, 19) = 1.7, p=.21] *(26ms of alternating switch cost, alternating switch M= 690[SE: 60] vs. double switch M= 654 [SE: 41]*) (see Figure 7).

A 2-way interaction between switch type and congruency was non-significant at the CTI=100, [F (2, 37) = .51, p=.60] and at CTI=1200, [F (1, 27) = .88, p=.38]. The effect of congruency was significant at the CTI=100 **[F (2, 46)= 4.4, p =.01]** *(110ms of congruency effect, M= 871 [SE: 48], M= 990 [SE: 64], M= 1012 [SE: 72], M= 940 [SE: 48])* and at the CTI=1200, **[F (2, 41)= 3.3, p=.04]** *(94ms of congruency effect, M= 602 [SE: 35], M= 692 [SE: 68], M= 706 [SE: 64], M= 689 [SE: 42]).*

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (19)= -.13, p =.90 and on the double switch trials, t (19)= -.50, p=.62.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (19)= -.60, p = .55 and on the double switch trials, t (19)= .-.08, p=.93.

Error (%)

There was a non-significant 2-way interaction (switch type and congruency) both at CTI=100, [F (2, 44)= 1.7, p=.18] and CTI=1200, [F (1, 27)=.77, p=.44].

A difference between alternating switch and double switch trials in error percentage was significant at the CTI=100 **[F (1, 18)= 6.4, p= . 02]** but not at the CTI=1200, [F (1, 18) =2.8, p=.11].

The effect of congruency was non-significant at CTI=100, [F (2, 40)= 1.7, p=.19] but it was significant at CTI=1200, **[F (2, 30) = 9, p=.001]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= .39, p =.70 and on the double switch trials, t (18)= -1.77, p=.11.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= .90, p =.38 and on the double switch trials, t (18)= -1.1, p=.30.

Summary

a. A main effect of alternating switch costs for the arrow task was non-significant for reaction time. However, it was observed on error for the short preparation interval.

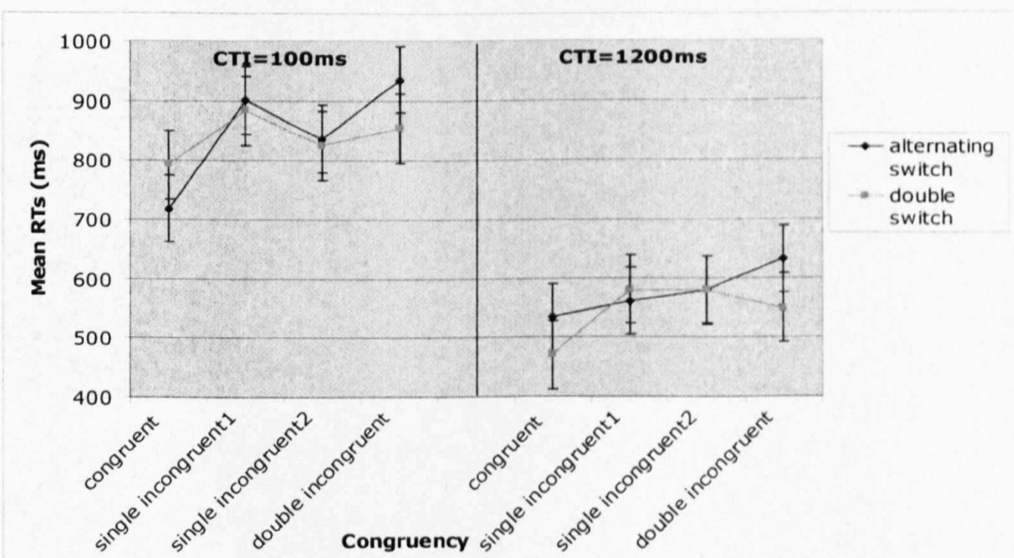
b. A main effect of congruency was observed on reaction time for both short and long preparation interval and on error for the long preparation interval, showing that congruency affected both alternating switch and double switching trials.

c. The interaction between congruency and switch type (alternating switch/double switch trials) on reaction time and error was non-significant.

d. The effect of previous congruency for the arrow task on reaction time and error was non-significant.

Location task

a. RT (ms)



b. Error (%)

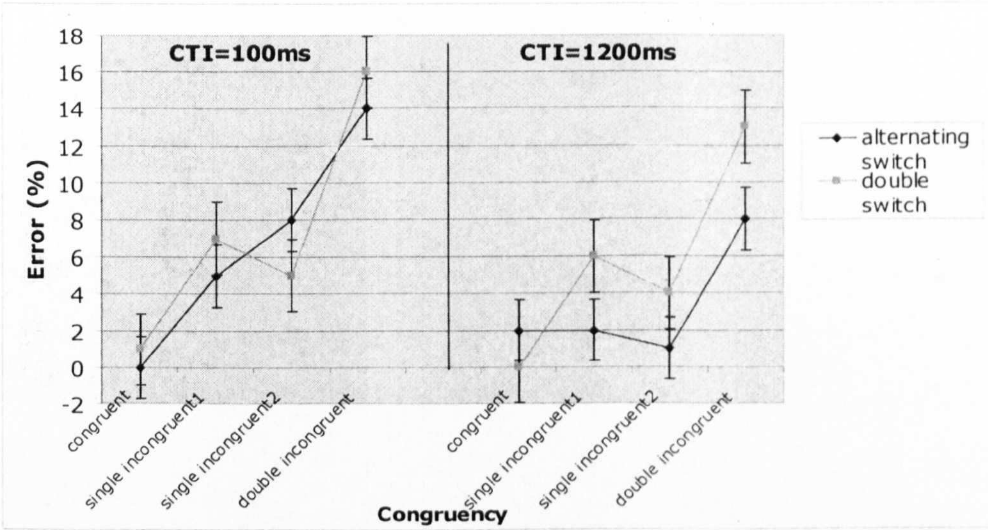


Figure 32. Mean RTs (and standard errors) (figure 32 a) and percent error scores (figure 32 b) in congruency and switch type in two CTI conditions for the location task.

RT (ms)

The effect of alternating tasks at the CTI= 100 was non-significant, **[F (1, 19) = .58, p =.46]** *(8ms alternating switch cost, alternating minus double switch, alternating switch M = 841 [SE: 35] vs. double switch M= 833 [SE: 33]).* It was also non-significant at CTI =1200, **[F (1, 19) =2, p=.17]**. *(32ms alternating switch cost, M = 570 [SE: 39] vs. M = 538 [SE: 40])* (see *Figure 32 a*).

There was a marginally significant 2-way interaction between switch type and congruency at CTI=100, **[F (2, 46)= 2.5, p=.08]** not at CTI=1200, [F (2, 43) = 1.2, p=.30]. The marginal interaction between switch type and congruency at the CTI=100 resulted from a significant effect of congruency on the alternating switch trials, **[F (3, 47)= 7.9, p <.001]** *(172ms congruency effect, M= 719 [SE: 43], M= 902 [SE: 46], M= 836 [SE: 41], M= 936 [SE: 54])* compared to the marginal effect of congruency effect on the double switch trials, **[F (3, 54)= 2.5, p=.06]** *(58ms congruency effect, M= 794 [SE: 41], M= 884 [SE: 39], M= 825 [SE: 40], M= 846 [SE: 38]).*

The effect of congruency was only significant at CTI=100, **[F (3, 51) = 9.4, p <.001]** *(114ms of congruency effect, congruent M= 752 [SE: 36], single incongruent 1 M= 884 [SE: 37], single incongruent 2 M= 826 [SE: 37], double incongruent M= 887 [SE: 42])* not at CTI=1200, [F (2, 44 = 1.8, p=.16].

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= 1.5, p =.14 and on the double switch trials, t (18)= 1.7, p=.11.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= .22, p = .83 and on the double switch trials, t (18)= .22, p=.83.

Error (%)

There was a non-significant 2-way interaction (switch type and congruency) in both at CTI=100, [F (2, 36)= 1, p= .34] and CTI=1200, [F (2, 38)=1.7, p= .19].

A difference between alternating switch and double switch trials in error percentage was non-significant at the CTI=100 [F (1, 18)= .52, p= . 48] and it was significant at CTI=1200, **[F (1, 18) =5.5, p=.03]**.

The effect of congruency was significant at CTI=100, **[F (2, 37)= 12, p<.001]** and at CTI=1200, **[F (1, 24) = 6.2, p=.013]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, $t(18) = 1.6$, $p = .13$ and on the double switch trials, $t(18) = -.85$, $p = .41$.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, $t(18) = -.09$, $p = .93$ and on the double switch trials, $t(18) = -.97$, $p = .34$.

Summary

a. A main effect of alternating switch costs for the location task on reaction time and error was non-significant.

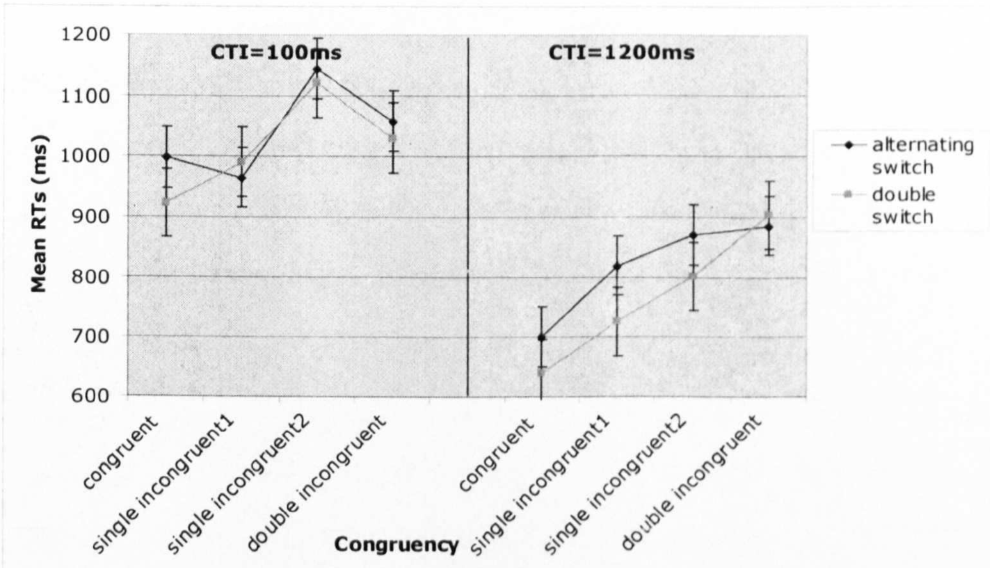
b. A main effect of congruency on reaction time was significant only for the short preparation interval whereas it was significant on error for both short and long preparation interval, showing that congruency affected both alternating switch and double switching trials.

c. The interaction between congruency and switch type (alternating switch/double switch trials) on reaction time was marginally significant for the short preparation interval and this was as a result from the bigger congruency effect on the alternating switch trials compared to the double switch trials. The interaction on error was not observed.

d. The effect of previous congruency for the location task was not observed on either reaction time or error.

Word task

a. RT (ms)



b. Error (%)

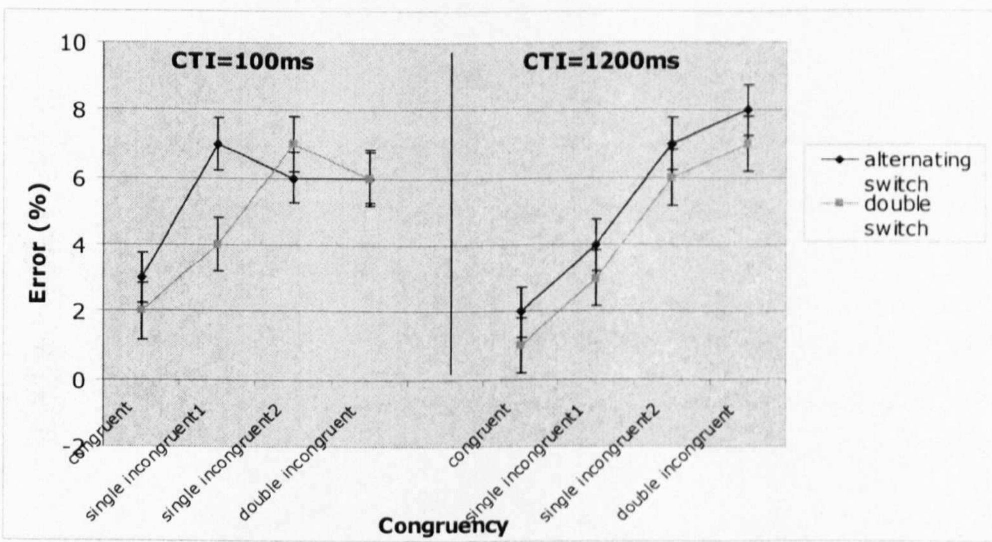


Figure 33. Mean RTs (and standard errors) (figure 33 a) and percent error scores (figure 33 b) in congruency and switch type in two CTI conditions for the word task.

RT (ms)

The effect of alternating task was non-significant at the CTI= 100, [F (1, 19)= 1.4, p =.25] and it was marginally significant at the CTI=1200, **[F (1, 19) = 3.5, p =.07]** *(62ms of alternating switch cost, alternating switch M = 831 [SE: 63] vs. double switch M = 769 [SE: 41])* (see Figure 33 a).

A significant 2-way interaction between switch type and congruency was non-significant at CTI=100, [F (2, 37)= .70, p=.50] and at CTI=1200, [F (2, 47) = .51, p=.64].

The effect of congruency was significant at CTI=100, **[F (2, 37) = 7.4, p =.002]** *(87ms congruency effect, congruent M= 968 [SE: 50], single incongruent 1 M= 985 [SE: 55], single incongruent 2 M= 11130 [SE: 74], double incongruent M= 1049 [SE: 47])* and at CTI=1200, **[F (2, 41) = 13, p <.001]** *(158 ms congruency effect, M= 682 [SE: 34], M= 778 [SE: 64], M= 844 [SE: 59], M= 897 [SE: 60]).*

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (19)= -2.8, p =.01** and on the double switch trials, **t (19)= -2.3, p=.03**.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the double switch trials, **t (19)= .-2.3, p=.04** but not on the alternating switch trials, t (19)= -1.1, p = .27.

Error (%)

There was a non-significant 2-way interaction (switch type and congruency) in both at CTI=100, [F (2, 45)= .39, p=.72] and CTI=1200, [F (3, 48)=.02, p=.99].

A difference between alternating switch and double switch trials in error percentage was non-significant at the CTI=100 [F (1, 18)= 1.1, p= . 30] and at CTI=1200, [F (1, 18) =.20, p=.66].

The effect of congruency was only significant at CTI=1200, **[F (2, 42) = 4.7, p=.01]** but not at CTI=100, [F (2, 41)= 2.0, p=.14].

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= -.22, p =.83 and on the double switch trials, t (18)= .99, p=.33.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= 1.2, p =.24 and on the double switch trials, t (18)= 1.2, p=.26.

Summary

a. A main effect of alternating switch costs for the word task was only marginal on reaction time during the long preparation interval occurred and it did not occur on error.
b. A main effect of congruency on reaction time was significant for both preparation interval and on error only for the long preparation interval.

c. The interaction between congruency and switch type (alternating switch/double switch trials) was non-significant on reaction time and error.

d. The effect of previous congruency for the word task was significant during both alternating and double switch trials for the short preparation interval and during the double switch trials for the long preparation interval. It was non-significant on error.

2) Effect of two different target information (exp 3 vs. exp5)

On Reaction Time (RT)

- **For switch and repeat trials**

There was an interaction between group (exp 3 vs. exp 5) and trial type, **[F (1, 38)= 5.9, p =.02]** which was caused by the significantly bigger switch cost in the experiment 3 *(48ms switch cost, switch M= 831 [SE: 34] vs. repeat M= 783 [SE: 36])* than the current experiment *(24ms switch cost, switch M= 738 [SE: 30] vs. repeat M= 714 [SE: 30])*. There was an interaction between group (exp 3 vs. exp 5) in task, **[F (2, 71)= 4.1, p=.02]** (see the *Figure 34*). As can be seen in figure 34, the significant group interaction in task was as a result from the significant RT difference in location task (p <.001) and arrow task (p <.001) but not in the word task. In other words, arrow and location task in the current experiment were much faster than those of the experiment 3, suggesting that the separate information between visual/perceptual code and verbal code was beneficial for the target processing. On the other hand, it also suggests that the linguistic information for the target was not influenced by the separate display for the word task.

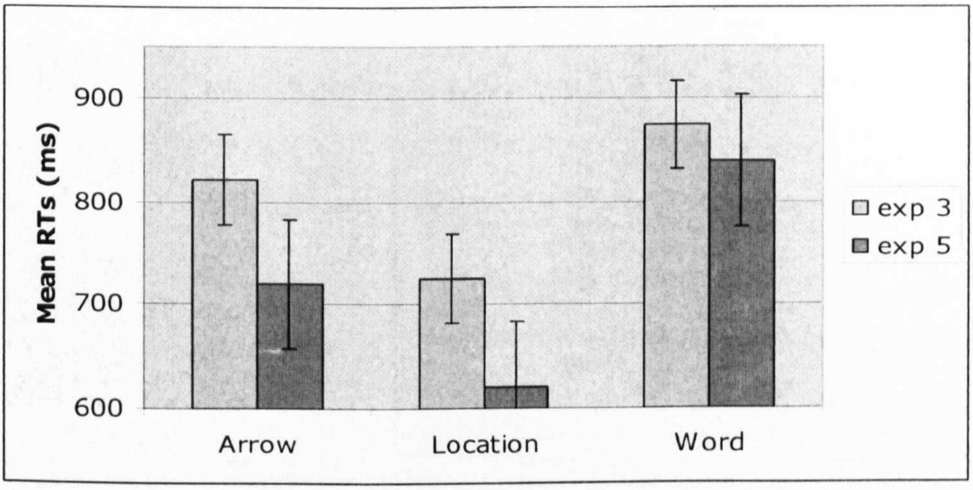


Figure 34. Mean reaction time (and standard error) in three tasks between experiment 3 and 5

Overall the mean RT in the current experiment was significantly faster *(M= 726 [SE: 30)* than experiment 3 with verbal cues *(M= 807 [SE: 30])* resulted in a marginal main effect of group, **[F (1, 38)= 3.8, p=.06]** *(see the Appendix, page 389 table 5).*

• For alternating and double switch trials

There was an interaction between group (exp 3 vs. exp5) in CTI, switch type, task and congruency, **[F (4, 164)]= 2.5, p= .04]** which was caused by a significant 4-way interaction in CTI, switch type, task and congruency for the exp3, **[F (4, 92)= 3.5, p=.007]** and a non-significant 4-way interaction for the current experiment, [F (3, 61)= 1.1, p=.34]. There was an interaction between group in task and congruency, **[F (4, 155)= 3.0, p=.02]** and a marginal interaction between group in CTI and task, **[F (2, 71)= 3.0, p=.06]**.

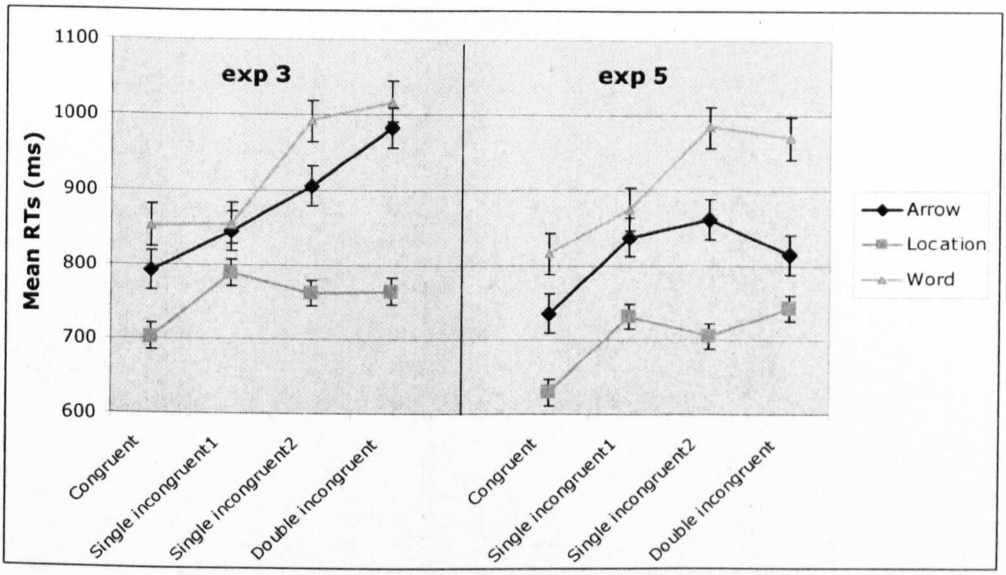


Figure 35. Mean reaction time (and standard error) for congruency and task between exp 3 and exp 5

The group interaction in congruency and task was caused by the mean RT at the double incongruent condition between two experiments (see the *Figure 35*) although the size of congruency effect in all three tasks are not significantly different between two experiments (arrow: location: word = 118ms: 70ms: 101ms for the exp 3 and arrow: location: word= 103ms: 98ms: 127ms for the exp 5).

The marginal interaction between group in CTI and task was caused by the word task between two experiments because the word in the current experiment showed the largest benefit from the long preparation interval *(235ms mean RT decrease, CTI=100 M= 1029 [SE: 46] vs. CTI=1200 M=794 [SE: 47])* compared to the word task in the exp 3 *(154ms mean RT decrease, CTI=100 M= 1006 [SE: 44] vs. CTI=1200 M= 852 [SE: 45]).* On the other hand, the arrow *(285ms RT decrease, CTI=100, M=1024 [SE: 38] vs. M= 1200, M=739 [SE: 42] in the exp 3: 286ms RT decrease, CTI= 100,* *M=956 [SE: 31], CTI=1200 M= 670 [SE: 36] in the exp 5)* and location task *(255ms RT decrease, CTI=100 M= 882 [SE: 43] vs. CTI= 1200 M= 627 [SE: 47] in the exp 3: CTI= 100 M= 844 [SE: 52] vs. CTI=1200 M= 561 [SE: 36] in the exp 5)* in both experiments showed the similar size of RT decrease from the long preparation interval.

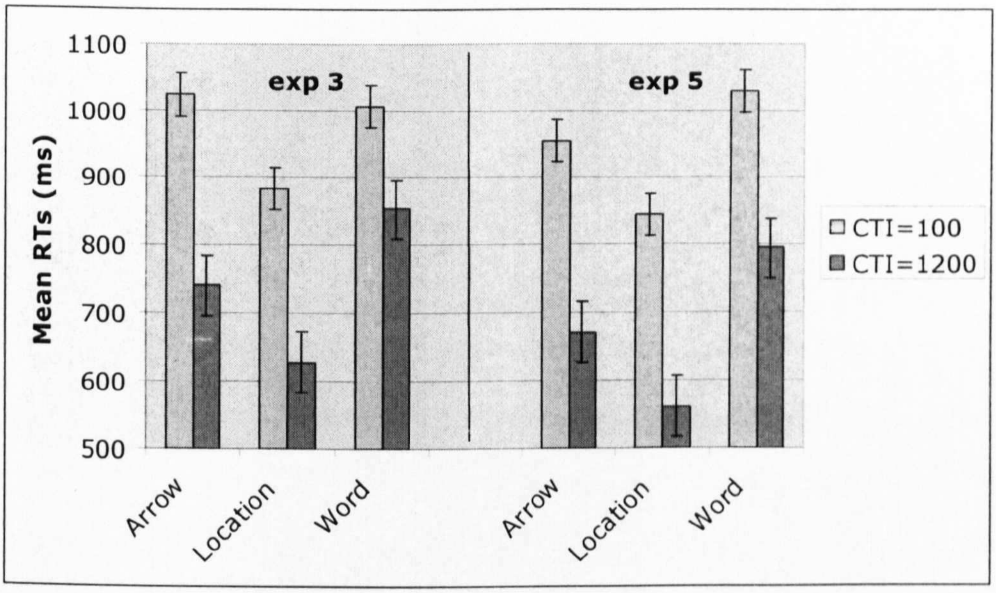


Figure 36. Mean reaction time (and standard error) in task and CTI between experiment 3 and 5

The current experiment revealed the faster mean reaction time (M=809 [SE: 41] than experiment 3 (M=855 [SE: 39]) but the main effect of group was non-significant, [F (1, 38)= .67, p=.47] *(see the Appendix, page 389, table 5).*

On Error (%)

• For switch and repeat trials

There was an interaction between group in trial type and congruency, **[F (3, 108)= 4, p=.01]** and in CTI and congruency, **[F (2, 95)= 20, p <.001]**. The main effect of group was non-significant, **[F (1, 37) = .32, p=.57].**

• **For alternating and double switch trials**

There was an marginal interaction between group in CTI, congruency, **[F (2, 84)= 2.7, p=.07]**. The main effect of group was non-significant, [F (1, 37)= .53, p=.47].

DISCUSSION

The main aim of this experiment was to understand if the feature of the target would be another important factor to influence the size of switch cost and alternating switch cost. In order to disentangle the combined information in the target (word information and perceptual information), the word 'Up'/'Down' inside the arrow stimulus was removed and positioned next to the target. The present results have shown that the overall size of switch cost and congruency effect was reduced but the manipulation of target features did not influence the occurrence of the alternating switch cost.

1) Effect of task switching

- ***Switch costs*** for reaction time in all three tasks were dramatically reduced during the long preparation interval, thus all three tasks showed the main effect of switch cost for the short preparation interval, suggesting that participants used long preparation interval for advanced reconfiguration. Switch costs for error was non-significant in the arrow and location task but it was significant in the word task during the both preparation intervals, indicating that target features between visual/perceptual code and verbal code might have separate processing and visually separate display for the target features might help to reconfigure the upcoming task sets. Note that the size of mean RT switch costs in the arrow and location tasks from the current experiment (arrow task: 99ms, location task: 62ms) were similar the experiment 3 (arrow task: 107ms, location task: 62ms) but the difference was that the arrow task in the current experiment did not show any error switch costs compared to the experiment 3, suggesting that arrow task had benefit from this manipulation.

- ***Congruency effect on the current trials*** shows how active the other task sets remain. More precisely, it is shown that the current level of activation are still interfered from the other tasks even when participants are given a long time to prepare to switch the task and even repeat the same task. The effect was depending on whether it activates a response that is the same (congruent) as or different (incongruent) from the response activated by the new upcoming task set (current task set). In other word, task switching performance was not only depended on the currently relevant task-set, but was also influenced by the set of temporary irrelevant task. In all three tasks, they demonstrated big congruency effect in reaction time and error, suggesting that participants made slower response and more errors when it was incongruent regardless of the preparation interval. It was interesting to note that congruency effect in task switching was not influenced by the manipulation of the target in the current experiment. One could assume that separate display of target information might reduce the interference from the temporary irrelevant task sets, which are still in an activated state. However, the current results suggest that the source of the congruency effect might be from the abstract task set rules, which could be restored in the Long-Term Memory, rather than from the visually presented target information that is changing constantly while switching tasks. These issues will be further discussed in the chapter 9.

- ***The interaction between congruency and trial type (switch/repeat)*** shows whether switch trials are more influenced by the repeat trials. If so, the bigger congruency effect on the switch trials suggests that switching different tasks are influenced by the level of activation from the other task sets on the current trials.

Arrow task did not show any interaction between congruency and trial type whereas the location and word task showed the interaction between congruency and trial type. Interestingly, the interaction in the word task was as a result from the big switch cost (187ms) at the single incongruent 2 condition during the short preparation interval. Word task also showed the interaction during the long preparation interval which was caused by the significant congruency effect on the switch trials not on the repeat trials. Location task also showed the interaction only during the short preparation interval which was caused by the significant congruency effect on the switch trials and marginal effect on the repeat trials. It is noteworthy that most of previous experiments demonstrated the significant congruency effect on the repeat trials. However, the current experiment showed the lack of congruency effect on the repeat trials in all three tasks, indicating that the manipulation of the target might weaken the current level of activation from the irrelevant task sets which still remains. Lastly, it is suggested that the lack of interaction between congruency and trial type in the arrow task might be due to the manipulation of the target. In other words, the arrow shape without any other task set information might help participants to resolve the competition with other task sets. However, this suggestion is contradictory to the follow results on the previous congruency, thus it is not certain why arrow task did not show any interaction in the present experiment.

- ***Previous congruency*** shows that the task set from the previous N-1 trials remains in a state of residual activation. In other words, the persisting activation of previous task set interfered with a subsequent task switch, depending on whether it activates a response that is the same as or different from the response by the new task set on the current trials. Arrow task did not show any previous congruency effect on reaction time but there was a previous congruency effect on error for the repeat trials during the short preparation interval. One could argue that separate arrow target might reduce the interference from the irrelevant task sets as the target information is visually separate from the word information for the word task set. However, this is not simply true according to the result from the previous exp 3. In both experiments, cues for all three tasks are verbally presented, thus the difference between two experiments was whether the target information is embedded in one single target (exp 3) or separately displayed (current exp). In both experiments, arrow task showed the same results; previous congruency effect occurred only on error when it was repeat trials during the short preparation interval. Location task also showed the similar results between two experiments. It has more facilitation from the previous trials rather than interference. On the other hand, both experiments showed that word task was significantly influenced by the previous incongruent trials during switch tasks as well as repeating the same task, suggesting that separate word information from the current target manipulation was not beneficial to reduce the interference from the other tasks (arrow and location). The interpretation for the strong previous congruency effect in the exp 3 (chapter 5)- the word information is the most conflicting information among the other task set information- is not valid. Note that the robust previous congruency effect in the word task was also observed in the exp 1 (chapter 3) and exp 4 (chapter 6). Therefore, it is possible to speculate that the competition from the other task sets is high when the current task is the word task, yet the nature of word task does not allow requiring the recruitment of an additional inhibitory mechanism based on the assumption that proactive control of inference is an optional extra process (Monsell & Mizon, 2006).

2) Effect of alternating task

Alternating switch costs were not observed on reaction time in all three tasks[2] and they were observed on error in the arrow task for the short preparation interval. It is noteworthy that arrow task at the single incongruent 2 condition for the short preparation demonstrated a huge RT alternating switch costs from the previous experiments. However, the arrow task in the current experiment did not have any significant RT alternating switch cost at the single incongruent 2 condition and it has to be careful to interpret why backward inhibition in the arrow task disappeared. Note that previous congruency effect in the arrow task in

[2] Word task only showed the marginal effect of RT alternating switch cost for the long preparation interval.

the current experiment was non-significant in any cases. Thus, it might be due to the fact that less interference from the previous trials might result in the lack of backward inhibition in the arrow task. However, if so, if the other tasks showed the significant previous congruency effect, there might be backward inhibition on the current trials. This issue will be discussed in the next paragraph for the previous congruency effect.

- ***Congruency effect on the current trials*** shows how active the other task sets remain. In all three tasks, they demonstrated big congruency effect on reaction time and error in both preparation intervals, suggesting that participants made slower response and more errors when the activation of current task sets are competing with the activation of the irrelevant task sets. Congruency of the current task affected both alternating and double switch trials.

- ***The interaction between congruency and switch type (alternating switch/double switch)*** demonstrates that the interference of the irrelevant task sets could occur the backward inhibition. In other words, it shows if the alternating and double switch trials are influenced by the congruency differently and thus if there is any alternating switch cost. In the experiment 3, there was a significant interaction between switch type and congruency ($p=.01$) during CTI=100 in the arrow task and it was as a result of a huge alternating switch cost (136ms) at the single incongruent 2 condition. Note that single incongruent 2 condition is when the current task is incongruent to the previous trials, suggesting that participants indeed used the backward inhibition to reduce the interference from previous trials for the arrow task. However, in the current experiment, there was no RT alternating switch cost at the single incongruent 2 condition during the short preparation interval but there was only interaction on error during the short preparation interval. For the location task, the current experiment showed the marginal interaction on reaction time which was caused by the bigger congruency effect on the alternating switch trials and this was previous found in the experiment 3. Word task in the current experiment did not show any significant interaction on reaction time and error whereas it showed the interaction in both preparation intervals on reaction time in the experiment 3.

- ***Previous congruency*** shows if the residual activation of the task set from the previous N-1 trials affect the performance of the forthcoming task which is different from N-1 trials. If there is an alternating switch cost when the effect of previous congruency was significant, it is possible to argue that the interference from the previous trials affect the backward inhibition. In the current experiment, arrow task did not show any previous congruency effect on reaction time and error. Word task in the current experiment was significantly influenced by the previous congruency in both experiments, however location task did not show any previous congruency effect in the current task and it showed the reversed congruency effect (facilitation from the previous incongruent trials) in the experiment 3. The consistent effect of previous congruency in the word task indicates that word information processing on the target presentation is not the source of the competition with the other task sets. Instead, the response selection of the word task set might be the source of the competition with that of the other task sets. Allport &

Wylie (2000) suggested that during task switching stimulus-response associations are constantly modified. Thus, when a stimulus is presented, previous response-related information of that stimulus is retrieved. In case of inconsistent information, there is interference that slow down the response selection. When a response selection is made, the relevant response-selection rules are activated and the irrelevant response translation rules are inhibited (Verbruggen et al., 2005). This implies that the rules that were relevant on the previous trials are activated to some degree until the next response selection is done.

3) Effect of separate target information

The main interest of the target manipulation in the current task was to see if the separate display of the task set information on the task would influence the size of switch cost and alternating switch cost. In order to answer this, experiment 3 and the current experiment were compared as they shared the same type of cues (verbal cues). The current experiment demonstrated the significantly reduced switch cost (24ms switch cost) than experiment 3 (48ms switch cost), suggesting that the target manipulation of the current task indeed changed the size of switch cost. Moreover, the overall RT in the arrow and location task was also dramatically reduced (see *the Figure 34, page 247*) whereas the overall RT in the word task between two experiments had no significant difference. It is assumed that the target processing between visual/perceptual and verbal information was separately encoded and the target in the current experiment might help to retrieve the task rule for arrow and location task. Although there was no change in alternating switch costs and congruency effect in both experiments, word task showed the largest benefit from the long preparation interval in the current task compared to the experiment 3 while switching tasks, causing the group effect in CTI and task. This suggests that the word task set from the current experiment required additional process to overcome the competition with the other two tasks.

CONCLUSION

The present experiment in this chapter demonstrated reduced switch costs and no backward inhibition in all three tasks; however, congruency effect occurred regardless of the target manipulation.

Unlike the previous experiments, arrow task in the current task did not show any alternating switch cost at the single incongruent 2 condition, suggesting that the absence of word information inside the arrow stimulus might reduce the interference from the irrelevant task sets and thus cause the lack of backward inhibition.

The consistent effect of previous congruency in the word task indicates that word information processing on the target presentation is not the source of the competition with the other task sets. Instead, the response selection of the word task set might be the source of the competition with that of the other task sets.

Chapter 8

Experiment 6: The role of the Cue-target joint and separate display in switch cost and backward inhibition
- 6a) with verbal cues, 6b) with arbitrary cues

INTRODUCTION

In the task-switching procedures for studying cognitive control, participants are indicated by a cue of some kind, either presented explicitly or coded in memory .In this respect, researchers aim to exercise the control processes that select the correct task for the current trial in a context in which task-related processing is simple enough that effects of control-related processing show through behaviourally (Altmann, 2007).

During the last decade, task switching researches have mainly focused on the interpretation of the switch cost in order to understand the cognitive control processes. As a result, there has been ample evidence for switch cost- - a kind of mental effort - by-products from performing the new upcoming task when participants have to switch different tasks. However, there has been another attempt to explain that the switch cost as a side effect of mental processes is not directly relevant to cognitive control (e.g., Allport & Wylie, 2000; Altmann & Gray, 2002; Mayr & Kliegl, 2000; Wazak, Hommel, & Allport, 2003).

One alternative that has drawn considerable attention is the compound-cue model (Arrington & Logan, 2004; Logan & Bundesnen, 2003, 2004; Logan & Schneider, 2006; Schneider & Logan, 2005, 2007). The model specifies three function processing stages: task cue encoding, trial stimulus encoding, and use of the two encoded percepts as a compound cue for retrieving a response from memory. According to this model, the switch cost is attributed to repetition priming's facilitation of the encoding of a repeated task cue (Meiran, Chorev, & Sapir, 2000; Sohn & Anderson, 2001). The model's innovative premise is that task representations apart from cues are not necessary for explaining task-switching performance. This model implies that other effects linked to switching tasks- beyond just switch cost- should be linked to switching cues (Altmann, 2007). Since the compound-cue model has been introduced, the role of the cue became the independent subject for understanding the switch cost. By comparison, the role of the cue in backward inhibition was overlooked until Arbuthnott (2005) found the result that the presence of the backward inhibition was influenced by the verbal cue (ref. chapter 5).

Apart from the role of the cue itself in task switching, the interval between the cue and the target has been another interest as it allows the preparation time for the task-set reconfiguration. During the cue-target-interval (CTI), as the notion of the advance reconfiguration suggests, task specific preparation involves more than just the characterisation or preparation of a motor response (Meiran, 1996).

By presenting the cue and target separately, it will allow participants to prepare all the relative importance of perceptual dimension and changing response selection criteria, which means that participants will use their working memory when the cue appears. More interestingly, a closer look at the recent studies on backward inhibition (Mayr and Keele, 2000;

Arbuthnott & Frank, 2000; Dreher & Berman, 2002; Dreher, Kohn & Berman, 2001; Gade & Koch, 2005; Mayr and Kliegl, 2003; Schuch & Koch, 2003) revealed that the cue remained present during the target presentation in all studies reporting BI effect (alternating switch costs).

This suggests that cues and their temporal relation to the target play a crucial role for backward inhibition. In order to examine whether presenting cues and targets temporally overlapping is indeed important for obtaining backward inhibition effect, Druey & Hübner (2007) recently conducted experiments whether participants had to judge either parity (odd/even), magnitude (less/greater than 5) or position on the number line from 1 to 9 (central [3, 4, 6, 7] /peripheral [1, 2, 8, 9]) of the target digit when there were only task switch trials. There were only task switch trials and participants had to press with the index and middle fingers of the right hand, respectively, served as response keys. 'Even, less, and central' were mapped to the left button, and 'odd, greater, and peripheral' to the right button. In their experiment 1, one block had the centrally- appeared- cue on the screen for 400 ms and disappeared 100ms before target onset, whereas another block had the centrally- appeared- cue and remained present until a response was made. Furthermore, they also examined which task-sequence position was essential regarding the effect of temporal cue-target overlap on the lag-2 repetition costs by varying the temporal cue-target overlap across trials in their experiment 2. The results showed that a reliable BI effect [1] (23ms in their experiment 1 and 40ms in their experiment 2) occurred for temporally overlapping cues and targets, whereas no such cost was found for the temporally separated cue. The

[1] In their article, they used the term lag-2 repetition cost.

overall RTs were faster in conditions with the temporally separated cues and targets than in conditions with the temporally overlapping cues and targets. In order to interpret the result, they suggested that several mechanisms could be responsible for this effect. For instance, the forewarning of stimulus onset could be more precise in the no-overlap condition. Furthermore, in this condition, there was also no need to divide attention between the cue and target, which could have been advantage. Finally, if the cue remained present during target presentation, this could have induced additional rechecking processes in order to select the correct task set. In any case, they argued that the performance difference between two blocked overlap conditions in their experiment 1 could not seriously be interpreted in terms of task-set inhibition. In contrast, they argued that a cue-target overlap on trial *n-2* produced costs for A-B-A sequence relative to C-B-A sequence could easily be interpreted as indicating backward inhibition: The task set for task A was inhibited on *n-1* trial in this case. Therefore, if the participants had to return to task A on *n* trial in A-B-A sequences, they had to overcome the residual inhibition associated with this task, which produced costs. In summary, their experiments demonstrated the cue-target joint display is only crucial if the cue-target overlapping presentation was on *n-2* trial. On the other hand, there were some previous speculations on cue-target joint display and its role in task switching.

For example, the cue-target joint display could affect the retrieval of the relevant task set when a cue has a strong prior association with a to-be-performed task and remains visible while the task is performed according to Mayr & Kliegl (2000).

Arbuthnott (2005) also suggested that this cue-target joint display would provide facilitation priming of the relevant response options in a similar manner to that associated with univalent stimuli. In her previous study (Arbuthnott and Woodward, 2002), they claimed that when a cue has a strong prior association with a to-be-performed task, and remains visible while the task is performed, this compound stimulus display could possibly aid retrieval of the relevant task set (Mayr & Kliegel, 2000) or provide facilitory priming of the relevant response options in a manner similar to that associated with univalent stimuli. If so, this information may reduce the need for executive control processes to resolve response competition created by the presentation of bivalent stimuli.

Therefore, it is important to pay attention to the role of the cue independently and distinguish its encoding process between the cue and the task stimulus separately in the task switching procedure. In the previous experimental design, the cue was presented first and then the target joined without the cue disappearing from the screen. Since the cue-target remained together, it was not necessary for participants to learn the cue-target association and remember which task they had to perform. In other words, participants might not have been using CSI (CTI) to prepare for the upcoming task-set in advance and they would have been using the cue presentation for a break between trials rather than for the task information, thus the purpose of the preparation interval might have been misused. Furthermore, the cue encoding stage must have been confounded with trial stimulus encoding once the cue is joint with target and remains together till the response.

In order to maximise the effect of CSI (CTI) as an advanced preparation interval and disentangle the cue encoding and trial encoding processes separately, cue-target joint screen was changed in the present experiments. In all the previous experiments, cues appeared on the screen first and these cues joined with the target when it was displayed on the screen. In contrast, cues in the current experiment will be separated from the target when it was on the screen. In other words, cues are only on screen during the cue-target-interval and it disappears when the target comes on the next screen. Without encoding the cue and preparing for the task actively, it is now difficult to perform the task as there is no information remains after the cue display.

Consequently, if the cue and target are now separately presented, 100ms and 1200ms as an short/ long preparation interval in my paradigm might cause more contrast effect; participants might struggle to remember which task they have to perform during the short CTI, causing slower responses whereas they might get more benefit of having the preparation interval for the long CTI. By using the preparation interval more actively, they might be more goal-directed to perform the task. More importantly, their task-set reconfiguration entirely depends on the cue during the CTI because the stimulus display itself does not include any information.

The purpose of the current experiments was to investigate the role of cue-target joint and cue-target separate display in switch cost and backward inhibition if the manipulation of the cue-target separate display influences the magnitude of the switch cost and alternating switch cost. It is also interesting to see if the congruency effect would be found regardless of this cue-target separate manipulation. Experiment 6a used the same verbal cue as experiment 3 and experiment 6b used the same arbitrary cue as experiment 4 in order to examine any differences on switch cost and alternating switch cost by presenting the cue and target separately. Simultaneously, the results between 6a and 6b were compared by group analysis to see the cue type effect because it is now possible to disentangle the cue processing from the target, thus the contrast between the strong and weak cue is more obvious. The results are presented by the separate section.

METHODS

Participants

For experiment 6a, twenty participants (8 women) were recruited from the University of Nottingham through advert, 12 of them were undergraduates and the rest of them were postgraduate in the psychology department. For the experiment 6b, twenty participants (14 women) were recruited from the University of Nottingham through the advert and 12 of them were undergraduates and the rest of them were postgraduate in the psychology department. The participants ranged age from 18 to 29 years (M= 22.4, SD=6) in the experiment 6a and age from 20 to 34 (M=26.5, SD=7) in the experiment 6b. They all reported normal and corrected-to-normal vision and were all right-handed by self-report except two participants. They received £4 as an inconvenience after completion of the experiment. The study took approximately 50 min to complete for each experiment including the instruction and practice session.

Stimuli and Procedures

The task, stimuli and study procedures were identical to the previous experiment 1 (ref. chapter 3) except the fact that separate cue-target display. The cue for the experiment 6a was the same as for the experiment 3 (all verbal cue) and the cue for the experiment 6b was the same as the experiment 4 (all arbitrary cue). The cues were presented in the centre of the screen (Arial font with capital letter, size 20) and disappeared when the target was presented. In all other respects the procedures was identical to that of Experiment 1. However, the number of blocks during the experimental session was reduced from 12 to 9 as I had some feedback from the participants that it was rather lengthy and tiring to concentrate during the previous experiments. The example of the experiment 6a and 6b were shown in the figure 37 and 38 respectively.

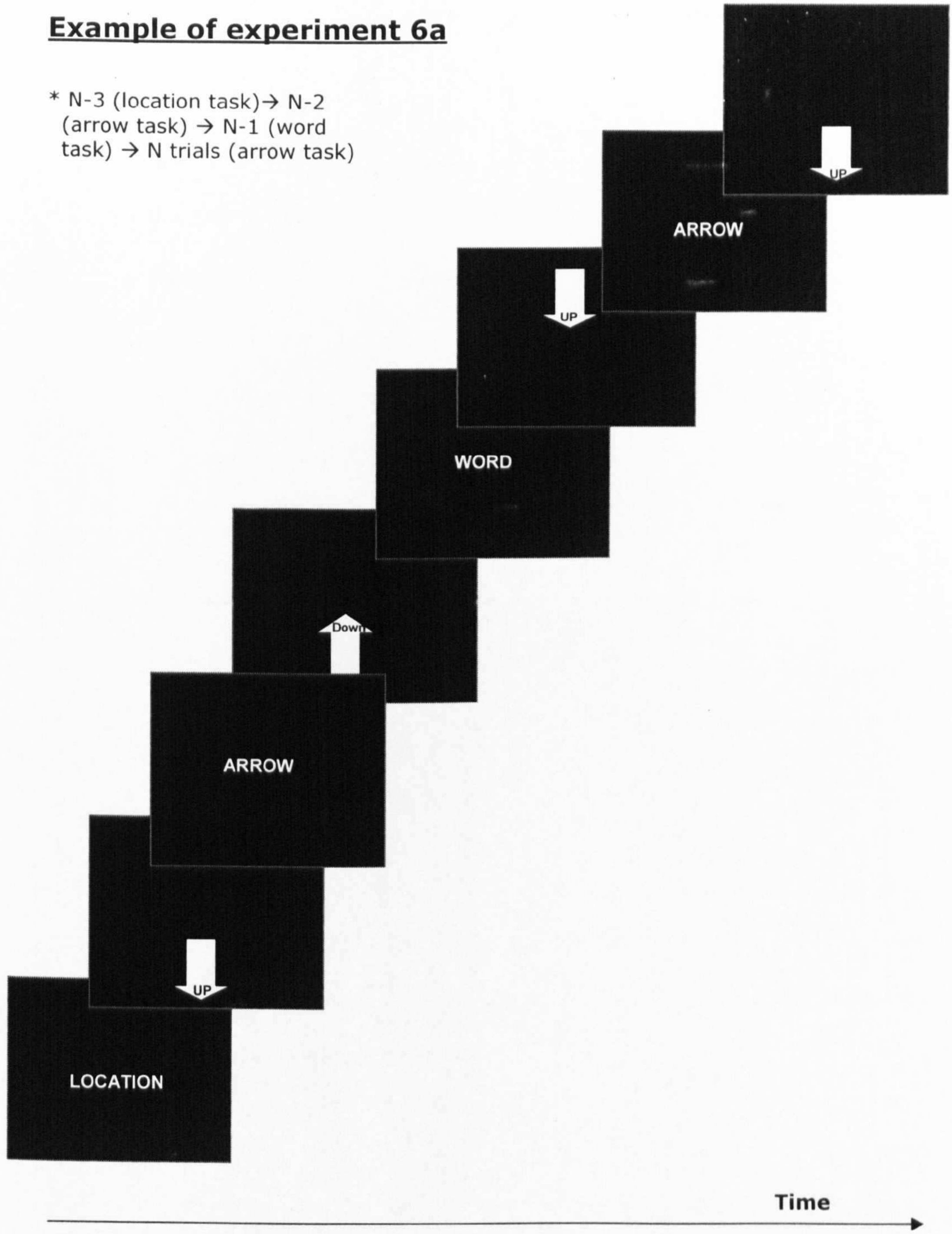


Figure 37. An example of the time course of task presentation in Experiment 6a. Tasks were described here were three tasks: arrow, location and word task. The Cue-target-interval (CTI) and Response-Cue-Interval (RCI) procedure is the same as the previous Exps (see the chapter 2 General method)

Example of experiment 6b

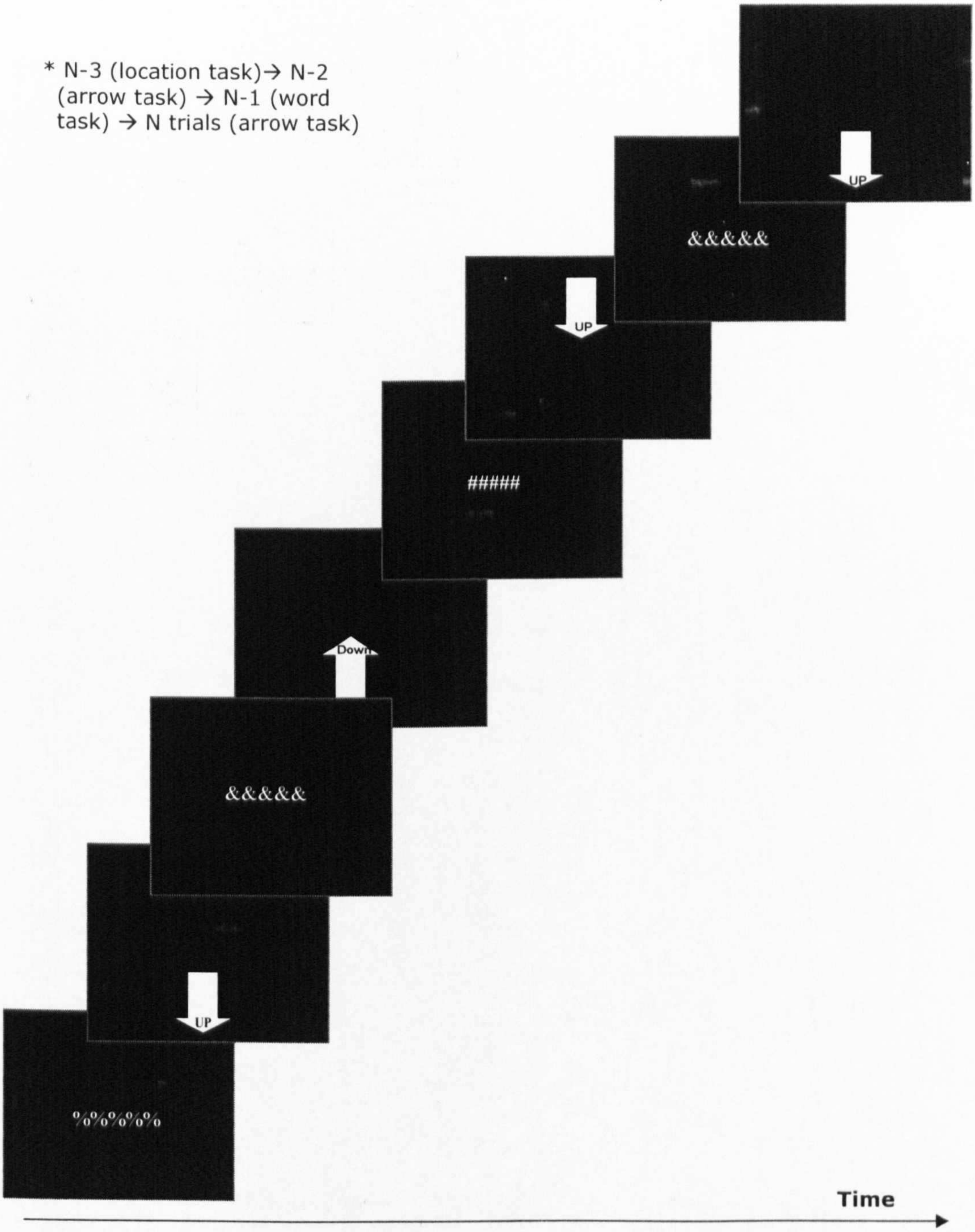


Figure 38. An example of the time course of task presentation in Experiment 6b. Tasks were described here were three tasks: arrow, location and word task. The difference between Exp 6 a and 6 b is to manipulate the cue. Arbitrary cues are made in order to compare the verbal cue in Exp 6a. The CTI and RCI procedure is the same as Exp 6a.

RESULTS

Exp 6 a (verbal cues)

1) Effect of task switching

On Reaction Time (RT)

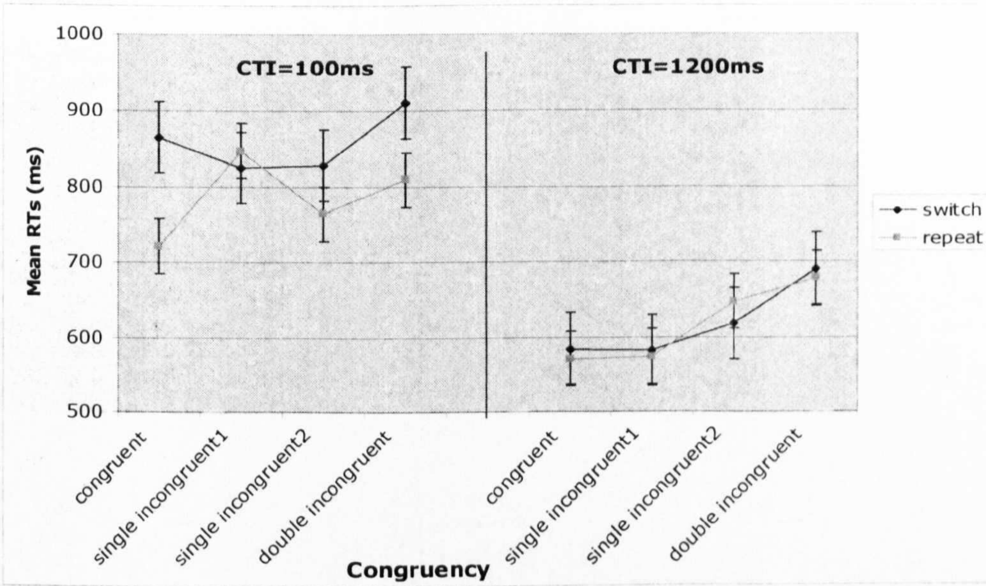
Analysis of the 4-way repeated measured ANOVA with factors CTI (100, 1200), trial type (switch, repeat), task (arrows, location, word), and congruency (congruent, single incongruent 1, single incongruent 2, double incongruent) revealed a significant 3-way interaction (trial type, task and congruency), **[F (4, 74) =2.4, p =.05],** and a marginally significant 3-way interaction (CTI, task and congruency), **[F (4, 74) =2.4, p =.06]** (*see the Appendix, page 405 table 1a*). This interaction was explored by conducting three separate 3-way (factors CTI, trial type, and congruency) repeated measures ANOVAs for each task. These are reported below.

On Error (%)

Analysis of the 4-way repeated measured ANOVA with factors CTI (100, 1200), trial type (switch, repeat), task (arrow, location, word), and congruency (congruent, single incongruent 1, single incongruent 2, double incongruent) revealed a non-significant 4-way interaction: **[F (3, 64)= 1.9, p = .12]** and a significant 3-way interaction (CTI, task and congruency): **[F (3, 58)= 14, p<.001]** and a significant 3-way interaction (CTI, trial type and congruency): **[F (2, 36)= 8.6, p=.001]** (*see the Appendix, page 405 table 1b*).

Arrow task

a. *RT (ms)*



b. *Error (%)*

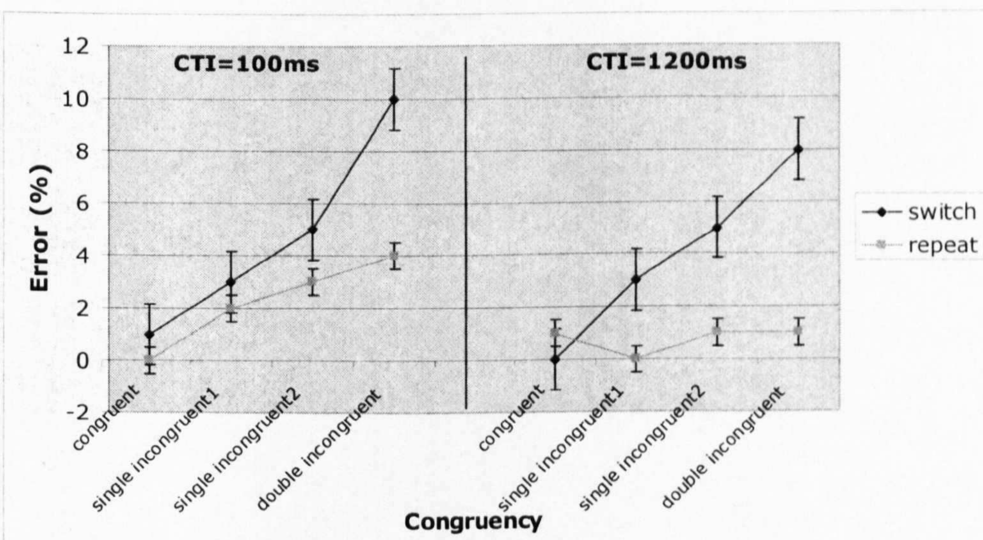


Figure 39. Mean RTs (and standard errors) (figure 39 a) and percent error scores (figure 39 b) in congruency and trial type in two CTI conditions for the arrow task.

RT (ms)

A significant difference between switch and repeat trials was found at CTI =100, **[F (1, 19) = 13, p =.002]** *(77ms of switch cost, switch M = 867 [SE: 36] vs. repeat M= 790 [SE: 28])* but not at CTI=1200, [F (1, 19) =.35, p =.56] (See *Figure 39 a*).

There was a significant 2-way interaction between trial type and congruency at the CTI= 100, **[F (2, 50) = 3.9, p=.02]** but not the CTI=1200, [F (2, 44) = .70, p= .52]. The interaction between trial type and congruency at the CTI=100 was as a result from the congruency effect at the repeat trials, **[F (2, 46)= 3, p=.05]** (78ms of congruency effect, congruent M= 731[SE:37], single incongruent 1 M= 848 [SE: 41], single incongruent 2 M= 766 [SE: 36], double incongruent M= 813 [SE: 39]) and a lack of congruency effect at the switch trials , [F (2, 43)= 4.9, p=.11]. As is clear from an examination of Figure 39 a, this was as a result of dramatic RT increase from congruent to single incongruent 1 during the repeat trials, resulting in no switch cost in the single incongruent 1 condition at CTI=100.

In both CTI conditions, the effect of congruency was significant at the CTI=100, **[F (2, 36) = 3.5, p =.04]** *(38ms of congruency effect, congruent M= 803 [SE: 37], single incongruent 1 M= 838 [SE: 31] vs. single incongruent 2 M= 800 [SE: 34], double incongruent M= 872 [SE: 36])* and at the CTI=1200, **[F (2, 46) =7.3, p =.001]** *(60ms of congruency effect, M= 583 [SE: 19], M= 598 [SE: 37], M= 638 [SE: 30] , M= 692 [SE: 35])*.

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (19)= 2.5, p =.02** but it was non-significant on the switch trials, t (19)= -.17, p=.87.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (19)= -1.5, p = .15 and it was also non-significant on the switch trials, t (19)= -.68, p=.51.

Error (%)

A significant difference in error percentage was found at the CTI= 100, **[F (1, 19) = 7.9, p =.01]** and CTI=1200, **[F (1, 19) = 16, p <.001]**.

There was a significant 2-way interaction between trial type and congruency at the CTI=100, **[F (2, 44) = 14, p <.001]** and CTI=1200, **[F (2, 31)= 3.7, p=.04].**

A significant effect of congruency was found at both CTI=100, **[F (2, 50) = 4.1, p=.015]** and CTI=1200, **[F (2, 32) = 8.7, p=.002].**

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non- significant on the repeat trials, t (16)= 1.1, p =.30 but it was marginally significant on the switch trials, **t (20)= 1.9, p=.08**.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (16)= .64, p =.53 and on the switch trials, t (16)= 1.8, p=.09.

Summary

a. A main effect of switch costs for the arrow task only occurred at the short preparation interval condition for reaction time whereas there was a main effect of switch costs in both short and long preparation interval condition on the error.

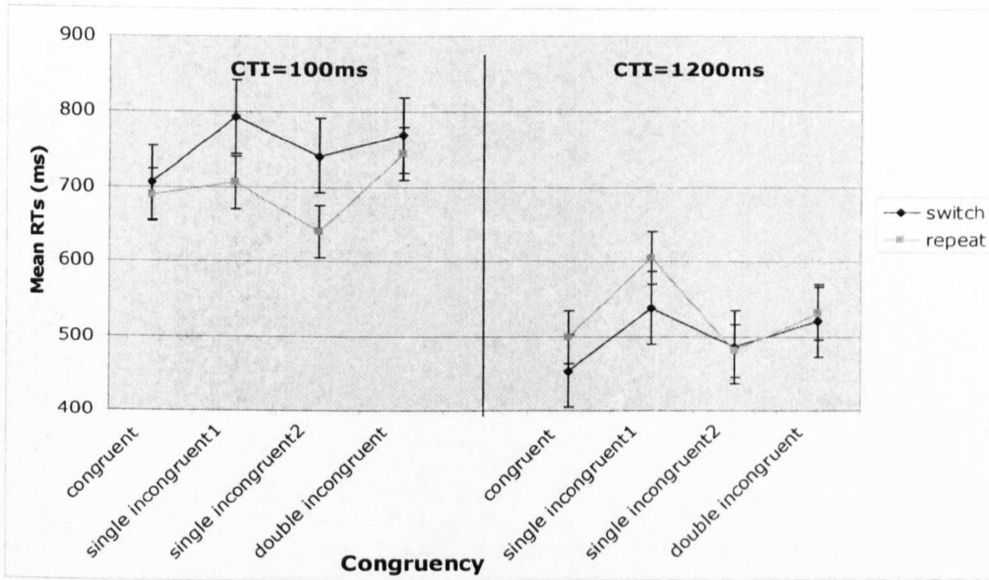
b. A main effect of congruency for the arrow task was observed on reaction time and error consistently for both short and long preparation interval.

c. The interaction between congruency and trial type (switch/repeat trials) was significant on reaction time for the short preparation interval and it was caused by the congruency effect on the repeat trials. The interaction on error was significant for the both preparation interval.

d. The effect of previous congruency for the arrow task occurred on reaction time during the repeat trials for the short preparation interval and during the switch trials for the short preparation interval on error.

Location task

a. ***RT (ms)***



b. ***Error (%)***

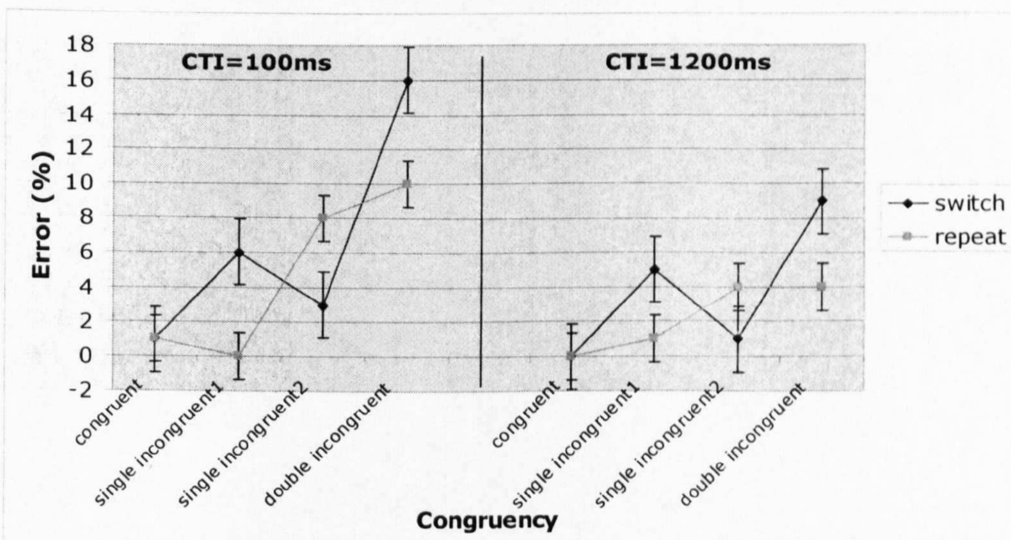


Figure 40. Mean RTs (and standard errors) (figure40 a) and percent error scores (figure 40 b) in congruency and trial type in two CTI conditions for the location task.

RT (ms)

A significant difference between switch and repeat trials was found at the CTI= 100, **[F (1, 19)= 21, p <.001]** *(67ms of switch cost, switch M = 770*

[SE: 30] vs. repeat M= 703 [SE: 28]) but not at the CTI=1200, [F (1, 19) = 1.8, p =.19] (*see Figure 40 a*).

A 2-way interaction between trial type and congruency was significant at the CTI=100, **[F (2, 43) = 4, p =.02]** but not at the CTI=1200, [F (2, 48) = 1, p =.38]. The interaction in trial type and congruency was as a result from more significant congruency effect on the switch trials, **[F (2, 42)=8, p=.001]** *(64ms congruency effect, congruent M= 722 [SE: 28], single incongruent 1 M= 809 [SE: 32], single incongruent 2 M= 763 [SE: 38], double incongruent M= 785 [SE: 30])* than on the repeat trials, **[F (3, 51)= 4.7, p =.008]** *(40ms congruency effect, congruent M= 698 [SE: 37], single incongruent 1 M= 709 [SE: 31], single incongruent 2 M= 647 [SE: 28], double incongruent M= 758 [SE: 37]).*

The effect of congruency was significant at the CTI=100, **[F (3, 51) = 7, p=.001]** *(35ms congruency effect, congruent M= 710 [SE: 29], single incongruent 1 M= 759 [SE: 30], single incongruent 2 M= 705 [SE: 31], double incongruent M= 772 [SE: 33])* and at CTI=1200, **[F (2, 47) =5, p=.007]** *(46ms congruency effect, congruent M= 492 [SE: 27], single incongruent 1 M= 574 [SE: 29], double incongruent M= 497 [SE: 22], M= 543 [SE: 32]).*

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (19)= 2.2, p =.04** and on the switch trials, **t (19)= 2.8, p=.01.**

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (19)= 2.7, p = .015** but not on the switch trials, t (19)= 1.6, p=.13.

Error (%)

There was a marginally significant difference in error percentage between switch and repeat trials at the CTI=100, **[F (1, 19)= 4.1, p=.06]** and CTI=1200, **[F (1, 19)= 5.2, p=.03]**.

The interaction between trial type and congruency was not significant at the CTI=100, [F (1, 30)= 2.5, p=.11] but it was significant at the CTI=1200, **[F (2, 47)= 3.4, p=.03]**.

A significant effect of congruency was found at both CTI=100, **[F (2, 39)= 15, p <.001]** and CTI=1200, **[F (2, 45)= 7.7, p=.001]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (16)= -.044, p =.97 and on the switch trials, t (16)= - .25, p=.81.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (16)= .03, p =.98 and on the switch trials, t (16)= -.41, p=.68.

Summary

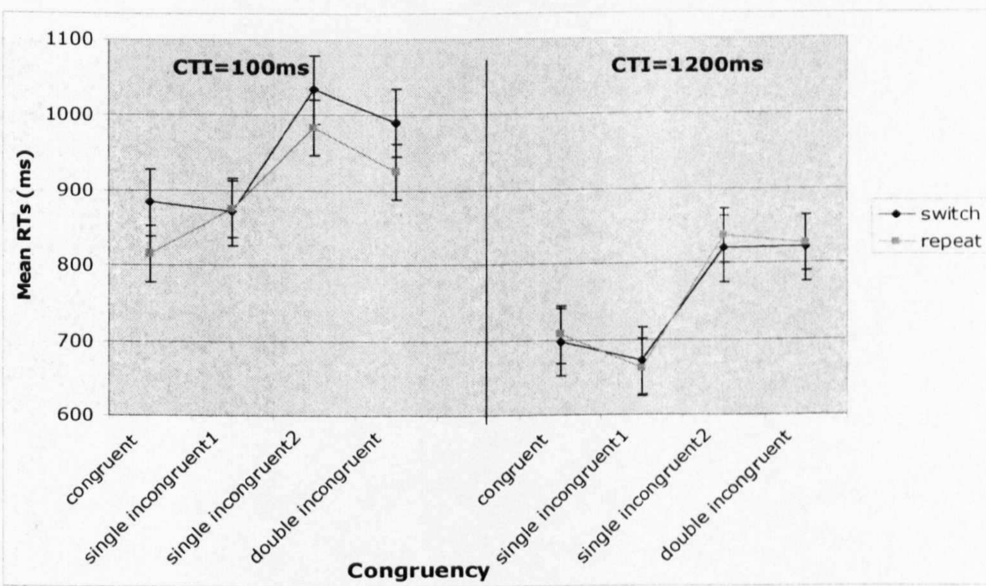
a. A main effect of switch costs for the location task occurred on reaction time for the short preparation interval and it occurred on error for the short preparation interval (marginal) and long preparation interval.
b. A main effect of congruency for the arrow task was observed on reaction time and error consistently for both short and long preparation interval.

c. The interaction between congruency and trial type (switch/repeat trials) was significant on reaction time for the short preparation interval and it was caused by more congruency effect on switch trials than repeat trials and it was also significant on error for the long preparation interval.

d. The effect of previous congruency for the location task occurred on reaction time during the repeat trials and switch trials for the short preparation interval and during the repeat trials for the long preparation interval. It was occurred on error only for the long preparation interval.

Word task

a. ***RT (ms)***



b. ***Error (%)***

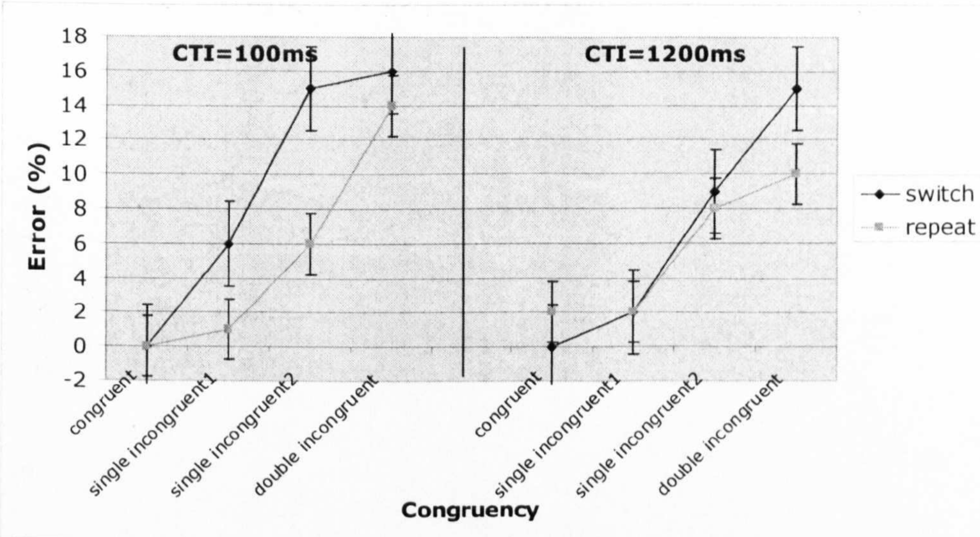


Figure 41. Mean RTs (and standard errors) (figure 41 a) and percent error scores (figure 41 b) in congruency and trial type in two CTI conditions for the word task.

RT (ms)

A significant difference between switch and repeat trials was found at the CTI= 100, **[F (1, 19)= 7, p =.01]** *(49ms of switch cost, switch M = 955 [SE: 33] vs. repeat M= 906 [SE: 35])* but not at the CTI=1200, [F (1, 28) = .14, p =.71] (*see Figure 41 a*).

A 2-way interaction in trial type and congruency was non-significant both at the CTI=100, [F (2, 39) = 1, p =.38] and CTI=1200, [F (2, 38) =.10, p =.91].

In both CTI conditions, the effect of congruency was significant at the CTI=100, **[F (2, 40)= 23, p<.001]** *(94ms congruency effect, congruent M= 860 [SE:35] vs. single incongruent 1M= 880 [SE: 41] vs. single incongruent 2 M= 1014[SE: 33] vs. double incongruent M= 969[SE:31])* and CTI= 1200, **[F(2, 44)= 21, p <.01]** *(72ms of congruency effect, M= 702 [SE: 33], M= 668 [SE:20], M= 829 [SE: 38], M= 825 [SE: 27])*.

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, **t (19)= -2.4, p =.03** but it was significant on the switch trials, **t (19)= -4.1, p=.001.**

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (19)= -4.7, p< .001** and on the switch trials, **t (19)= -5.8, p<.001**.

Error (%)

The difference in error percentage between switch and repeat trials was not significant at the CTI=100, [F (1, 19)= .94, p=.34] and CTI=1200, [F (1, 19)= 1.6, p=.22]. There was non-significant 2-way interaction between trial type and congruency at the CTI=100, [F (2, 43)=1, p=.35] and CTI=1200, [F (2, 37)= 1.4, p=.25].

A significant effect of congruency was found at the CTI=100, **[F (2, 35)= 26, p <.001]** and CTI=1200, **[F (2, 38)= 20, p <.001].**

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (16)= 2.2, p =.04** but not on the switch trials, t (16)= 1.1, p=.30.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (16)= 1.1, p =.30 and on the switch trials, t (20)= .10, p=.33.

Summary

a. A main effect of switch costs for the word task occurred on reaction time only for the short preparation interval and not on error.

b. A main effect of congruency for the word task was observed on reaction time and error consistently for both short and long preparation interval.

c. The interaction between congruency and trial type (switch/repeat trials) was non-significant on reaction time and error.

d. The effect of previous congruency for the word task occurred on error during the switch and repeat trials for both preparation interval and it was occurred on error during the repeat trials for the short preparation interval.

2) Effect of alternating task

On Reaction Time (ms)

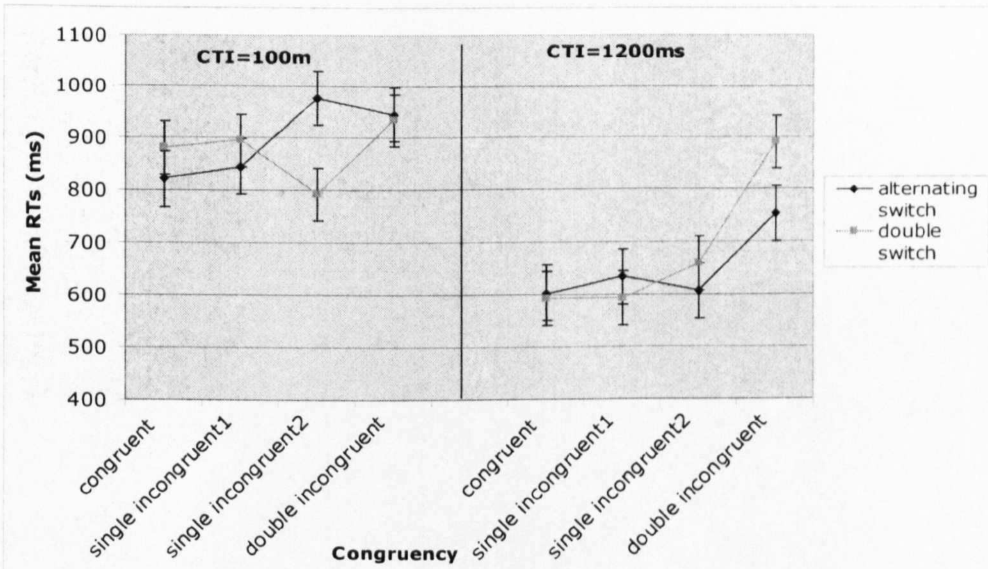
The repeated measures ANOVA with the factors CTI, switch type, task, and congruency revealed a significant 4-way interaction, **[F (4, 79) =2.6, p =.04]** (*see the Appendix, page 406 table 2a*). This interaction was explored by conducting three separate 3-way repeated measures ANOVA for each task. Each of these is reported below.

On Errors (%)

4-way repeated measured ANOVA with factors CTI (100, 1200), switch type (alternating switch, double switch), task (arrow, location, word), and congruency (congruent, single incongruent 1, single incongruent 2, double incongruent) revealed a non-significant 4-way interaction: [F (4, 70)= .99, p= .41] and a significant 3-way interaction (CTI, task and congruency): **[F (4, 71)= 2.8, p=.03]** and another significant 3-way interaction (CTI, switch type and congruency): **[F (2, 41)= 4.4, p=.01]** (*see the Appendix, page 406 table 2b*).

Arrow task

a. ***RT (ms)***



b. ***Error (%)***

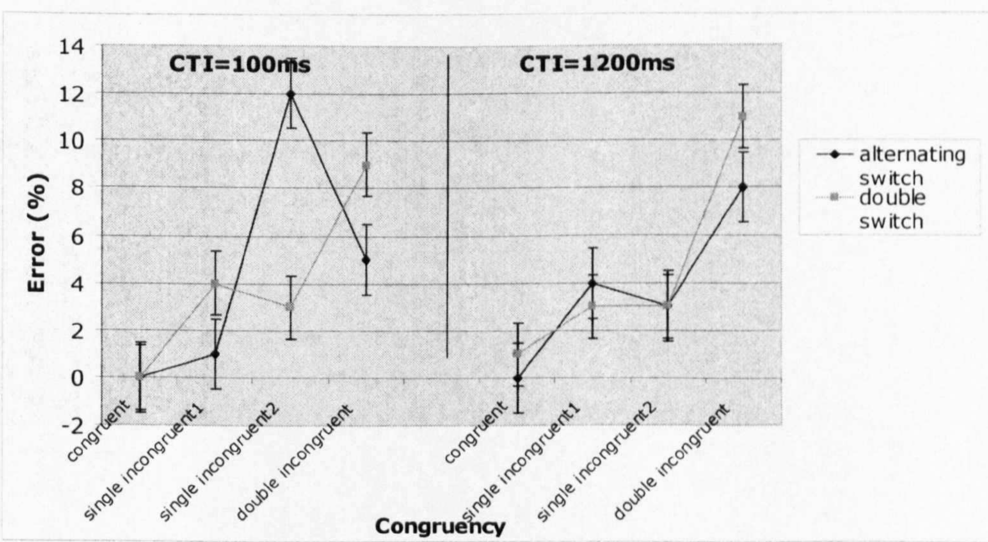


Figure 42. Mean RTs (and standard errors) (figure 42 a) and percent error scores (figure 42 b) in congruency and switch type in two CTI conditions for the arrow task.

RT (ms)

The effect of alternating switch was non-significant, [F (1, 19) =.71, p =. 41] *(19ms alternating switch cost, alternating switch M= 896 [SE: 43] vs. double switch M= 875 [SE: 34])* both at the CTI= 100 and at the CTI=1200, [F (1, 19) = 1.7, p=.21] *(34ms alternating switch cost, alternating switch M= 649 [SE: 25] vs. double switch M= 683 [SE: 33])* *(see Figure 42 a).*

A 2-way interaction between switch type and congruency was significant at the CTI=100, **[F (2, 47) = 5.4, p=.004]** and marginally significant at CTI=1200, **[F (2, 46) =2.8, p=.06].** As is clear from an examination of Figure 42 a the interaction in switch type and congruency at the CTI=100 was as a result of a large RT difference in alternating and double switch trials at the single incongruent 2 condition only *(184ms of alternating switch cost, M= 976 [SE: 48] vs. M= 792 [SE: 52])* which was confirmed by a paired-samples T-test: **t (19)= 3.5, p=.002**. The marginal interaction in switch type and congruency at the CTI=1200 was as a result from a marginally significant RT difference in alternating and double switch trials at the double incongruent condition only (-137ms of alternating switch cost, M= 753 [SE: 41] vs. M= 890 [SE: 73]) which was confirmed by a paired-samples T-test: **t (19)= -1.9, p=.07**.

During the CTI=100, the effect of congruency was non-significant, [F (2, 38)= 1.5, p=.22] whereas it was significant during the CTI=1200, **[F (2, 40) =19, p <.001]** (91ms congruency effect, congruent M= 598 [SE: 23], single incongruent 1 M= 614 [SE: 35], single incongruent 2 M= 632 [SE:21], double incongruent M= 821 [SE: 47]).

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was marginally significant on the alternating switch trials, **t (19)= -1.9, p =.06** and on the double switch trials, **t (19)= 1.9, p=.07**.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (19)=. .68, p = .51 and on the double switch trials, t (19)= -1.4, p=.19.

Error (%)

There was a marginally significant 2-way interaction (switch type and congruency) at CTI=100, **[F (1, 26)= 3, p=.08]** and a non-significant 2-way interaction at CTI=1200, [F (2, 32)=.49, p=.63].

The difference between alternating switch and double switch trials in error percentage was non-significant at the CTI=100, [F (1, 18)= .25, p= .62] and CTI=1200, [F (1, 18) =1.1, p=.30].

The effect of congruency was significant both at CTI=100, **[F (2, 43) 5.3, p=.006]** and CTI=1200, **[F (1, 42) = 9.2, p=.002]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= .39, p =.70 and on the double switch trials, t (18)= -1.7, p=.10.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= .90, p =.38 and on the double switch trials, t (18)= -1.1, p=.30.

Summary

a. A main effect of alternating switch cost on reaction time and error did not occur for the arrow task.

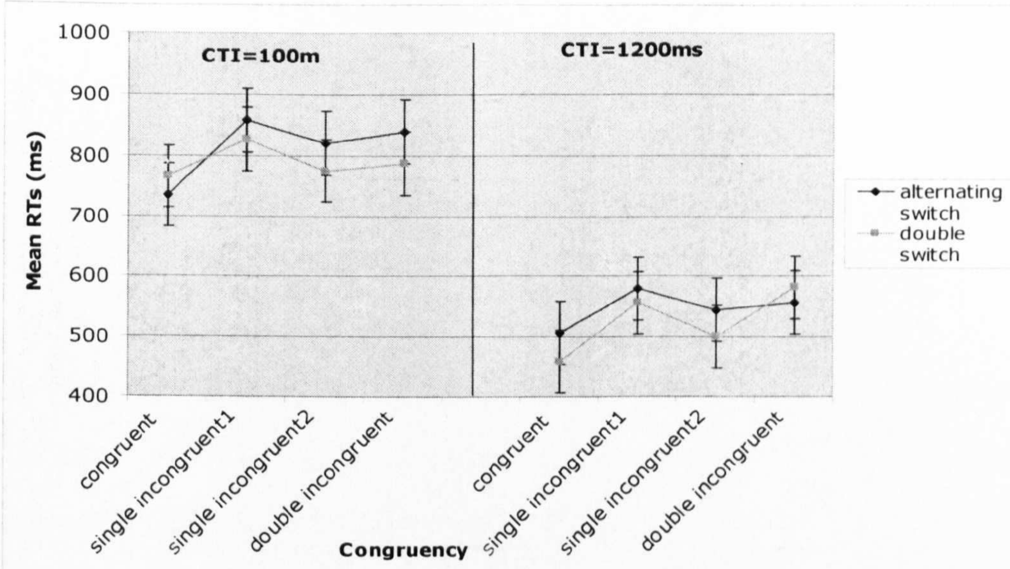
b. A main effect of congruency was observed on reaction time only for the long preparation interval and on error for both short and long preparation interval, showing that congruency affected both alternating switch and double switching trials.

c. The interaction between congruency and switch type (alternating switch/double switch trials) on reaction time was significant for the short preparation interval and it was caused by the big alternating switch cost (184ms) at the single incongruent 2 condition and reversed alternating switch cost (-137ms) at the double incongruent condition. It was non-significant on error.

d. The effect of previous congruency for the arrow task on reaction time was marginally significant during the alternating and double switch trials for the short preparation interval. It was non-significant on error.

Location task

a. *RT (ms)*



b. *Error (%)*

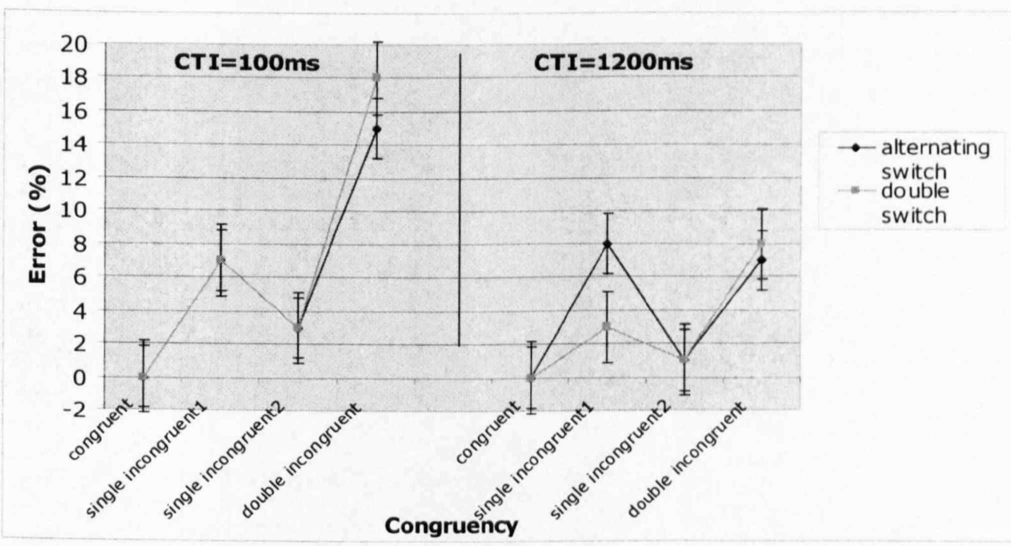


Figure 43. Mean RTs (and standard errors) (figure 43 a) and percent error scores (figure 43 b) in congruency and switch type in two CTI conditions for the location task

RT (ms)

The effect of alternating tasks at the CTI= 100 was non-significant, [F (1, 19) = 1.7, p =.21] *(25ms alternating switch cost, alternating minus double switch, alternating switch M = 813 [SE: 33] vs. double switch M= 788 [SE: 35]).* It was also non-significant at CTI =1200, [F (1, 19) =.78, p=.39] *(23 ms alternating switch cost, M = 547 [SE: 35] vs. M = 524 [SE: 26])* (see *Figure 43* a).

There was a non-significant 3-way interaction between CTI, switch type and congruency, [F (3, 52) = 1.7, p =.19]. A 2-way interaction between switch type and congruency was non-significant at CTI=100, [F (3, 52)= 1, p=.39] and at CTI=1200, [F (3, 52) = .65, p=.57].

The effect of congruency was significant at CTI=100, **[F (3, 50) = 3.5, p =.025]** *(67ms congruency effect, congruent M= 750 [SE: 30], single incongruent 1 M= 841 [SE: 34], single incongruent 2 M= 797[SE: 45], double incongruent M= 814 [SE: 38])* and at CTI=1200, **[F (3, 53) = 5.1, p=.004]** *(71ms of congruency effect, M= 482 [SE: 35], M= 568 [SE: 32], M= 522 [SE: 29], M= 570 [SE: 33]).*

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (19)= .73, p =.47 but it was marginally significant on the double switch trials, **t (19)= 1.8, p=.08.**

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (19)= 1, p = .33 and on the double switch trials, t (19)= 1.4, p=.16.

Error (%)

There was a non-significant 2-way interaction (switch type and congruency) at CTI=100, [F (2, 33)= .50, p=.60] and a non-significant 2-way interaction at CTI=1200, [F (1, 28)= 1.2, p=.31].

The difference between alternating switch and double switch trials in error percentage was non-significant at the CTI=100, [F (1, 18)= .78, p= .39] and CTI=1200, [F (1, 18) =1.1, p=.30].

The effect of congruency was significant both at CTI=100, **[F (2, 36)= 16, p<.001]** and CTI=1200, **[F (2, 37) = 11, p<.001]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= 1.5, p =.13 and on the double switch trials, t (18)= .41, p=.85.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= -.09, p =.93 and on the double switch trials, t (18)= -.97, p=.34.

Summary

a. A main effect of alternating switch costs for the location task did not occur on reaction time and on error.

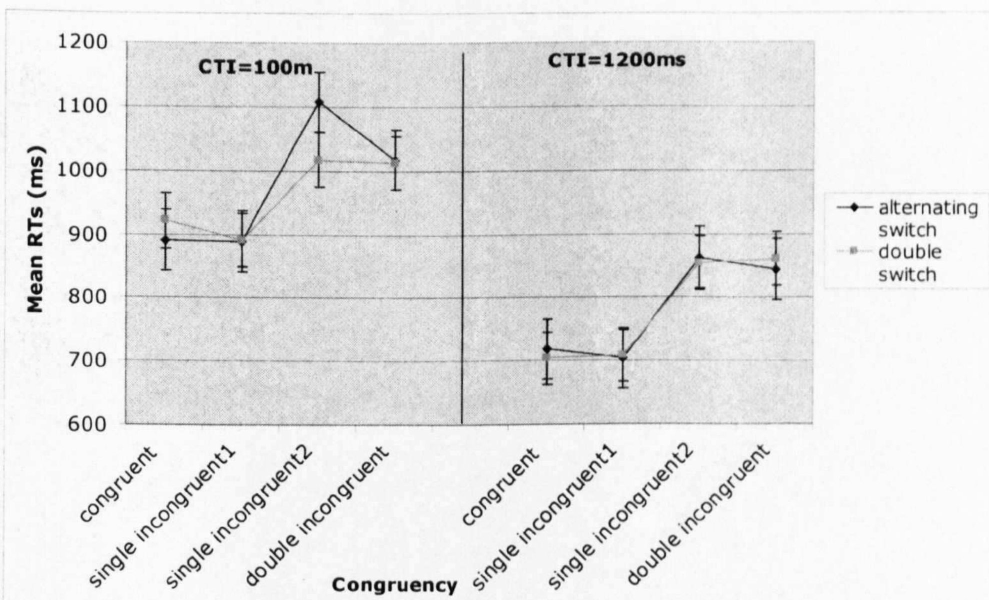
b. A main effect of congruency was observed on reaction time for both short and long preparation interval and on error for the long preparation interval, showing that congruency affected both alternating switch and double switching trials.

c. The interaction between congruency and switch type (alternating switch/double switch trials) on reaction time and error was non-significant.

d. The effect of previous congruency for the location task on reaction time was only marginally significant during the double switch trials for the short preparation interval but it was non-significant on error.

Word task

a. *RT (ms)*



b. *Error (%)*

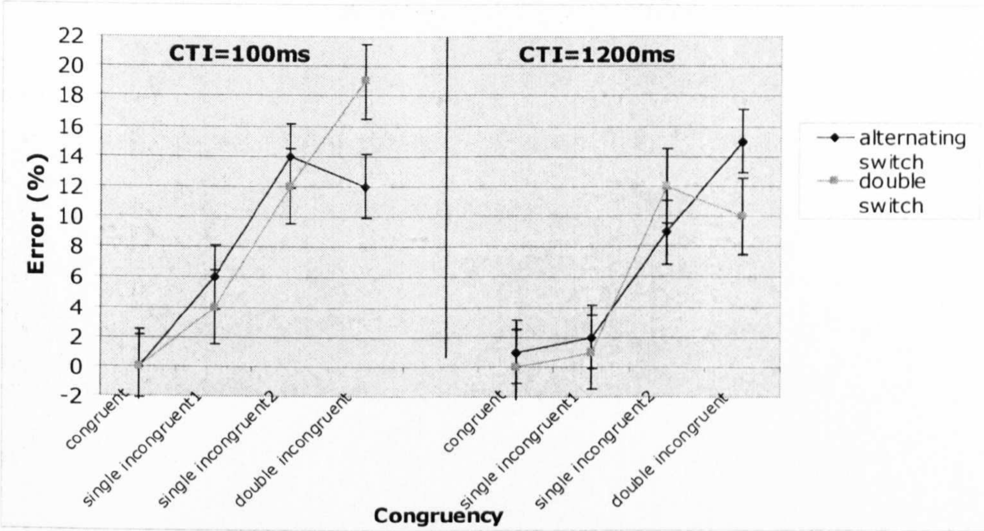


Figure 44. Mean RTs (and standard errors) (figurer 44 a) and percent error scores (figure 44 b) in congruency and switch type in two CTI conditions for the word task.

RT (ms)

The effect of alternating task was non-significant both at the CTI= 100, [F (1, 19)= .55, p =.46] *(16ms of alternating switch cost, alternating switch M = 976 [SE: 38] vs. double switch M= 960[SE: 38])* and at the CTI=1200, [F (1, 19) = .001, p =.97] *(0ms of alternating switch cost, alternating switch M = 782 [SE: 30] vs. double switch M = 782 [SE: 29])* (see *Figure 44* a).

There was a non-significant 3-way interaction (CTI, switch type and congruency) for the word task, [F (3, 50) = .48, p=.69].

A 2-way interaction between switch type and congruency was non-significant at CTI=100, [F (2, 41) = 1.6, p=.20] and at CTI=1200, [F (3, 54) = .14, p=.93].

The effect of congruency was significant at CTI=100, **[F (2, 39) = 16, p <.001]** *(82ms of congruency effect, congruent M= 906 [SE: 39], single incongruent 1 M= 889 [SE: 42], single incongruent 2 M= 1062 [SE: 45], double incongruent M= 1014 [SE: 37])* and at CTI=1200, **[F (2, 43) = 14,**

p <.001] *(100ms of congruency effect, M= 712 [SE: 36], M= 706 [SE: 32], M= 859 [SE: 36], M= 852 [SE: 33]).*

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (19)= -4.7, p <.001** and on the double switch trials, **t (19)= -2.3, p=.03**.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (19)= -3.2, p = .005** and on the double switch trials, **t (19)= -4.5, p<.001**.

Error (%)

There was a non-significant 2-way interaction (switch type and congruency) at CTI=100, [F (2, 39)= 1.6, p=.22] and a marginally significant 2-way interaction at CTI=1200, **[F (2, 36)= 2.6, p=.08]**.

The difference between alternating switch and double switch trials in error percentage was non-significant at the CTI=100, [F (1, 18)= .05, p= .82] and CTI=1200, [F (1, 18) =.65, p=.43].

The effect of congruency was significant both at CTI=100, **[F (2, 44)= 9, p<.001]** and CTI=1200, **[F (2, 39) = 11, p<.001]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)= .82, p = -.22 and on the double switch trials, t (18)= .99, p=.33.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (18)=1.2, p =.24 and on the double switch trials, t (18)= 1.2, p=.25.

Summary

a. A main effect of alternating switch costs for the word task did not occur on reaction time and on error.
b. A main effect of congruency was observed on reaction time for both short and long preparation interval and on error for the long preparation interval, showing that congruency affected both alternating switch and double switching trials.
c. The interaction between congruency and switch type (alternating switch/double switch trials) on reaction time was non-significant and on error it was only marginally significant during the long preparation interval.
d. The effect of previous congruency for the word task on reaction time was significant during the alternating and double switch trials for both preparation intervals but it did not occur on error.

Exp 6 b (arbitrary cues)

1) Effect of Task switching

On Reaction Time (RT)

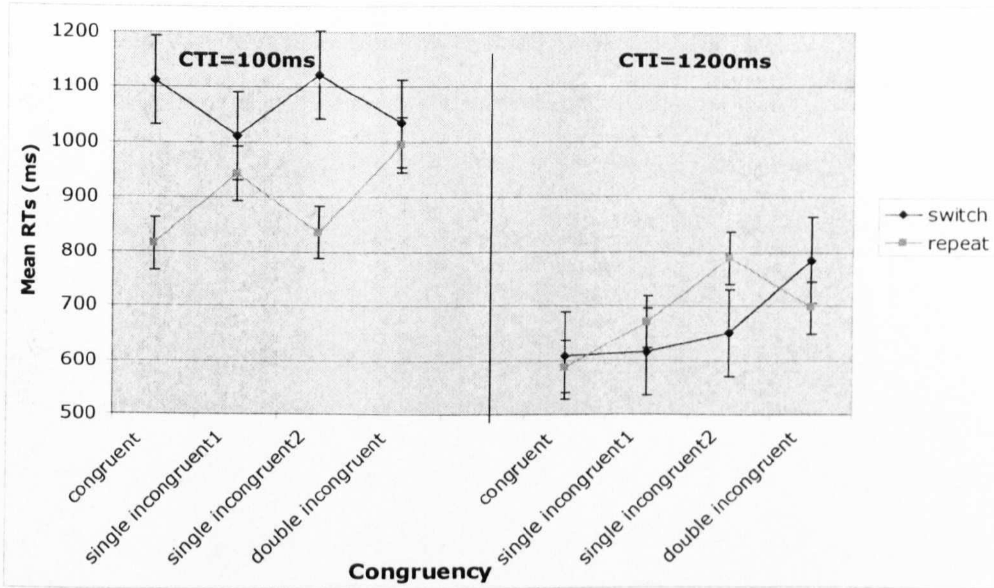
Analysis of the 4-way repeated measured ANOVA with factors CTI (100, 1200), trial type (switch, repeat), task (arrow, location, word), and congruency (congruent, single incongruent 1, single incongruent 2[2], double incongruent) revealed a significant 4-way interaction (CTI, trial type, task and congruency), **[F (4, 57) =3.8, p =.007]** *(see the Appendix, page 407 table 1a)*. This interaction was explored by conducting three separate 3-way (factors CTI, trial type, and congruency) repeated measures ANOVAs for each task. These are reported below.

On Error (%)

Analysis of the 4-way repeated measured ANOVA with factors CTI (100, 1200), trial type (switch, repeat), task (arrow, location, word), and congruency (congruent, single incongruent 1, single incongruent 2, double incongruent) revealed a non-significant 4-way interaction: [F (4, 63)= 1.6, p = .19] and a significant 2-way interaction (CTI and task): **[F (2, 28)= 3.3, p=.05]** and a marginally significant 2-way interaction (CTI and congruency): **[F (2, 37)= 2.8, p=.06]** *(see the Appendix, page 407 table 1b)*.

Arrow task

a. RT (ms)



b. Error (%)

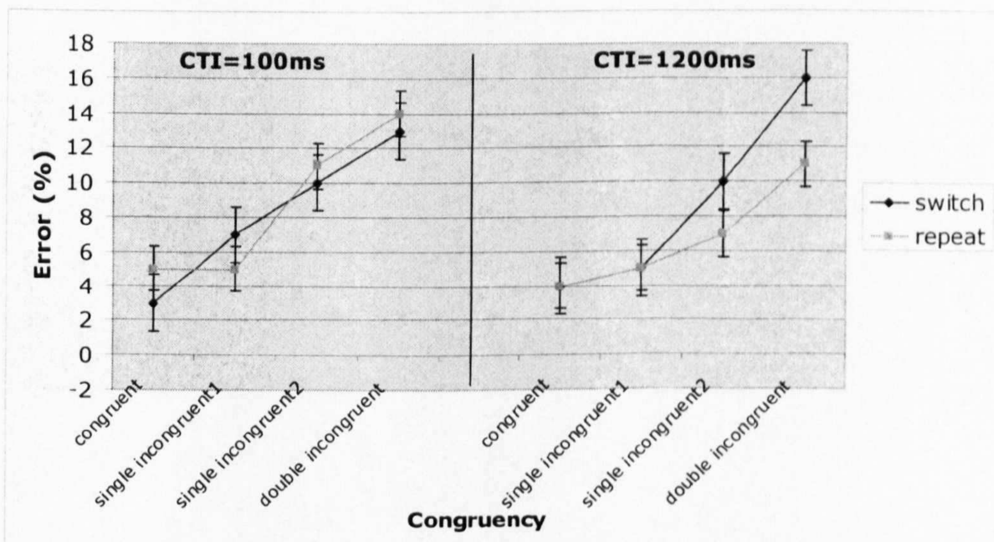


Figure 45. Mean RTs (and standard errors) (figure 45 a) and percent error scores (figure 45 b) in congruency and trial type in two CTI conditions for the arrow task.

RT (ms)

A significant difference between switch and repeat trials was found at CTI =100, **[F (1, 17) = 16, p =.001]** *(58ms switch cost, switch M = 1033*

[SE: 63] vs. repeat M= 875 [SE: 55]) but not at CTI=1200, [F (1, 17) =.18, p =.67] (See *Figure 45* a).

There was a significant 3-way interaction (CTI, trial type and congruency), **[F (3, 45) =7.4, p <.001]** which resulted from two effects which impacted CTI=100 but not CTI=1200. Thus, there was a significant 2-way interaction between trial type and congruency at the CTI= 100, **[F (2, 41) = 8.5, p<.001]** but not the CTI=1200, [F (2, 38) = 2.0, p= .14].

As is clear from an examination of Figure 45 a, this was as a result of dramatic RT differences between switch and repeat trials at the congruent and single incongruent 2 condition. These are confirmed by Paired-Samples T- test between switch and repeat trials for each congruent condition at the CTI=100: A significant RT difference between switch and repeat trials occurred at the congruent condition, **t (20)= = 6.4 , p<.001** *(292ms switch cost, switch M= 112 [SE: 92] vs. repeat M= 815 [SE: 58])* and single incongruent 2 condition, **t (20)= -5.1, p <.001** *(277ms switch cost, M= 1122 [SE: 75] vs. M= 835 [SE: 83])* but not at the single incongruent 1, t(20)= -4.6, p=.65 *(64ms switch cost, M= 1011 [SE: 72] vs. M= 943 [SE: 72])* and double incongruent condition, t (17)= .11, p=.91 *(39ms switch cost, M= 1034 [SE: 83] vs. M= 995 [SE: 103])*.

In both CTI conditions, the effect of congruency was non- significant at the CTI=100, [F (2, 39) = 1.4, p =.24] but it was significant at the CTI=1200, **[F (2, 41) =5.6, p =.005]** *(105ms of congruency effect, M= 614 [SE: 35], M= 643 [SE: 41], M= 736 [SE: 49], M= 778 [SE: 66])*.

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was marginally significant on the repeat trials, **t (20)= 1.8, p =.08** and it was significant on the switch trials, **t (20)= -3.0, p=.007**.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (18)= -1.7, p = .11 but it was significant on the switch trials, **t (20)= -2.6, p=.017**.

Error (%)

There was a non-significant 2-way interaction (trial type and congruency) in both at CTI=100, [F (2, 26)= .15, p=.82] and CTI=1200, [F (2, 31)=.92, p=.41].

The difference between switch and repeat trials in error percentage was non-significant at the CTI=100 [F (1, 16)= .003, p= .96] and it was marginally significant CTI=1200, **[F (1, 16) =3.5, p=.08]**.

The effect of congruency was significant both at CTI=100, **[F (2, 31) = 5.6, p=.008]** and CTI=1200, **[F (1, 25) = 4.8, p=.02]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (20)= .66, p =.52 and on the switch trials, t (20)= .33, p=.74.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the repeat trials, t (20)= .51, p =.62 and on the switch trials, t (20)= .74, p=.47.

Summary

a. A main effect of switch costs for the arrow task only occurred on reaction time for the short preparation interval and it was only marginally significant on error for the short preparation interval.

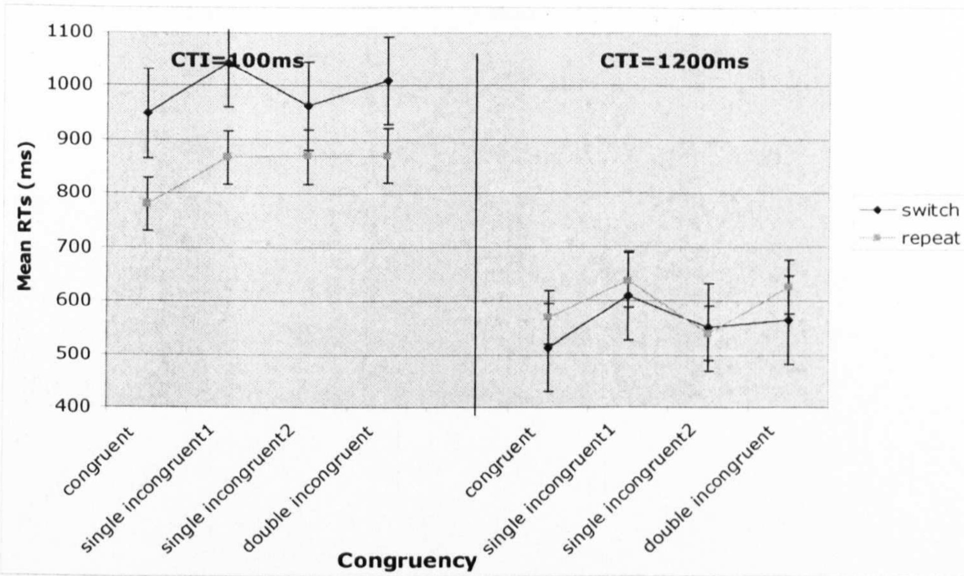
b. A main effect of congruency for the arrow task was observed on reaction time only for the long preparation interval and it was observed on error for both preparation intervals.

c. The interaction between congruency and trial type (switch/repeat trials) on reaction time was only significant for the short preparation interval and it was caused by the big switch cost at the congruent condition (292ms) and at the single incongruent 2 condition (277ms). It was non-significant on error.

d. The effect of previous congruency for the arrow task on reaction time was marginally significant during the repeat trials and it was significant during the switch trials for the short preparation interval. It was non-significant on error.

Location task

a. *RT (ms)*



b. *Error (%)*

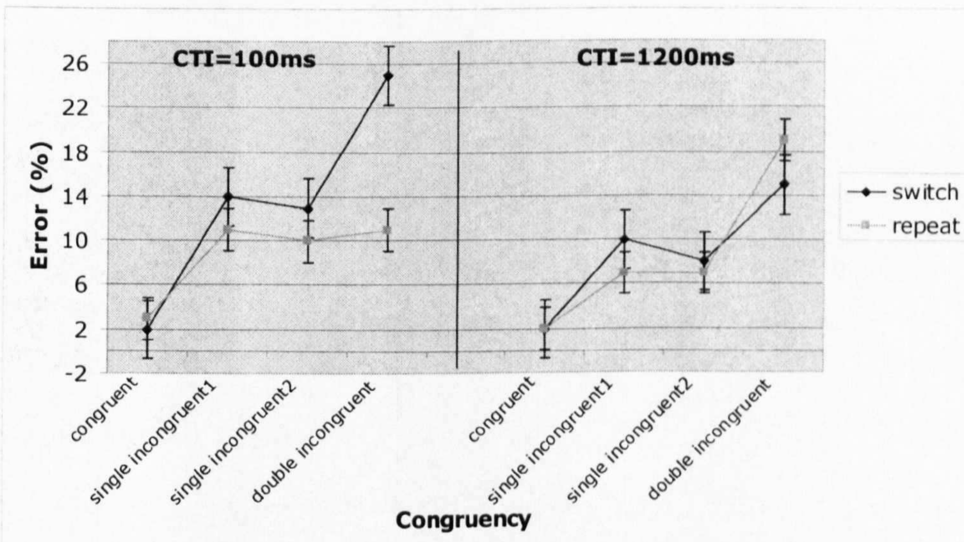


Figure 46. Mean RTs (and standard errors) (figure 46 a) and percent error scores (figure 46 b) in congruency and trial type in two CTI conditions for the location task.

RT (ms)

A significant difference between switch and repeat trials was found at the CTI= 100, **[F (1, 16)= 20, p =.005]** *(132ms of switch cost, switch M = 972 [SE: 65] vs. repeat M= 840 [SE: 53])* but not at the CTI=1200, [F (1, 18) = .03, p =.86] (see *Figure 46 a*).

A 2-way interaction between trial type and congruency was non-significant at the CTI=100, [F (2, 38) = 1.8, p =.17] and at the CTI=1200, [F (2, 35) = 1.1, p =.35].

The effect of congruency was marginally significant at the CTI=100, **[F (2, 37) = 2.9, p=.06]** *(75ms of congruency effect, M= 849 [SE: 59], M= 955 [SE: 63], M= 908 [SE: 62], M= 910 [SE: 61])* and it was significant at CTI=1200, **[F (2, 41) =5.6, p=.005]** *(56ms congruency effect, M=562 [SE: 41], M= 652 [SE: 43], M= 553 [SE: 45], M= 648 [SE: 57]).*

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the switch trials, **t (20)= 3.9, p=.001** but not on the repeat trials, t (18)= .06, p =.95.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (19)= 3.2, p = .005** but not on the switch trials, t (20)= 1.7, p=.10.

Error (%)

There was a non-significant 2-way interaction (trial type and congruency) in both at CTI=100, [F (2, 36)= 1.0, p=.38] and CTI=1200, [F (2, 27)= 1.1, p=.32].

The difference between switch and repeat trials in error percentage was non-significant at the CTI=100 [F (1, 16)= 2.3, p= .15] and CTI=1200, [F (1, 16) =.03, p=.86].

The effect of congruency was significant both at CTI=100, **[F (1, 23)= 7.5, p=.006]** and CTI=1200, **[F (1, 21) = 4.3, p=.04]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was marginally significant on the repeat trials, t (20)= .32, p =.75 but not on the switch trials, t (20)= -.44, p=.66.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (20)= -6.3, p <.001** and it was marginally significant on the switch trials, **t (20)= 1.9, p=.07**.

Summary

a. A main effect of switch costs for the location task on reaction time was only significant for the sort preparation interval whereas it was non-significant on error.

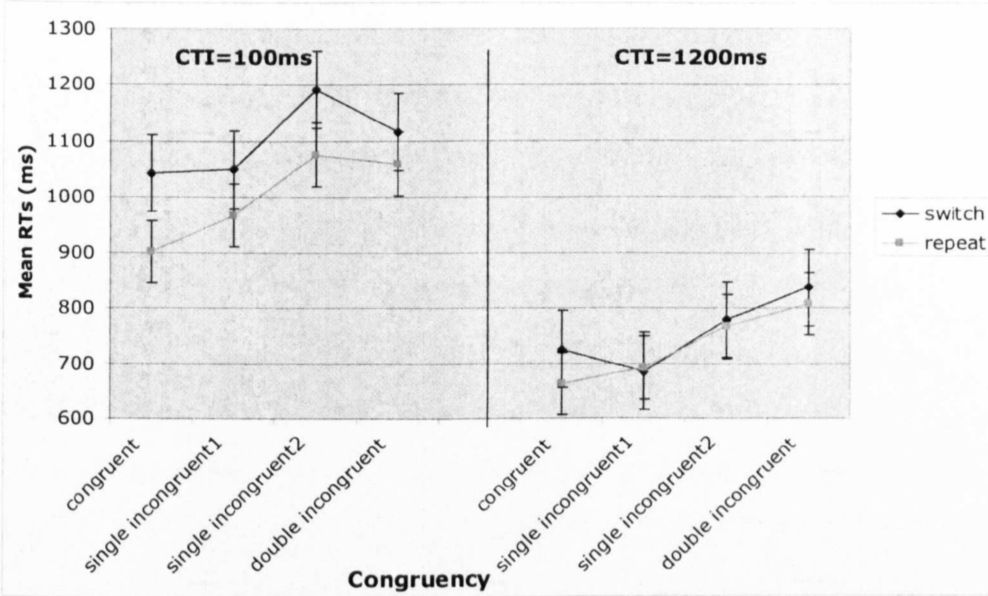
b. A main effect of congruency for the arrow task was observed on reaction time and error consistently for both short and long preparation interval.

c. The interaction between congruency and trial type (switch/repeat trials) was non-significant on reaction time and error.

d. The effect of previous congruency for the location task was only occurred on error during the repeat trials for the long preparation interval.

Word task

a. *RT (ms)*



b. *Error (%)*

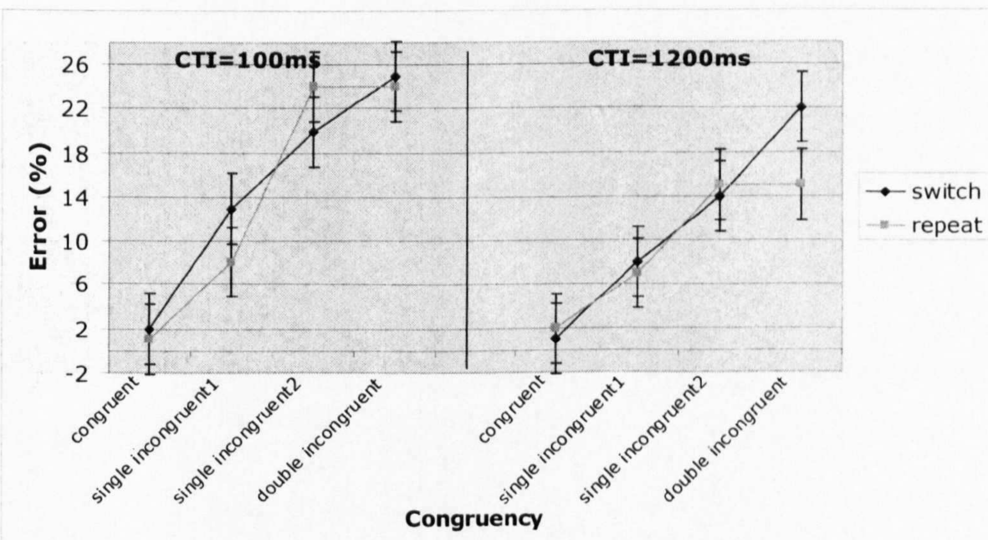


Figure 47. Mean RTs (and standard errors) (figure 47 a) and percent error scores (figure 47 b) in congruency and trial type in two CTI conditions for the word task.

RT (ms)

A significant difference between switch and repeat trials was found at the CTI= 100, **[F (1, 19)= 9, p =.007]** *(80ms of switch cost, switch M = 1074 [SE: 46] vs. repeat M= 994 [SE: 50])* and at the CTI=1200, **[F (1, 18) =**

7.7, p =.012] *(30ms of switch cost, switch M = 771 [SE: 35] vs. repeat M = 741 [SE: 34])* (see *Figure 47 a*).

A 2-way interaction in trial type and congruency was non-significant both at the CTI=100, [F (2, 43) =.15, p =.88] and CTI=1200, [F (3, 51) =.81, p =.50].

In both CTI conditions, the effect of congruency was significant at the CTI=100, **[F (2, 36)= 14, p<.001]** *(122ms of congruency effect, congruent M= 942 [SE:43], single incongruent 1 M= 965 [SE: 54], single incongruent 2 M= 1129 [SE: 54], double incongruent M= 1098 [SE:52])* and CTI= 1200, **[F(2, 51)= 22, p <.001]** *(81ms of congruency effect, M= 695 [SE:33], M= 690 [SE: 36], M= 807 [SE: 41], M= 832 [SE: 36]).*

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the switch trials, **t (20)= -3.7, p=.001** but not on the repeat trials, t (20)= -1.5, p =.15.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (19)= -4.1, p = .001** and on the switch trials, **t (20)= -4.9, p<.001**.

Error (%)

There was a non-significant 2-way interaction (trial type and congruency) in both at CTI=100, [F (2, 38)= 1.1, p=.36] and CTI=1200, [F (2, 42)=.79, p=.47].

The difference between switch and repeat trials in error percentage was non-significant at the CTI=100 [F (1, 16) =.96, p= .34] and CTI=1200, [F (1, 16) =1.6, p=.22].

The effect of congruency was significant both at CTI=100, **[F (2, 31)= 7.5, p=.002]** and CTI=1200, **[F (2, 26) = 4.5, p=.03]**.

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (20)= 3.0, p =.007** and it was marginally significant on the switch trials, **t (20)= 1.8, p=.08.**

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was significant on the repeat trials, **t (20)= 2.0, p =.05** and on the switch trials, **t (20)= 2.9, p=.008**.

Summary

a. A main effect of switch costs for the word task on reaction time occurred for both preparation intervals but not on error.

b. A main effect of congruency for the arrow task was observed on reaction time and error consistently for both short and long preparation interval.

c. The interaction between congruency and trial type (switch/repeat trials) was non-significant on reaction time and error.

d. The effect of previous congruency for the word task on reaction time was significant during the switch trials for the short preparation interval and during the switch and repeat trials for the long preparation interval. It was significant on error during the repeat trials and it was marginally significant during the switch trials for the short preparation interval. It was also significant during the switch and repeat trials for the long preparation interval.

2) Effect of alternating task

On Reaction Time (ms)

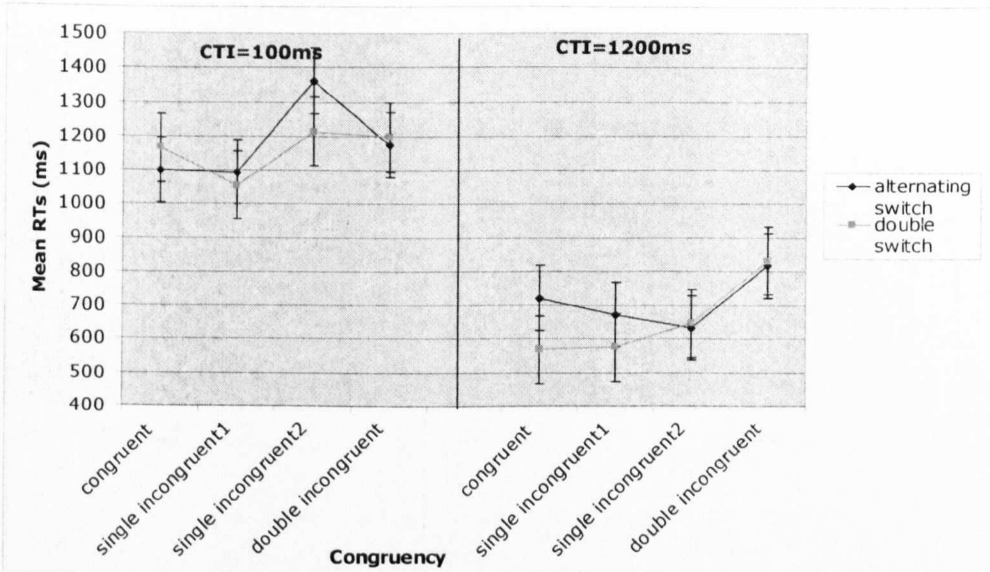
The repeated measures ANOVA with the factors CTI, switch type, task, and congruency revealed a non-significant 4-way interaction, [F (3, 45) =.96, p =.42] and a significant 3-way interaction (CTI, task and congruency), [F (4, 61) = 1.7, p=.16] (*see the Appendix, page 408 table 2a*). This interaction was explored by conducting three separate 3-way repeated measures ANOVA for each task. Each of these is reported below.

On Error (%)

Analysis of the 4-way repeated measured ANOVA with factors CTI, switch type, task and congruency revealed a non-significant 4-way interaction, [F (2, 41) = .40, p=.72], a significant 3-way interaction (CTI, switch type and congruency), **[F (2, 28)= 4.1, p=.03]** and a significant 2-way interaction (CTI and task) **[F (2, 29)= 6.4, p=.006]** (*see the Appendix, page 408 table 2b*). This 3-way interaction was explored by presenting three separate figures by each task as these figures were previously presented on the reaction time (RT). Each figure is reported below.

Arrow task

a. RT (ms)



b. Error (%)

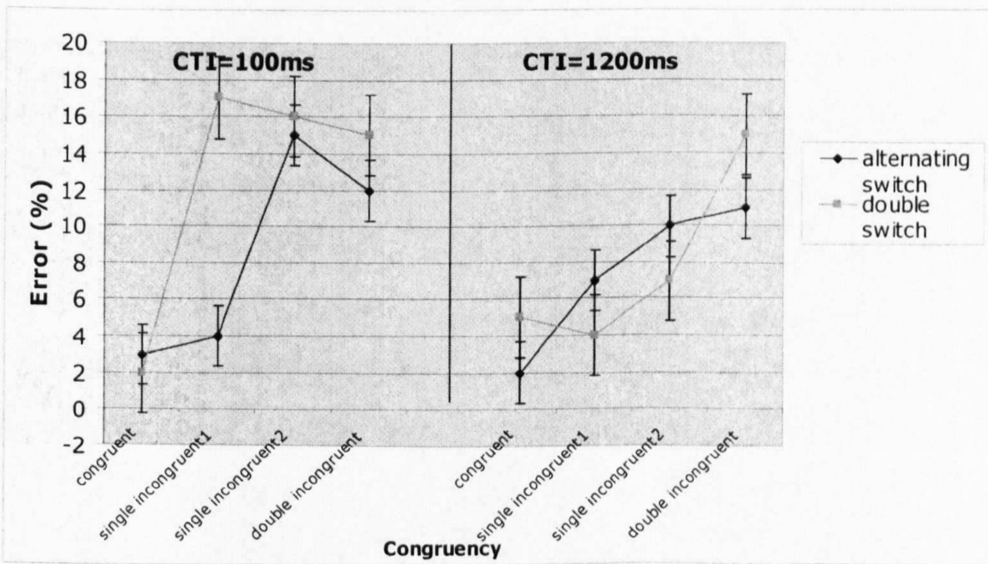


Figure 48. Mean RTs (and standard errors) (figure 48 a) and percent error scores (figure 48 b) in congruency and switch type in two CTI conditions for the arrow task.

RT (ms)

The effect of alternating switch was non-significant, [F (1, 15) =.35, p =.56] *(25ms of alternating switch cost, alternating switch M= 1183 [SE:*

94] vs. double switch M= 1009 [SE: 40]) both at the CTI= 100 and at the CTI=1200, [F (1, 15) =.49, p=.49] *(55ms of alternating switch cost, alternating switch M= 711 [SE: 59] vs. double switch M= 656 [SE: 34])* (see *Figure 48 a*).

A 2-way interaction between switch type and congruency was non-significant at the CTI=100, [F (2, 35)= .60, p=.57] and at CTI=1200, **[F (2, 31)=1.4, p=.25]**.

The effect of congruency was marginally significant at the CTI=100, **[F (2, 37)= 2.9, p=.06]** (50ms congruency effect, *M= 1133 [SE: 106], M=1075 [SE: 86], M= 1287 [SE: 99], M=1187 [SE: 103]*) and it was significant at the CTI=1200, **[F (2, 39)= 7.0, p=.001]** *(52ms congruency effect, M= 645 [SE: 38], M= 625 [SE: 41], M= 641 [SE: 25], M= 925 [SE: 55]).*

At the CTI=100, alternating switch trials were marginally affected by the factor congruency, **[F (2, 35)= 2.5, p=.08]** *(111ms congruency effect, M= 1100 [SE: 127], M= 1095 [SE: 103], M= 1361 [SE: 115], M= 1176 [SE: 117])* whereas double switch trials were not affected by the congruency, [F (2, 30)= .76, p=.48].

At the CTI=1200, double switch trials were only significantly affected by the factor congruency, **[F (2, 28)= 8.6, p=.001]** *(116ms congruency effect, M= 569 [SE: 33], M= 576 [SE: 43], M= 647 [SE: 36], M= 832 [SE: 74])* whereas alternating switch trials were not affected by the congruency, [F (2, 37)= 2, p=.14].

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (15)= -3.2, p =.006** but not on the double switch trials, t (15)= -1.2, p=.23.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (15)= .57, p = .57 and on the double switch trials, t (15)= -1.4, p=.18.

Error (%)

A difference in alternating switch and double switch trials was not significant either at CTI=100, [F (1, 16) =.36, p=.56] and CTI=1200, [F (1, 16)=.70, p=.41]. A significant effect of congruency was found in both CTI=100, **[F (2, 32)= 6.1, p=.006]** and CTI=1200, **[F (2, 35)= 13, p <.001].** The interaction in switch type and congruency was non-significant at the CTI=100, [F (2, 30)= 1.5, p=.24] and CTI=1200, [F (2, 33)= .77, p=.47].

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (20)= 1.2, p =.25 and on the double switch trials, t (20)= .98, p=.34.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (20)= -.48, p =.64 and on the double switch trials, t (20)= .60, p=.56.

Summary

a. A main effect of alternating switch costs for the arrow task did not occur on reaction time and error.

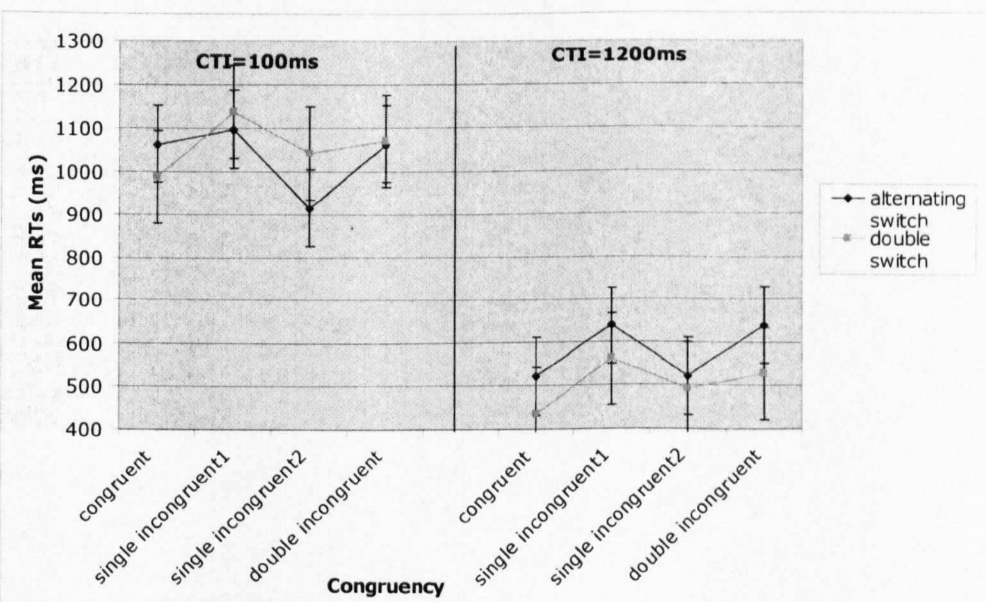
b. A main effect of congruency was observed on reaction time was marginal for short preparation interval and significant for the long preparation interval whereas it was significant for both preparation intervals on error.

c. The interaction between congruency and switch type (alternating switch/double switch trials) on reaction time and error was non-significant.

d. The effect of previous congruency for the arrow task was only significant during the alternating switch trials for the short preparation interval.

Location task

a. RT (ms)



b. Error (%)

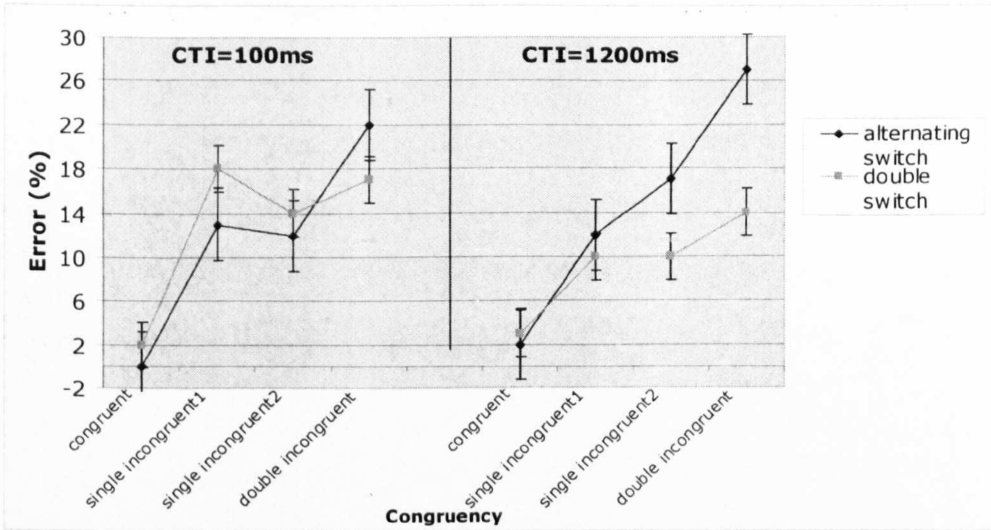


Figure 49. Mean RTs (and standard errors) (figure 49 a) and percent error scores (figure 49 b) in congruency and switch type in two CTI conditions for the location task.

RT (ms)

The effect of alternating tasks at the CTI= 100 was non-significant, [F (1, 15) = .00, p =.99] and at CTI =1200, [F (1, 15) =1.2, p=.29]. *(76ms alternating switch cost, M = 580[SE: 53] vs. M = 504 [SE: 26])* (see *Figure 49 a*).

A significant 2-way interaction between switch type and congruency was non-significant at CTI=100, [F (3, 39)= 1.9, p=.15] and at CTI=1200, [F (2, 38) = .46, p=.68].

The effect of congruency was significant at CTI=1200, **[F (2, 32) = 7.5, p=.002]** *(76ms of congruency effect, M= 478 [SE: 22], M= 601 [SE: 33], M= 507 [SE: 24], M= 583 [SE: 36]) but not* at CTI=100, [F (2, 31) = 2.1, p =.14].

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was marginally significant on the double switch trials, t (15)= 2.0, p=.07 but not, t (15)= 1.7, p =.10.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (15)= 3.0, p = .008** but not on the double switch trials, t (15)= 1.6, p=.13.

Error (%)

There was no significant difference in error percentage between alternating switch and double switch trials was found at the CTI= 100, [F (1, 16)= 2.9, p=.11] and at the CTI=1200, [F (1, 16)= .00, p=.99]. A significant effect of congruency was found at the CTI=100, **[F (1, 24)= 7.0, p =.007]** and marginally significant effect of congruency at the CTI=1200, **[F (1, 24)=3.1, p =.07]**. The interaction in switch type and congruency was non-significant at the CTI=100, [F (2, 32)= .42, p=.66] and CTI=1200, [F (2, 29)= .69, p=.49].

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (20)= 1.2, p =.25 and on the double switch trials, t (20)= .98, p=.34.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (20)= -.48, p =.64 and on the double switch trials, t (20)= .60, p=.56.

Summary

a. A main effect of alternating switch costs for the location task did occur neither on reaction time nor on error.

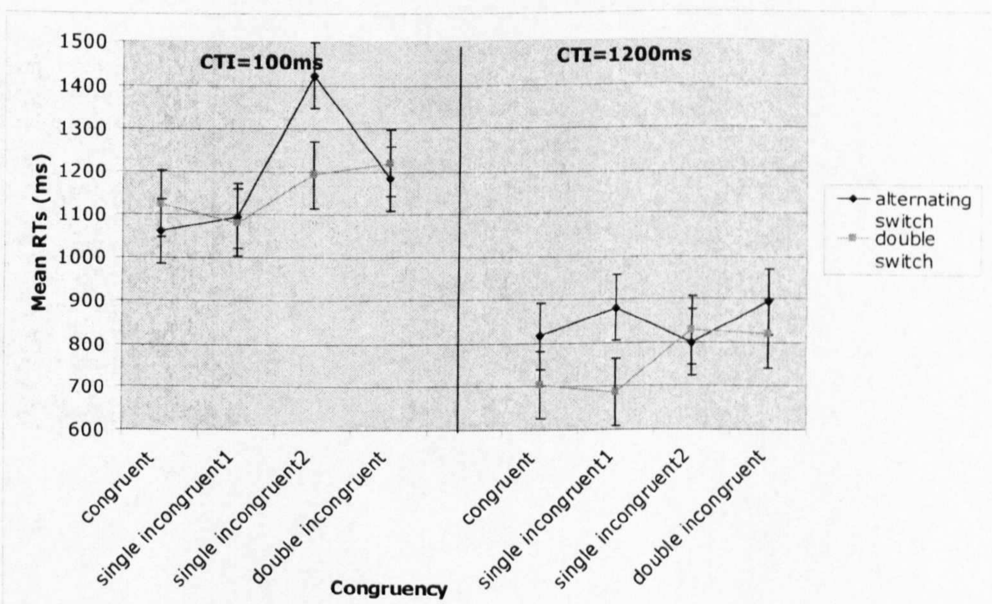
b. A main effect of congruency was observed on reaction time for short preparation interval and on error for both preparation intervals, showing that congruency affected both alternating switch and double switching trials.

c. The interaction between congruency and switch type (alternating switch/double switch trials) on reaction time and error was non-significant.

d. The effect of previous congruency for the location task was marginally significant during the alternating switch trials and it was significant during the double switch trials on reaction time. It was non-significant on error.

Word task

a. RT (ms)



b. Error (%)

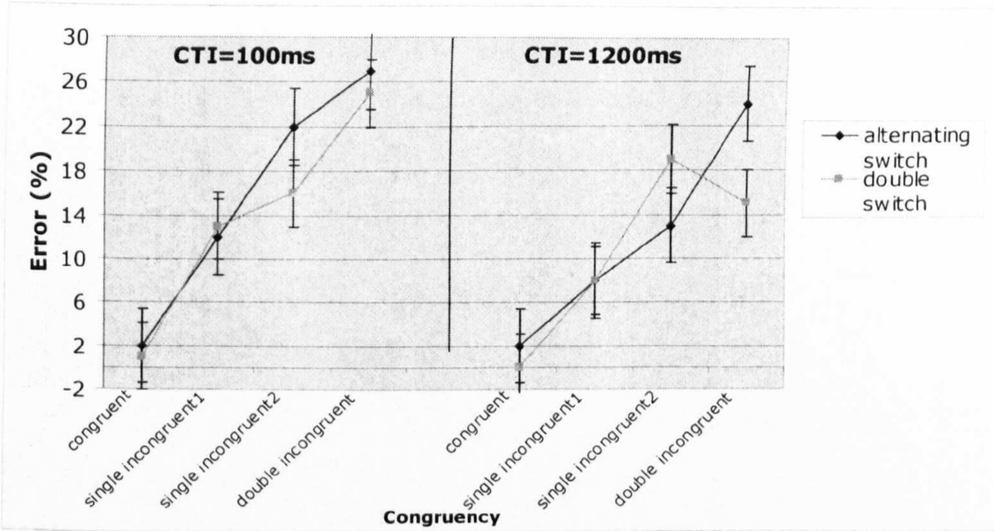


Figure 50. Mean RTs (and standard errors) (figure 50 a) and percent error scores (figure 50 b) in congruency and switch type in two CTI conditions for the word task.

RT (ms)

The effect of alternating task was non-significant both at the CTI= 100, [F (1, 15)= .63, p =.44] *(37ms of alternating switch cost, alternating switch M = 1191 [SE: 74] vs. double switch M= 1154 [SE: 48])* and at the CTI=1200, [F (1, 15) = 1.4, p =.26] *(88ms of alternating switch cost, alternating switch M = 848 [SE: 62] vs. double switch M = 760 [SE: 32]) (see Figure 50 a).*

The effect of congruency was significant both at the CTI=100, **[F (2, 32) = 5.5, p =.008]** *(106 ms congruency effect, M= 1093 [SE: 56], M= 1087 [SE: 64], M= 1308 [SE:83], M= 1202 [SE: 74])* but not at the CTI=1200, [F (1, 22)= .80, p =.43]. The congruency effect at the CTI=100 was as a result from the fact that alternating switch trials were marginally affected by the congruency, **[F (2, 35)= 2.5, p=.08]** *(173ms of congruency effect, M= 1061 [SE: 88], M= 1094 [SE: 82], M= 1422 [SE: 134], M= 1185 [SE:*

108]) whereas double switch trials were not affected by the congruency, [F (2, 30)= .76, p=.48].

The interaction in switch type and congruency was non-significant both at the CTI=100, [F (2, 34)= 1.6, p=.21] and CTI=1200, [F (1, 21)= 1.1, p=. 32].

The Effect of Previous Congruency

At the CTI=100, RT difference between single incongruent 1 and single incongruent 2 was significant on the alternating switch trials, **t (15)= -2.7, p =.02** but not on the double switch trials, t (15)= -1.5, p=.16.

At the CTI= 1200, RT difference between single incongruent 1 and single incongruent 2 was significant on the double switch trials, **t (20)= -4.9, p <.001** but not on the alternating switch trials, t (15)= -.49, p = .63.

Error (%)

A difference in alternating switch and double switch trials was not significant at CTI=100, [F (1, 16) = 1.1, p =.30] and CTI=1200, [F (1, 16)= .82, p =.38]. A significant effect of congruency was found at both CTI=100, **[F (2, 36) = 6.6, p=.003]** and CTI=1200, **[F (2, 30)= 4.2, p =.025]**. The interaction in switch type and congruency was significant at the CTI=1200, **[F (2, 32)= 4.4, p=.02]** but not at the CTI=100, [F (2, 38)= 1, p=.38].

The Effect of Previous Congruency

At the CTI=100, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (20)= 1.2, p =.25 and on the double switch trials, t (20)= .98, p=.34.

At the CTI= 1200, mean error percentage between single incongruent 1 and single incongruent 2 was non-significant on the alternating switch trials, t (20)= -.48, p =.64 and on the double switch trials, t (20)= .60, p=.56.

Summary

a. A main effect of alternating switch costs for the word task did not occur on reaction time. Note that there was 88ms of alternating switch cost in the long preparation interval but it was not statistically significant. It was observed on error for the short preparation interval.
b. A main effect of congruency was observed on reaction time only for the short preparation interval and on error for the long preparation interval.
c. The interaction between congruency and switch type (alternating switch/double switch trials) was non-significant on reaction time error.
d. The effect of previous congruency for the word task on reaction time was significant during the alternating switch trials for the short preparation interval and during the double switch trials for the long preparation interval. It was non-significant on error.

3) Effect of cues (exp 6a vs. exp 6b)

On Reaction Time (ms)

- **For switch/ repeat trials**

There was a group effect in 4 way interaction (CTI, trial type task and, congruency) **[F (5, 145)= 2.9, p =.02]** and group effect in CTI and trial type, **[F (1, 31)= 7.9, p=.009]**. The group effect in 4-way interaction was as a result from a significant 4-way interaction in the experiment 6b with arbitrary cues, **[F (4, 57)= 3.8, p=.007]** but not in the experiment 6a with verbal cues, [F (4, 73)= 1.5, p=.22]. The group effect in CTI and trial type was as a result from a big switch cost during the CTI=100 in the experiment 6b *(139ms switch cost, switch M= 1054 [SE: 48], repeat M= 915 [SE: 44])* compared to the experiment 6a *(58ms switch cost, switch M= 852 [SE: 41], M= 794 [SE: 38])* whereas the switch costs in both experiments disappeared during the CTI=1200 (see *Figure 51*).

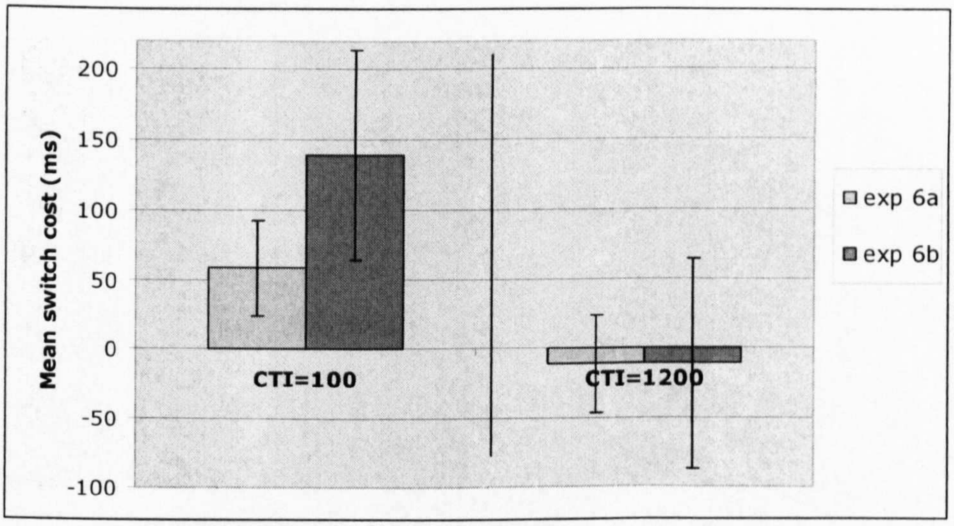


Figure 51. Mean RT switch cost (and standard error) during the two preparation intervals for experiment 6a and 6b.

Thus, there was a group effect of trial type, **[F (1, 31)=7.1, p=.01]** because the experiment 6b *(119ms switch cost, switch M= 857 [SE: 39], repeat M= 738 [SE: 33])* demonstrated more switch costs than experiment 6a *(77ms switch cost, switch M= 793ms [SE: 36], repeat M= 738 [SE: 33])*. The main effect of group was significant, **[F (1, 31)= 4.1, p=.05]** *(exp 6a, M= 727 [SE: 32] vs. exp 6b M= 825 [SE: 37]) (see the Appendix, page 392, table 8).*

• **For alternating / double switch trials**

There was only a main effect of group, **[F (1, 33) = 8.6, p= .006]** *(exp 6a M= 764 [SE: 32] vs. exp 6b M= 905 [SE: 35])* as the experiment 6b demonstrated much slower RT than experiment 6b (*see the Appendix, page 392, table 8*).

On Error (%)

• **For switch/ repeat trials**

There was a group effect in CTI, trial type, task and congruency, **[F (4, 151)= 9.2, p<.001].** As the mean of error percentage for each experiment has already been discussed previously by demonstrating the figures for each task, The main effect of group was significant, **[F (1, 36)= 4.2, p=.05].**

• **For alternating switch/double switch trials**

There was no group interaction with each factors, however, the main effect of group was significant, **[F (1, 34)= 5.3, p=.03]** because the mean error percentage of exp 6b was significantly bigger than exp 6 a (exp 6a: 5% vs. exp 6b: 11%).

DISCUSSION

The main aim of this experiment was to see whether separate display of the cue and target influence the size of switch cost and backward inhibition as well as congruency effect. In addition, experiment 6a and 6 b were compared to see the cue type effect between verbal and arbitrary cues for all three tasks.

1) Effect of task switching

- ***Switch costs*** for the long preparation interval in all three tasks were dramatically reduced in terms of reaction time compared with the short preparation interval, suggesting that participants used long preparation interval for advanced configuration process based on the hypothesis that preparation effect indicates the time required to establish a task set. In all three tasks, main effect of switch cost was only significant in the short preparation interval for the reaction time whereas it was significant for both preparation interval for the error except for the word task (only significant at the long CTI for the error), suggesting that participants still made errors while making a fast response (cf. speed-accuracy trade-off). This pattern was similar to the previous experiment 1.
- ***Congruency effect on the current trials*** shows how active the other task sets remains. In all three tasks, they demonstrated big congruency effect in reaction time and error, suggesting that participants made slower response and more errors when it was incongruent regardless of the preparation interval. Note that significant congruency effects were observed in both switch and repeat trials. Having congruency effects during the repeat trials for all three tasks suggests that the persistent activation of the irrelevant task set indeed interfere with the current task set because there is no need to suppress the irrelevant task set during the repeat trials, causing the other task set to be persistently activated.
- ***The interaction between congruency and trial type (switch/repeat)*** shows whether switch trials are more influenced by the repeat trials. If so, the bigger congruency effect on the switch trials suggests that switching different tasks are influenced by the level of

activation from the other task sets on the current trials. In the current experiment, there was only significant interaction for the arrow task during the short preparation interval which was as a result from the lack of switch cost at the single incongruent 1 condition and the significant switch cost at the rest of congruent condition (congruent, single incongruent 2 and double incongruent). At this stage, it is not clear why single incongruent 1 condition caused no switch cost during the short preparation interval for the arrow task.

- ***Previous congruency*** shows that the task set from the previous N-1 trials remains in a state of residual activation. In other words, the persisting activation of previous task set interfered with a subsequent task switch, depending on whether it activates a response that is the same as or different from the response by the new task set on the current trials. In the arrow task, the repeat trials were only influenced by the previous congruency during the short preparation interval on reaction time. However, in the location task, the switch trials were only influenced by the previous congruency during the long preparation interval on reaction time and error. In the word task, both switch and repeat trials in any preparation interval (short and long) were influenced by previous congruency on reaction time.

2) Effect of alternating task

- ***Alternating switch costs*** was only observed in the arrow task during the short preparation interval at the single incongruent 2 condition (136ms) whereas the rest of tasks did not show any significant alternating switch cost on reaction time and error. Note that there were 68ms of alternating switch cost at the single incongruent 2 and 71ms of alternating switch cost at the congruent condition for the location task when the preparation interval was 1200ms.

- ***Congruency effect on the current trials*** shows how active the other task sets remain. In all three tasks, they demonstrated big congruency effect in reaction time and error, suggesting that participants made slower response and more errors when it was incongruent regardless of the preparation interval.
- ***The interaction between congruency and switch type (alternating switch/double switch)*** occurred only on reaction time not on error in all three tasks. In the arrow task, the interaction was only significant at the long preparation interval which was as a result from a huge reversed alternating switch cost (-122ms) at the single incongruent 2 condition. In the location task, the interaction was only significant at the short preparation interval which was as a result from the significant congruency effect on the alternating switch trials and a non-significant congruency effect on the double switch trials. In the word task, the interaction was significant in both preparation intervals as the current congruency had more impact on the alternating switch trials than double switch trials.
- ***Previous congruency*** significantly affected the double switch trials during the long preparation interval for the arrow task on reaction time and it also marginally affected the alternating switch trials during the long preparation interval on error. For the location task, it only occurred on error but the previous congruency on the double switch trials at the short preparation interval and on the alternating switch trials at the long preparation interval were opposite direction. In other words, the error was larger on the current location task when the previous trials were

congruent compared to when the previous trials were incongruent. This suggests that participants had more difficulties performing the location task when it was congruent to the previous task. The word task was also affected by the previous congruency in both switch trials during the both preparation intervals on reaction time.

3) Effect of cues

Exp 6 b with arbitrary cues had a huge switch cost (139ms switch cost) compared to exp 6 a with verbal cues (58ms switch cost) during the short preparation interval, suggesting that exp 6 b required a high working memory load for learning the meaning of cues during the short CTI. However, there was no group interaction in alternating switch cost. Overall, the RT was slower in the exp 6b than in the exp 6 a resulted in a main effect of group.

CONCLUSION

The present experiment in this chapter demonstrated the substantial amount of switch costs and congruency effect on the current trials whereas the alternating switch costs were not observed. Having a separate display between cue and target indeed might require the extra time to overcome the inhibition from the previous trials but the current result demonstrated that this cue-target separate presentation did not cause backward inhibition. One speculation is that there might be another inhibitory control mechanism on the response selection level in task switching, yet alternating switch costs might be not the right measurement in this particular experiment paradigm. Further study is required to examine the separate inhibitory mechanism apart from the backward inhibition.

Chapter 9

Cognitive model for backward inhibition in task switching

Since the task switching paradigm has been introduced to understand the cognitive control, various models of task switching have been proposed to explain the consistent finding that even a simple switch between different tasks causes participants to take extra time to complete the task (known as 'switch cost'). In this chapter, some of earlier studies on modelling in task switching will be discussed and a new backward inhibition model based on parallel-distributed processing (PDP) model which I developed for my experimental paradigm will be proposed.

A. Cognitive models in task switching

The basic and simple question among researchers who study task switching must be to explain switch costs. In the past decade, two primary account have emerged which I already introduced in the first chapter: task-set reconfiguration and task set inertia (task set priming). Although the current trend in task switching now accepts the idea that both accounts are not mutually exclusive, there has been ample amount of work to develop the cognitive model either to support one of two accounts or to combine both while the classical debate on switch cost has become less dominant.

For example, one class of early models suggests that switch costs reflect an additional control reconfiguration needed to reconfigure the system for the switch to a new task. This model has two variants, differing in the stage where the control processes takes place.

Rubinstein et al. (2001) suggested that one of the switch-specific control processes (e.g., rule activation) is inserted between the stimulus and identification and response stages, causing a delay in the onset of response selection on switch trials (Hiesh & Liu, 2005). According to Rubinstein et al. (2001)'s model, performance during the successive-task procedure entails two complementary sets of stages: *executive control processes* and *task processes*. For the executive control processes, they included two distinct stage, 1) *goal shifting* and 2) *rule activation*, which are accomplished through executive production rules. Together, goal shifting and rule activation respectively ensure that the contents of declarative and procedural working memory are appropriately configured for the task at hand. For the task processes, they assumed that task processes are used for performing individual perceptual-motor and cognitive tasks under both single-task and multiple-task conditions. In their model, they included three principal stages, stimulus identification, response selection and movement production, which operate on the basis of information in declarative and procedural working memory (Meyer & Kieras, 1997a, 1997b; Sternberg, 1969). In their four experiments, participants had to alternate between different tasks or performed the same task repeatedly. The tasks for two of the experiments required responding to geometric objects in terms of alternative classification rules, and the tasks for the other two experiments required solving arithmetic problems in terms of alternative numerical operations. Performance was measured as a function of whether the tasks were familiar or unfamiliar, the rules were simple or complex, and visual cues were present or absent about which tasks should be performed. Task alternating yielded the switch costs that increased with rule complexity but decreased with task cuing. They found that rule activation takes more time for switching from familiar to unfamiliar tasks than for switching from unfamiliar to familiar task.

On the other hand, Meiran (2000) suggested that the control processes (e.g., Stimulus-Set Biasing) is inserted soon after the stimulus onset and before the stimulus identification stage. His assumption was that when stimuli and responses are bivalent, switching between stimulus classification tasks entails a change in the interpretation of stimuli, responses or both. In other words, the target stimuli as well as the responses are bivalent. Specifically, a given target stimulus could be classified both in up-down terms and in right-left terms. Similarly, a given physical response could serve to indicate a nominal response to either task, e.g., up, belonging to the up-down task, and left, belonging to the right-left task. In his model, the important concept was the task sets which govern how mental representations are formed. He suggested that there are three task sets, a *stimulus task set (S-Set)*, and two *response task sets (R-sets)* and the role of the task sets is to deal with the bivalent aspects of the task. He also argued that this would be done through the biasing of the mental representation in favour of one dimension. For example, applying the appropriate S-Set to the upper-left target stimulus results in a mental representation where 'up' is emphasised relative to 'left'. His model suggested that the preparatory switching cost reflects the duration of the S-

Set biasing stage. S-Set biasing is required only when the stimulus are bivalent, not when they are univalent.

The other class of models, however, suggests that both switch and repeat trials entail the same set of processes, but that on switch trials, at least one process is prolonged by a carry-over effect from the previous trials (Allport et al., 1994; Allport & Whylie, 2000; Sohn & Anderson, 2001) . Despite their emphasis on the priming/ carry-over effect, they also include the possibility that endogenous executive processes do exist, which may reconfigure task processing systems before or after stimulus onset. For example, Sohn & Carlson (2000) compared switch and repeat trials with and without foreknowledge- a kind of pre-information about the task- about whether to switch or repeat a task. The author (2000) suggested that an example of executive control is the foreknowledge effect. In other words, when a task goal is specified in advance, the task can benefit significantly from the endogenous preparation on the basis of foreknowledge even if the stimuli to be processes are not yet available (Carlson & Ludy, 1992; Sohn & Carlson, 1998). They observed that the cost decreased with RSI and practice regardless of foreknowledge. In other words, the amount of switch cost did not depend on foreknowledge. The results clearly showed that no interaction in task type (switch vs. repeat) and foreknowledge.

The reduction was greater with foreknowledge than without foreknowledge. These results suggest that switch costs with foreknowledge may consist of both inadequate preparation and repetition benefit but switch costs without foreknowledge may reflect repetition benefit only.

The premise was that task preparation can be achieved by giving people foreknowledge that they would perform a specific task; its effect reflects endogenous executive control whereas task repetition could be achieved by having people perform the same task; its effects without foreknowledge of repetition reflect exogenous automatic control. Their results supported the view that switch costs represent an automatic carry-over effect that is unaffected by advance reconfiguration. They suggested that although foreknowledge allows preparation of both repeat and switch tasks, repeat the same task has benefits over task switching regardless of foreknowledge. In particular, Sohn & Anderson (2001) soon proposed ACT-R (adaptive control of thought-rational) model accommodating both preparation and priming effect with two independent processes: 1) *conflict resolution among productions* - declarative component and 2) *decay of chunk activation* - procedural component. Precisely, declarative component will hold information such as the mapping of the colour onto task or the mapping of categories (e.g., odd and even) and repetition of such declarative components will provide the repetition priming benefit with or without foreknowledge. The procedural component will be responsible for setting the goal to do one task or another and then for the preparation for the task switching during RSI.

On the other hand, Ruthruff et al. (2001) argued for the existence of a task set configuration stage, but proposed that this stage is needed only when the task is unexpected, not when it is task switch (Hiseh & Liu, 2005). In their experiments, they showed additive effect between *task expectancy* (reconfiguration control process) and *task recency* (carry-over effect) and surmised that task expectancy affects the time required to prepare upcoming central mental operations (task set configuration), whereas task switch (task recency) affects the duration of the response selection stage which does not begin until a) the required input processing has been completed and b) the task set has been configured (see page 1408 in their article, Ruthruff et al, 2001). Their so-called 'configuration-execution model' is in line with the computational models proposed by Gilbert & Shallice (2002) as well as Yeung & Monsell (2003) in that it triggers the reconfiguration process sóon after stimulus onset that then operates in parallel with stimulus identification. However, such a configuration is only required on unexpected trials, not on switch trials. Computational models from Gilbert & Shallice (2002) and Yeung & Monsell (2003) shares the same characteristics in their serial stage-like cognitive architecture but the differences lies in a postulation of where a reconfiguration control process specific to switch trials occurs in the stream of task information processing (Hsieh & Liu, 2005).

For example, Gilbert & Shallice (2002) presented a parallel distributed processing (PDP) model that simulates the switch cost when participants switch between word reading and colour naming in response to Stroop stimuli. Reaction time on 'switch trials can be slowed by an extended response selection process which result from a) *persisting, inappropriate states of activation and inhibition of task-controlling representations*; and b) *associative learning*, which allows stimuli to evoke task sets with which they have recently been associated (as proposed by Allport & Wylie, 2000). Their model provided a good fit to a large body of explanation of switch costs, especially asymmetrical switch cost[1] in the Stroop task. According to

[1] Stroop (1935) demonstrated that it was easier to read the word than to name the colour. Allport et al.(1994) proposed that the colour task requires strong suppression of word reading, but not vice versa. As a result, the word task is strongly suppressed following a switch from colour naming. This generates a large switch cost in the word task, but there is a smaller cost for switches into the colour task since it was not previously suppressed or was suppressed to a lesser degree (Gilbert & Shallice, 2002).

their model, a paradoxical asymmetry in switch costs can result from differences in top-down inputs for the two tasks, regardless of their possible differences in the requirement for competitor suppression between the two tasks. Arguably, they concluded that switch costs reflect an interference effect caused by a carry-over of task set and task switching paradigm might have less relevance to executive control if the switch cost simply reflects an interference effect caused by a carry-over of task set. However, they also insisted that their model could still reflect states of executive control, i.e., the top-down control inputs that both tasks receive, thus they aimed to study these top-down control inputs indirectly, using the model to infer top-down input settings from behavioural data. They also pinpointed that the role of the task switching paradigm in the study of cognitive control could occur once the carry-over effect of task set and stimulus-driven retrieval of task set are understood.

Later on, Yeung & Monsell (2003a) provided an analytical demonstration of how the interaction the observed between switching, interference, and relative task strength can emerge from an interaction between task priming and control input. In their model, task sets are held to compete according to their degree of activation, with competition between task sets dependent on task strength, control input, and task priming effects as in previous task priming accounts of the switch cost (e.g., Allport et al., 1994). They assumed that a) *asymmetrical priming*: task priming effects are particularly large following performance of a weak task like Allport et al. (1994) and b)

However, Yeung & Monsell (2003a) later showed the reverse Stroop effect; it was easier to name the colours than to name words by training extensively; the word-reading task was the stronger (easier) task for participants because they had more practice.

minimisation of control: participants typically apply the minimum control to perform the required task with a reasonable degree of accuracy (cf. Goschke, 2000) as the top-down is effortful. By simulating their results in a simple formula model, they emphasised that the importance of the modelling work was to distinguish the use of the term 'switch cost' from 'task priming effect'. In other words, the implication of their model was to ensure the term 'switch cost' should not be allowed to obscure the fact that task priming effects benefit performance when a task is repeated as well as disrupting performance when task requirements change. They suggested that the expression of these positive and negative effects of task priming would be influenced by the strength of top-down control biases applied to ensure that the appropriate task was performed.

More recently, Logan & Schneider (2006) argued that switch costs reflect priming of cue encoding when successive cues are identical or associatively related. They agreed with Logan & Bundesen (2003, 2004) and Arrington & Logan (2004)'s idea that performance in the explicit task-cuing procedure (ref. *see the chapter 8, page 259-269*) may reflect a *compound stimulus strategy* or a *compound retrieval cue strategy*, in which subjects encode the cue, encode the target, and use them as a joint retrieval cue to pull an appropriate response from memory. However, Logan and Schneider (2006) argued that the compound retrieval cue strategy does not explain the small but persistent difference between task repetitions and task alternations that often occurs with meaningful word cues although it explains the difference between cue repetitions and task repetitions. Across experiments, this difference ranges in magnitude from -2 ms (Logan & Bundesen, 2004) to 69 ms (Arrington & Logan, 2004). Schneider and Logan (2005) also noted that meaningful word cues assigned to the same task are semantically related, so they may prime each other on task repetition trials. Thus, Logan and Schneider (2006) questioned that these semantic or associative priming effects on task repetition trials should be smaller than the repetition priming effects on cue repetition trials. They also suggested that task repetitions should be slower than cue repetitions but faster than task alternation. In order to test this priming hypothesis, they used four cues for two tasks (parity/ magnitude judgements for single digits). They used word cues in order to manipulate the semantic and associative relations between the cues assigned to same and different tasks. They used word cues that were arbitrarily related to the tasks to be performed: four pairs of associated words - day/night, noun/verb, king/queen and salt/pepper. One subject group (associated-within condition); both words in an associated pair were assigned to the same task. For example, day/night for the magnitude task and noun/verb for the parity task were assigned. The other subject group (associated-between condition); the words in an associated pair were assigned to different tasks. For example, day/noun was assigned to the magnitude task and night/verb was assigned to the parity task. In the unassociated condition, four words from different associated pairs were assigned to the two tasks. For example, day/noun for the magnitude task, and queen/pepper for the parity task were assigned. By using two cues for each task, it allowed the three transitions between trials: cue repetition, task repetitions and task alternations. The novel contribution from their experiments was to demonstrate cue-encoding benefits from semantic or associative priming for task repetitions, in which the cue changed but the task stayed the same. For these transitions, cue encoding was faster if successive cues were semantically or associatively related than if they were unrelated. They demonstrated semantic or associative priming of cue encoding in analyses of mean RTs and in fits of the models based on their priming hypothesis to the time course function. From their results, they suggested that those differences between task repetitions and task alternations can be interpreted in terms of semantic or associative priming between related cues, which would occur for task repetitions but not for task alternations.

Note that Mayr and Kliegl (2003) previously reported experiments with two cues for each task. Their research question was simple: Are switch costs actually due to a trial-to-trial change in the task itself, or can they be attributed to a trial-to-trial change in retrieval path? Because whenever there is a change in cue, there is also a change in task; whenever cues stay the same across the trials, tasks also stay the same. Thus, they wanted to separate the cue-switch component and the actual task-switch component which both contribute to total switch costs in an undifferentiated manner.
Like Logan and Bundesen (2003), they found large differences between cue repetitions and task repetitions (298 ms in one experiment; 204 ms in another), but Unlike Logan and Bundesen (2003)'s experiments, they found large differences between task repetitions and task alternations (302ms in one experiment; 204 ms in another). They also found that cue-switch costs but not task-switch cost were sensitive to the practice and preparation whereas task-switch costs were particularly sensitive to response-priming effect and task-set inhibition.

Mayr and Kliegl (2003) interpreted their results as consistent with reprogramming theories (reconfiguration theories) of task switching.

Specifically, they proposed that two distinct, serial processing stages are critical during changes of task configurations and thus for the emergence of switch costs. The first stage is associated with cue-driven retrieval of rules for upcoming task demands from long-term memory (LTM) into working memory (*retrieval stage*). This stage cane be triggered through any internal or external signal that indicates an upcoming task, and it can run off in an anticipatory manner (i.e., before the response relevant stimulus appears). The second stage, which we refer to as the *application stage*, is much more closely tied to the actual stimulus than to the task cues. During this stage, task rules were applied in a relatively automatic manner once this stimulus was presented (although they did not want to exclude the possibility that an imagined stimulus may be sufficient). This two stage conceptualization was similar to some other two-process accounts of task switching (e.g., Meiran, 2000; Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, 2001) which I introduced earlier in this chapter.

In summary, the earlier models on task switching have focused on where this reconfiguration actually occurs with different ideas. Later on, the models have been more moved on to the carry-over (priming) theory by implementing the data and simulating the formula. In the next section, I will introduce the backward inhibition model based on PDP model by Gilbert and Shallice (2002) in order to understand the relationship between switch cost and backward inhibition.

In the next section, the conceptual model for the experiements will be presented and then PDP model in backward inhibition will be discussed by providing the basic formula based on Gilbert and Shallice (2002) model in task switching.

B. PDP model in backward inhibition

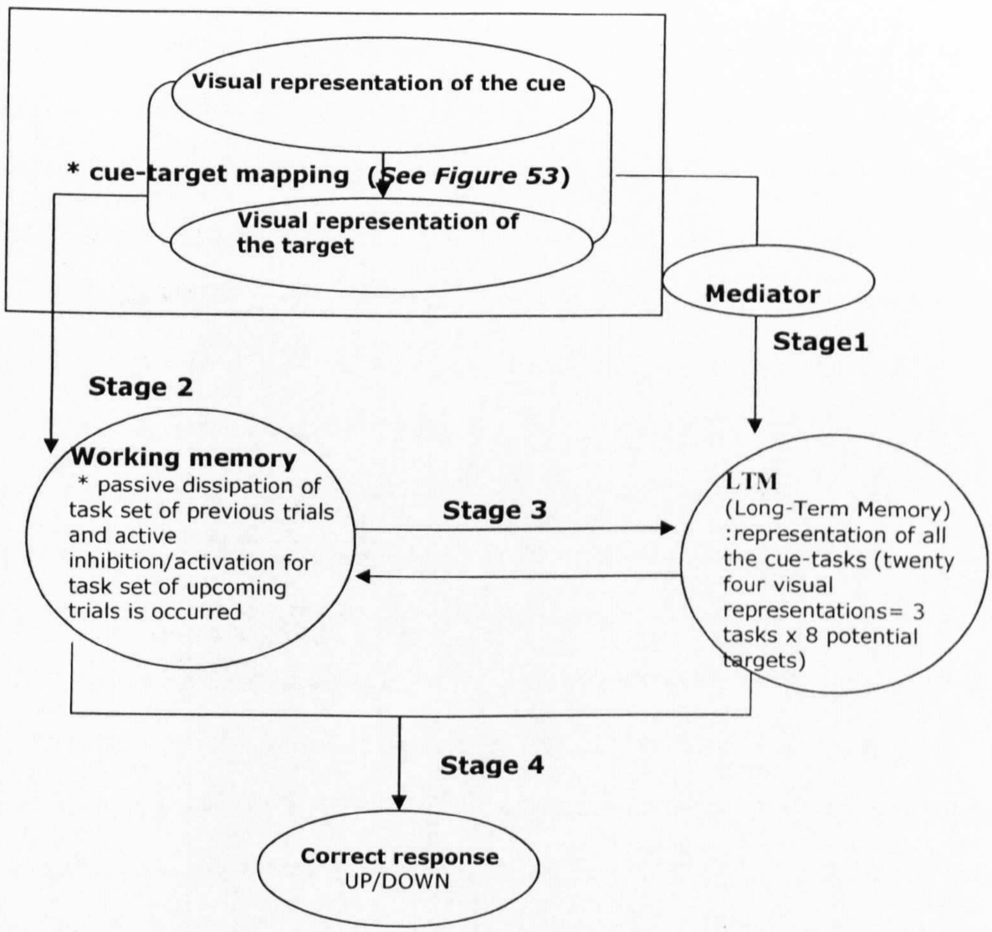


Figure 52. presents conceptual model in the current experimental paradigm.
* Note: The PDP model of cue-target mapping will be presented in the next figure 53.

Figure 52 presents the dynamics between working memory and long-term memory (LTM) while performing task switching in my experimental paradigm. When participants perform the current task, they learn the meaning of cues for each task and twenty-four visual representations are encoded in the LTM. During this stage, there is a mediator- a kind of mental bridge- helps to encode all the twenty-four visual representations in LTM. This is a hypothesis that 'mediator' helps encoding to LTM in a fast and efficient way, by reflecting either the activation of the abstract irrelevant-response category or the rule relating the stimulus to the irrelevant category. However, it is still tentative to define the role of mediator at this point. One of options for explaining the role of mediator is that inner speech (verbalisation) would be responsible for the efficient processing. The idea of inner speech has been previous suggested (Carlson, 1997; Mecklinger et al., 1999; Goshke, 2000; Emerson & Miyake; 2003). For example, Emerson & Miyake (2003) examined the role of inner speech in task switching by dual-task and demonstrated that disrupting inner speech via articulatory suppression dramatically increased switch costs. They concluded that inner speech serves as an internal self-cuing device by retrieving and activating a phonological representation of the upcoming task. Goshke (2000, exp 2) also demonstrated that participants showed the smaller switch costs between colour judgement and letter judgement task who said the task name than among those who verbalised an irrelevant word. In fact, the switch cost for participants who verbalised the task name was virtually identical to the cost for participants who had a long preparation interval of 1500ms without any verbalisation requirement, whereas the switch cost for participants who verbalised an irrelevant word was similar to the cost observed for participants who received a short preparation interval of 14ms. These findings suggest that the opportunity to verbally remind oneself which task to perform next may indeed be an effective strategy to prepare for the forthcoming switch (Emerson & Miyake, 2003).

Although the results from both of these studies poin to the role of inner speech in task switching, they also raised a number of questions that need to be answered. For example, it was unclear whether the switching impairment associated with articulatory suppression go beyond the general decrement often observed when two tasks are performed simultaneously.

In my current model, my aim was not focused on addressing these questions but on the fact that inner speech would be one of hypotheses to function mediator stage. For example, arrow and location tasks when there was no verbal cues (e.g., Exp 1) compared to the word task with verbal cues, these tasks are much needed for mediator. Once the mediator is playing a role to links to the stimulus directly to the response, it will be actively involved in task switching performance.

For instances, when participants prepare themselves for task switching, some or all of LTM representation (twenty four representations) that were used to make the classifications become a part of activated LTM. It is assumed that mediator is highly accessible and efficient. Thus, when a target stimulus is presented, both relevant response category (i.e., the correct response for the current task) and the irrelevant category (i.e., the correct response for the other two tasks) become activated.

In order to avoid the risk that participants apply the wrong response, they had to activate the eight target representations (i.e. each task has eight target representations) in their working memory and inhibit the rest of target representations (sixteen representations). In the realm of working memory, the activation of the upcoming task and inhibition of the previous tasks are always working for the successful task switching performance (*see Figure 54*). Depending on the weights through this active stage, it will facilitate or slows down the response selection (stage 4). Because of the limited capacity of working memory, performance will suffer if WM load increases. In fact, exp 4 with all arbitrary cues and exp 6 when the cue and target are separately presented, switch costs and overall reaction time were increased. Table 6 summarises the conceptual model in Figure 52.

Stage 1: All the task demand units are encoded in the LTM and mediator is the bridge between cue-target representation and links directly to the stimulus from the task demand unit in LTM.

Stage 2: Visual information of the cue and target for each tasks are represented for interpreting the meaning of cues. Thus, this stage is about the cue-target association.

Stage 3: Working memory load depends on the cue (e.g. arbitrary cues) and cue-target separate presentation (e.g., exp 6a and exp 6b) and it is on-going process between activation of the current task set and inhibition of the previous task set while switching tasks.

Stage 4: Response selection process is made for the execution of the current task. Here, it is assumed that participants might use the inner speech for self-instruction.

Table 6. presents four stage processing for the conceptual model in the figure 52.

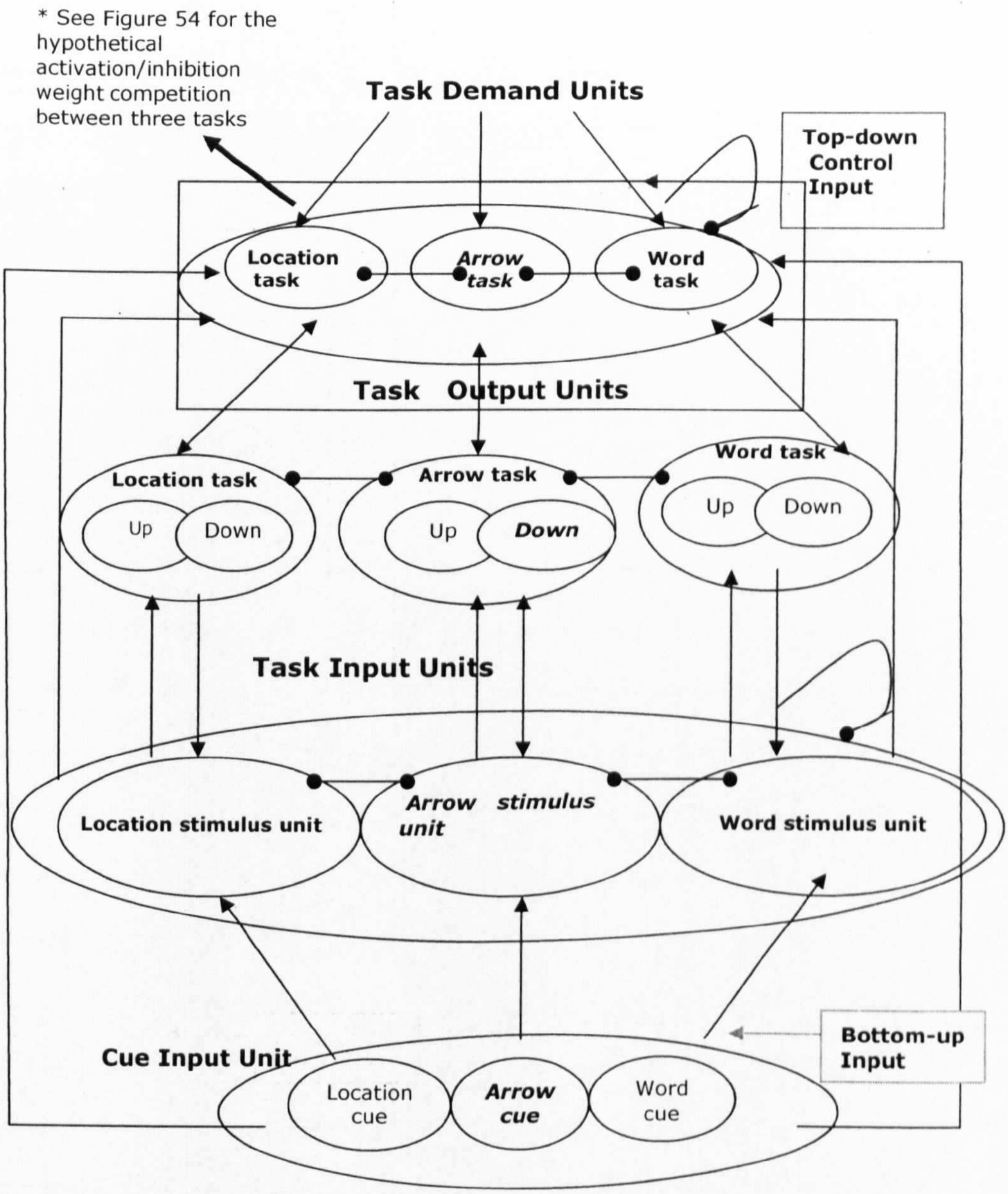


Figure 53. Architecture of PDP model in the current experimental paradigm (e.g., the current task is the arrow task, the correct response is 'down')

→ : excitation (positive)

—● : inhibition (negative)

Based on Gilbert and Shallice (2002)'s PDP (parallel distributed processing) model, the current model is composed of three separate pathways, for the arrow, location and word task (*see Figure 53*).

It is composed of Task Input Units (cue input and target input) and Response Units (up/ down) and Task Demand Units. In each pathway, there are eight input units representing the presentation of the stimulus in the arrow, location and word task.

Each pathway has three output units, representing the response 'up' and 'down' for the each task. Thus, this model has a total twenty four input units and six output units. Each input unit has a positive connection with its corresponding output units. For example, in order to simulate a stimulus of the word task (e.g., inside the arrow shape pointing up and located in the bottom of the screen written 'down'), word stimulus input unit which is single incongruent target presentation and the location stimulus input unit (because the arrow target is located in the bottom of the screen) would both be activated whereas the arrow stimulus input unit would be inhibited (because the arrow is pointing up). This would send activation to the 'word output unit' in the word task pathway and 'location output unit' in the location pathway. Immediately, this would send activation to the 'down' in Response Units in both word and location task.

Processing in the model, i.e., the passing of activation between units along their connections is iterated for a number of cycles. This allows the simulation of reaction time: on each cycle, "evidence" is collected from activation values of the six output units, two of which represent each possible response, 'up' or 'down'. When the evidence for one of these two responses passes a fixed threshold, the trial is terminated. In this way, it is possible to compare the number of cycles required for the model to reach its response threshold with the mean reaction time of participants.

The connection strengths from the input to the output units are stronger in the word task pathway than the other two task pathway. This simulates the greater experience that people have of reading written words than paying attention to the point of the arrow or the location of the arrow in my experimental paradigm. As a result, the word task output unit become more strongly active than the arrow and location task output units when the model is presented with an arrow stimulus. The evidence for the response represented in the word task pathway is therefore greater than the evidence for the response represented in the arrow and location task.
As a result, the model will tend to respond by 'reading out' the word task is presented with whereas by making an 'inner speech' for the correct response in the arrow and location task which is not presented with.
However, since both the word output unit and the location output unit - because the correct response for these two tasks are 'down' even though the current task is the word task – it is now in an activated state in the Response Units for both tasks. In order to perform the word task, 'Task Demand Units' have to send activation to their corresponding pathways. For example, when the word task demand unit is activated, it sends activation to the output units in the word task pathway, allowing them to win competition with the output units in the location task pathway. As well as sending a positive input to the output units of their corresponding pathway, the task demand units also send a negative (i.e., inhibitory) input to the output units of the other pathway.

The word and location task output units also send activation back to the task demand units. This introduces feedback as well as feedforward connectivity into the model, allowing activity in the word and location pathways to modulate activity in the task demand units (Gilbert & Shallice, 2002). The task demand units receive an additional "top-down control input", which specifies which task the model should perform.

Three tasks output units are interconnected, so that congruent word (written 'down') and location (located in the bottom of the screen so the correct response is 'down' if the current task is the location task) response units (e.g., the two 'down' units) have reciprocal positive connection and incongruent pairs of units (e.g., word 'down' but arrow is pointing 'up') have reciprocal negative connections. Finally, there are lateral inhibitory connections between all units within each task output units and task demand units. The weights of the connections between stimulus input and task demand units are determined by Hebbian learning at the end of each trial, so that the weight between co-active units are adjusted in proportion to the product of their activation values. As can be seen in figure 53, the concept of the model has two inputs: one for the 'top-down control input' that indicates which task is currently appropriate, and another for the 'bottom-up input' that the task demand units receive from the stimulus input units. Like Gilbert & Shallice (2002)'s model, the top-down input is not equal for the three task demand units. They assumed that the control mechanism provided by the task demand units is required more for the colour than the word task because the colour-naming pathway in their Stroop task is weaker. Following their logic, I also assume that the top-down input received by the location or arrow task demand unit, when the location or arrow task is the currently required task, is greater than the top-down input received by the word task demand unit on word task trials.

Operation of the Model

1) The task demand units are set to a proportion of their activation values at the end of the previous trials. In order to avoid the potential problem that weights between a pair of repeatedly coactive units may lead to such a strong input into the task demand units that the model is unable to switch task, the weights between stimulus input and task demand units are reset to zero at the end of each trial, before the new weights are calculated, so that the effects of learning on trial N-1 persist only for trial N. Note that this is an simple assumption. Assuming that the activations of the stimulus input and output units are set to zero as well, **2)** the appropriate top-down control input is added to the net input of the each task demand units, depending on which task is required. This input is added to the task demand unit's net input on every cycle. **3)** When the preparation interval begins, with all of stimulus input units set to zero after the cue input unit, the top-down input is applied to the task demand units for the number of cycles set as the preparation interval. The activation levels of the output units are not updated during this period. **4)** After the end of the preparation interval, the appropriate task demand unit is activated as before and one stimulus input unit has its activation values set to the maximum value, until the end of the trial. Imagine that the current task is the word task: Congruent (e.g., arrow pointing up with the word 'up' inside which is located in the top of the screen) and single incongruent (e.g, arrow pointing up with the word 'down' inside which is located in the bottom of the screen) and double incongruent (e.g., arrow pointing up with the word 'down' inside which is located in the top of the screen) trials are simulated by activating three stimulus input units, one in the word task pathway, the other two in the arrow and location task pathway. **5)** Activation is allowed to propagate until a response threshold is reached. The number of cycles since stimulus presentation is recorded as the 'reaction time'.

Activation Levels and Weights Updates

Activation levels are determined by the standard interactive activation equations (McClelland & Rumelhart, 1981). On every cycle, the net input for each unit is calculated by summing the activation values of each unit from which it receives a connection, multiplied in each case by the appropriate connection weight. In addition, units in the task demand, the arrow, location and word task each have a bias, a constant which is added to their net inputs on every cycle as well as the inputs received from other units. Each unit's activation value is then updated according to the following equations:

If the net input is positive: Δ act = step × net × (max – act)

If the net input is negative: Δ act = step × net × (act – min)

- act = current activation
- step = step size (This parameter determines the magnitude of the change in activation on each cycle, setting the speed of processing)
- net = net input
- max = maximum activation value
- min = minimum activation value

When the activation values have been updated for each unit, the net inputs are calculated again and a new cycle begins. On each cycle, a random noise also added to the activation values of each unit. This term is drawn from a Gaussian distribution (normal distribution), with a mean of zero; the standard deviation of this distribution determines how much disruption is caused by noise on each cycle. After noise has been added, the activation levels of any units outside the maximum and minimum values are reset to the relevant extreme.

At the end of each trial, the weights between the stimulus input and task demand units are set according to the following equation:

$$w_{ijk} = \text{lrate} \times a_j \times a_i \times a_k$$

- w_{ijk} = weight of the connection unit *j* to unit *i* and to unit *k*
- lrate = learning rate(i.e., the magnitude of the change in weights for each trial)
- a_j, a_i, a_k = the activation levels of units *j, i* and *k* respectively

Note that this equation does not take into account the previous weight of the connection between the two relevant units. Thus, these weights are calculated anew at the end of each trial, i.e., the weights derived from the activation levels of the units at the end of the trial N-1 only affect the model's performance for trial N.

Competition

When activation propagates from the input units to each of the output units, they compete with each other via the inhibitory connections until only one remains active. This is the winner[2]: the strengths of connections to the winning output unit from active output units are increased and those from

[2] In some competitive networks, there is a gradation of success for different units, not just one winner. But the principles are similar, so for simplicity I will consider networks with a single winner in the model.

inactive input units are decrease. To keep the calculations simple, I assume that the output units have a linear activation function, so the activity is proportional to the net input. The activities of the output units are compared to determine the winner. The identification of the winner may be achieved by selecting the unit with the highest activity value. Alternatively, units may be set in direct competition with each other through their inhibitory connections. The more active units will force the other to become inactive. This operation identifies which output unit had the largest net input, that is, the largest product between its weight vector and the input vector.

$\Delta w_{ijk} = 0$ if unit i loses

$= E(a_j - w_{ijk})$ if unit i wins

- E = a learning rate parameter
- a_j = the activity of input unit j when the cue p is presented
- w_{ijk} = weight of the connection unit j to unit i and to unit k before the trial

The Hebbian learning rule results in adjustment to the strengths of the connections to the winning unit until each weight has the same value as the activity of the corresponding input unit in that input pattern, that is, until $w_{ijk} = a_j$. If w_{ijk} is smaller than a_j it is increased; if it is larger it is reduced.

E determines how quickly this process takes place. The result is that the winning unit's weight vector is changed to make it more similar to the input vector for which it was the winner.

Response Threshold

The purpose of the response threshold is to provide a way to determine the moment when enough evidence has been accumulated from the word and colour units for a response to be emitted. This is implemented as follows. At the end of each cycle, the arrow, location and word task output unit with the greatest level of activation is compared with one another, except for the unit which commands the same response in the other stimulus dimension (e.g., the word task output unit if the arrow is pointing down with the word 'down' which is located in the bottom of the screen – "congruent"). The difference in activation between the most active unit and the next most active unit is calculated. When this difference passes a fixed threshold the trial is terminated. Thus, a response is simulated as occurring when the amount of evidence for that response exceeds the evidence for any other responses by a fixed amount (Gilbert & Shallice, 2002; Logan & Gordon, 2001; Nosofsky & Palmeri, 1997).

Hypothetical explanations of the observed effects

Switch cost

Recall that the task demand unit bias processing in each task pathways so that intended task is facilitated or excitated (i.e., receives positive connections) and the unintended task is inhibited (i.e., receives negative connections). Therefore, the task demand units help to resolve competition between three tasks, leading to one of the output units in the correct response dimension (up or down) becoming more active. On switch trials, the task demand units take longer to reach the activation levels required to facilitate the intended task and inhibit the unintended one. Thus, competition between the responses is extended, in comparison with repeat trials, because the task demand units are less effective at biasing the network toward the correct task (see Figure 53). Gilbert and Shallice (2002) argued that this occurs for two reasons. First, the activation values of the task demand units have the wrong sign at the beginning of the trial and so take longer to reach activation levels which would facilitate the intended task and inhibit the unintended one. This is caused by the carryover of the task demand units' activation values from the previous trial. Second, this is from network's learning mechanism and repetition of the same item for three tasks, causing the relative ineffectiveness of the task demand units on switch trials. Figure 54 presents the hypothetical figure between activation of the current task and inhibition of the previous task set while switching tasks to see the source of switch cost. According to the figure 54, the activation level of the current task is overshadowed by the residual activation of the other task when switching tasks. This residual activation of the previous task and the current activation of the forthcoming task is the by-product of the dynamics of inhibition and activation during the switching trials. On the other hand, the activation of the current task becomes stronger when repeating the single task. As a result, switch costs occurs when there is no competition in repeating trials. In other words, there is no use of inhibiting the previous task set in the repeating trials, causing the strong weight of positive connection.

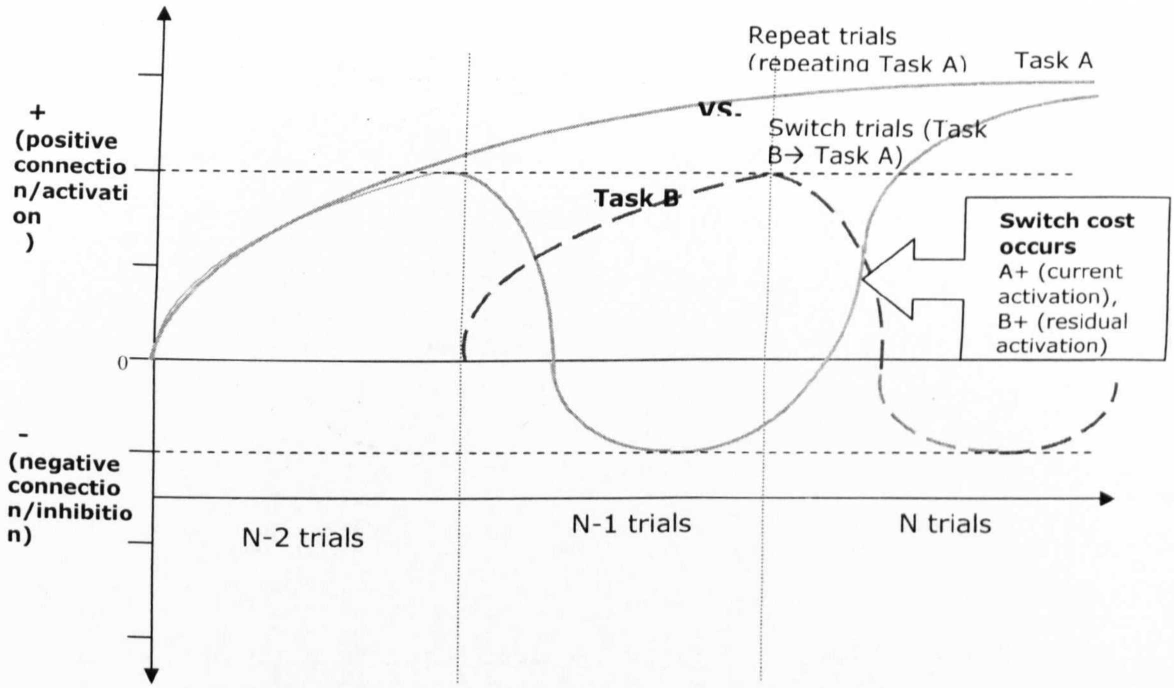


Figure 54. presents the hypothetical figure between activation of the current task and inhibition of the previous task set while switching tasks to see the source of switch cost

Alternating switch cost

As I discussed earlier, the role of task demand units is to facilitate the intended task (i.e., receives positive connections) and inhibit the unintended task (i.e., receives negative connections). Thus, during the alternating switching sequence and double switching sequence, the role of task demand units becomes more important to resolve competition between tasks consecutively. As can be seen in Figure 55, the level of activation and inhibition in three tasks at the task demand units are dynamically changing. According to the figure 55, it is clear to see that the different weight of activation level is as a result from the task on the previous trials (N-1 trials) but not the task on the N-2 trials, causing the alternating switch cost in the alternating sequence on the N trials.

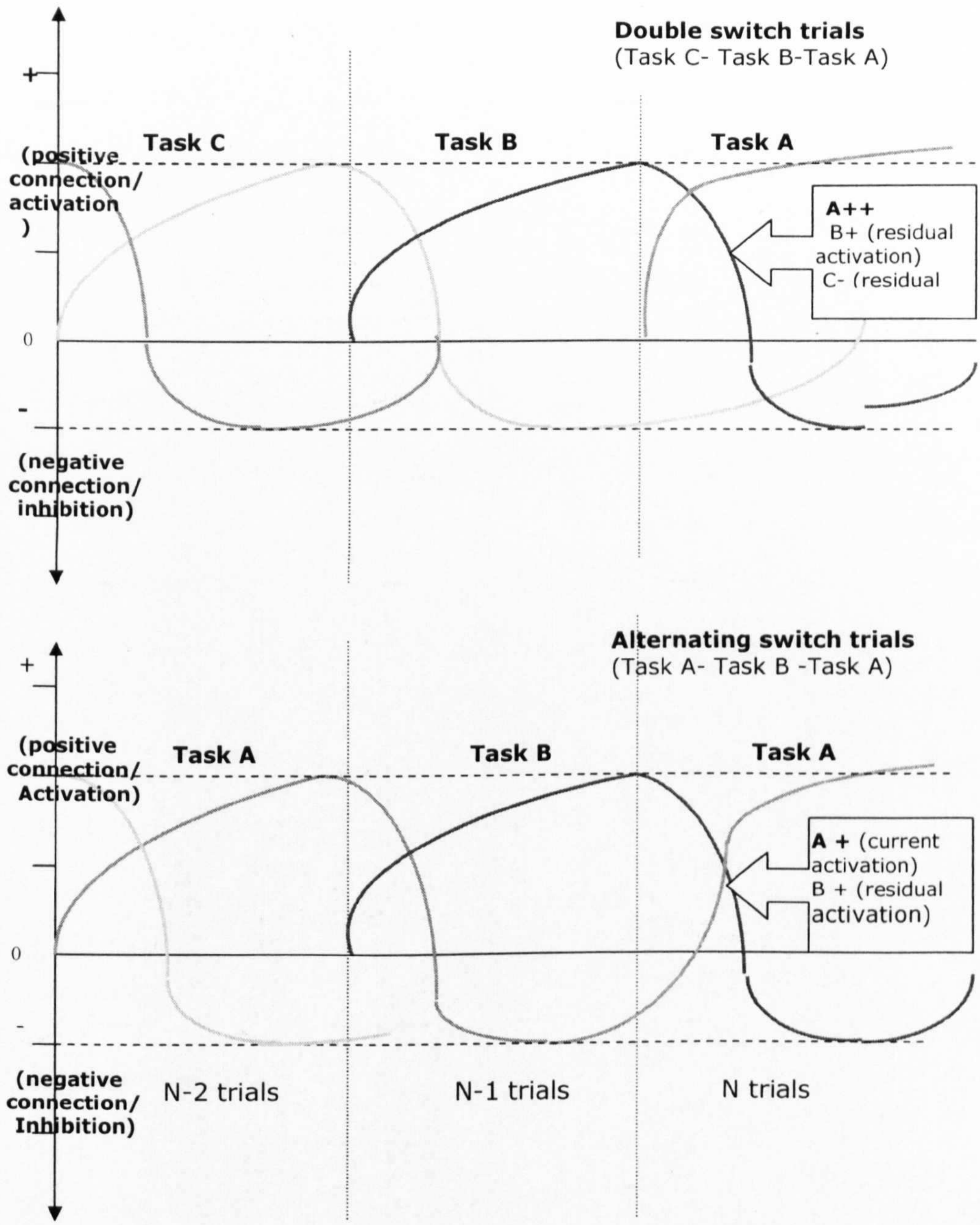


Figure 55. presents the hypothetical figure between activation of the current task and inhibition of the previous task set while alternating task and switch three tasks (double switching trials) in order to see the source of alternating switch cost.

In several previous studies, BI was assumed to operate on task switch trials in order to reduce interference from the previously relevant task set

(Arbuthnott, 2005; Mayr & Keele, 2000; Schuch & Koch, 2003). According to these accounts BI must be strong if the previous task set is still activated to a large extent (cf. Gade & Koch, 2005), or if the activation differences between the relevant and irrelevant task sets are rather small (cf. Arbuthnott, 2005), or both. However, although it seems reasonable to assume that the strength of task-set inhibition depends on the (absolute and relative) strengths of task-set activation, the results from the thesis suggests that BI might be playing an role only when interference from the previous trials are high (single incongruent condition).

Preparation effect

Preparation is simulated by activating the task demand units in advance of the cue input and stimulus input units, without activating the output units. Thus, the switch trials have more benefit to reduce switch costs from preparation interval but little effect on repeat trials because the task demand units on switch trials take longer to reach the activation levels required to facilitate the intended task and inhibit the unintended one.

Congruency effect

Congruency effect is stimulated by activating task demand unit once the task demand unit is restored in the Long-Term Memory. When three types[3] of representation for the task set reconfiguration is restored, there will be an mediate route (mediator) for response selection which links the stimulus directly to the response. Thus, when there is a target stimulus on the screen, both the relevant response category (up/down) and the irrelevant

[3] My hypothesis is that cue representation, stimulus representation and response representation are crucial for reconfiguring the task set but there will be the transformation- a kind of bridge between them- representation that link altogether.

category (up/down) will be competed with each other as they share the same response either 'up' or 'down'. This activation might create the risk that participants will apply the wrong task rules during making a response. Activated LTM codes that are triggered by the target stimulus continue to influence performance. As a result, this activation of the irrelevant task sets can either facilitate or slow the response depending on the congruency relationship whether the response of the current task is the same (congruent) or different (incongruent) from the response of the other tasks. In addition, the target stimulus activates three task-sets because only one stimulus (Arrow shape) is used for three tasks and shares thee task features. Thus, it activates both 'up' and 'down' response in the incongruent condition as well as the task information (e.g., arrow task-see the point of the arrow/ location task-see the position of the arrow/ word task-see the word inside the arrow). Hence the congruent condition yields faster response for two reasons. Firstly, there is no competition from the alternative response. Secondly, both the relevant target feature and the irrelevant target features activate the correct response (Meiran, 2000).

Conclusion

To be considered as a general model, it must fit results from my experimental paradigm and a variety of other experimental paradigms. In order to achieve this, it is necessary to do the data implementation for computational model and make theoretical framework afterwards.

However, it is noteworthy that the cognitive model in backward inhibition has not been developed in the field of task switching. Thus, it is important to expand the current model for the model-fitting and parameter estimation in the near future. Furthermore, it will be ideal to compare with other models in task switching. In summary, the model presented in this chapter implements the idea that switch costs reflects ain interference effect caused by a carry-over of task set and expand this to the backward inhibition. It might seem that the task switching paradigm has less relevance to executive control if the switch cost simply reflects an interference effect caused by a carryover of task set. More importantly, the backward inhibition in task switching is a by-product of the dynamics between activation of the forthcoming task and inhibition of the previous task on N-1 trials. However, even if switch costs result from an automatic process of response conflict, they can still reflects the states of executive control, i.e., the top-down control inputs that three tasks receives and the relationship with LTM etc. Thus, it should be possible to study these top-down control inputs indirectly, using the model to infer top-down input settings from behavioural data (Gilbert & Shallice, 2002).

Chapter 10

GENERAL DISCUSSION

A. Synopsis of the results

The goal of the study was to explore the role of inhibition in task switching by backward inhibition and to examine if backward inhibition was the part of main processes or independent processing in cognitive control mechanism. The major research question was raised from the assumption that there were at least two control processes in task switching: 1) overcoming the inhibition of a previously performed task when re-engaging and 2) restarting a sequence of tasks after a period of interruption. One mechanism to overcome the persisting inhibition of a previously performed task was backward inhibition because it suppresses the 'to-be-abandoned-task set' unconditionally for a certain period of time (Mayr and Keele, 2000). This persistent activation of a previous task set would also affect the switching performance, depending on whether it activates a response that was the same (congruent) as or different (incongruent) from the response activated by the new upcoming task set (current task set).

In order to see if task switching performance not only depends on the currently relevant task set, but is also influenced by the set of temporary irrelevant task set, three task switching experiments were developed in the thesis. The experiments reported here was to examine the dynamics of task switching by showing switch cost, alternating switch cost and congruency effect.

The present studies showed that the ability to switch from one task to another were affected by the length of cue-target-interval, suggesting that switch cost reflected the time consumed by the task set reconfiguration process. In other words, all the experiments in the thesis showed the significantly reduced switch costs when advance knowledge of the task set was given for the upcoming task and enough time for preparation was allowed. This preparation effect (see the chapter 1) clearly showed the benefit of longer CTI (cue-target-interval) and a certain amount of time was necessary to establish a task set to perform successfully. These results supported the hypothesis that switch cost is the time consumed by task-set reconfiguration (Roger & Monsell, 1995; Monsell, 2003). In addition, the thesis showed that both transient and long-term carry-over of 'task-set' activation and inhibition are also part of task switching by providing that backward inhibition was immune to the length of preparation interval. In other words, the magnitude of backward inhibition (measured by alternating switch cost) was not influenced by the advanced reconfiguration processing with ample amount of preparation. It indicates that backward inhibition occurs on a level of representation that is insensitive to advanced preparation of the task sets. It is noteworthy that the magnitude of switch costs was substantially large compared to that of alternating switch costs, suggesting that backward inhibition occurs in switching situation to suppress the old task set which is no longer to use. On the other hand, it was not necessary to suppress the previous task set when repeating one task and by the time you have been repeating the task, it would give the current task set more weight and/or strength to use the current task set which remains in an activated state. In this case, the suppressing the previous task set is not essentially required, giving the supporting evidence to the hypothesis that task switching requires two different processes: 1) activation of the upcoming task set 2) inhibition of the previous task set. In contrast, it was necessary to suppress the previous task set for switching to another upcoming task in both alternating and double switch trials. Thus, alternating switch cost is the extra time for overcoming the residual inhibition when switching back to the task you have just abandoned (task A→ B→ A), causing the relatively small RT differences from when you are switching to the new task consecutively (C→ B→ A). In that sense, it might be possible to argue that backward inhibition is more fundamental process for switching task successfully in order to protect the performance on a currently-held goal from interference and it is not necessarily to require the ample preparation interval.

In addition, congruency effects on the current trials were also insensitive to the preparation intervals in all experiments. There was a little reduction of the size during the long preparation interval, however congruency effects were significant in both CTI=100 and CTI=1200, demonstrating that the other task sets remained so strong and active. Furthermore, it suggests that task switching needs a complex interplay between deliberate intentions that are governed by goals ('endogenous' control) and the availability, recency and level of interference of the other tasks afforded by the stimulus and its context ('exogenous' influence). It is noteworthy that congruency effect on the current trials was still observed in the repeat trials as well as switch trials. As mentioned earlier, there was no need to suppress the previous task set during repeating trials. Although the current task set have more weight and/or strength and this accumulated weight through repeating one task would benefit the successful performance for the current task, it would also allow the activation of the other task sets to be active and strong enough to interfere with. Note that the stimulus for the experiments in this thesis always has three different characteristics for each task, which lead to the interference from the other task sets unless the level of the congruency on the current task is the congruent condition. When the interference was more dominant on the incongruent condition, competition between current task set and the other task sets were high, causing more switch costs in the incongruent condition.

It indicates that the persistent activation of the irrelevant task sets in the current trials indeed interfered with the current task and backward inhibition as one of mechanisms to overcome the persisting inhibition of a previous task set failed to remove or at least to reduce the interference and competition during task switching. One possible explanation was that backward inhibition would occur and be present only when there is sufficient interference with a current trial as I argued in the general introduction.

In fact, the results from the thesis demonstrated the interesting evidence for this. Arrow task at the single incongruent 2 condition during the short preparation interval showed a large size of backward inhibition in all experiments [1](Exp1: 310ms, Exp 3: 136ms, Exp 4: 385ms, Exp6a:184ms and Exp 6b: 277ms) except the Exp 5 (separate target information). These results suggest that backward inhibition were present when the interference from the previous trials was high.

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[1] Chapter 4 for PD patient experiment did not run the further separate ANOVA for each task as it aimed to see the group comparison and there was no significant group difference in tasks. However, it will be worthwhile to see the arrow task separately for both groups if they show a large size of backward inhibition (by alternating switch costs) during the short preparation interval.

In all the experiments reported in this thesis, there were trials when the stimulus for the current task received the same response in three tasks (congruent) as well as when the stimulus for the current task received the different responses in three-tasks (incongruent). The results in all experiments demonstrate that reaction time and error was increased during the incongruent conditions (single 1, single 2 and double incongruent condition).

Recently, Meiran and Kessler (2008) argued that reaction time task rule congruency (RT-TRCEs) reflect faster response to stimuli for switch competing task rules indicate the same correct response than to stimuli indicating conflicting response. The author tested the hypothesis that RT-TRCE reflects activated overlearned response category codes in long-term memory (such as 'up or 'left' in their experiments). Their results supported the hypothesis by showing that a) RT-TRCE was absent for tasks for which there were no response codes ready beforehand, b) RT-TRCE was present after these task were practiced, and c) these practice effects were found only if the tasks permitted forming abstract response category codes.

In the current experiments, there were two types of congruency effect: 1) response-level 2) stimulus-level. In other words, there was response-congruency (i.e., the correct response of the current task is congruent to the other tasks vs. the correct response of the current task is incongruent to the other tasks) and stimulus-feature congruency (i.e., features of the stimulus is all congruent-e.g., word inside says 'up' arrow points 'up' the location vs. features of the stimulus is incongruent). Note that making response is always between 'up' and 'down' when there are three-task switching, causing the single incongruent condition. Furthermore, single incongruent condition had two types of conditions which are determined by the previous trial N-1. Therefore, the results from the congruency effect is rather complicated to interpret, however, the robust congruency effects clearly demonstrated that the interference from the other task sets as well as from their stimulus features were so strong and dominant that there might be another inhibitory mechanism which could be used apart from backward inhibition. Arbuthontt (2005) argued that backward inhibition is an inhibitory mechanism of sequential control and it is not specific to one particular type of cognitive processing. She argued that backward inhibition selectively protects against interference from features of the most recently abandoned thask set (Hübner et al, 2003), facilitating the speed and accuracy of switches in complex task situations. However, the studies reported here are against previous studies (Hübner et al, 2003; Arbuthnott, 2005). At this stage, it is not clear why backward inhibition could not overcome the interference form the other task sets. On possible idea is that backward inhibition mechanism is extremely flexible, responding selectively to aspects of a task context that cause interference. It is likely that this flexibility arises from a low-level mechanism, such as lateral inhibition of category response rules (Arbuthnott, 2005; Gade & Koch, 2005; Schuch & Koch, 2003). This inhibition combines with activation processes to influence performance, which affects whether inhibition or activation dominates in different contexts.

In summary, the present results in the thesis reconcile two opposing views regarding the reduction in switching costs by prolonging the preparation interval. According to the one view (Rogers & Monsell, 1995; De jong, 2002; Fagot, 1994; Goschke, 2002; Merian, 1996), the reduction of in switch costs by long preparation intervals reflects advanced task-se`t reconfiguration. According to the alternative view (Allport et al, 1994; 1996; Allport & Wylie, 2000; Logan and Schneider, 2003, 2006 a, 2000b), reduction in switch cost reflects passive dissipation of the previous task set. Monsell (2003) previously proposed that switch costs 'results from both transient and long-term carry-over of 'task set' activation and inhibition as well as time consumed by task-set reconfiguration processes' (p. 134). Switch costs in the current experiments supported that these two views are not mutually exclusive.

B. Inhibitory control in task switching

It is said that the ability to switch efficiently between two or more tasks is thought to require executive control because the control setting appropriate on one trial are no longer relevant when a new task is required. As such, inhibitory mechanisms that suppress the now inappropriate task may be required to facilitate switches between two or more tasks. If inhibitory mechanisms are inefficient, irrelevant information from both the past and present will disrupt performance on the current task. Cumulative evidence suggests that inhibition of a just-performed task set does occur in task switching (Allport et al, 1994; Allport & Wylie, 2000; Arbuthnott & Frank, 2000; Arbuthnott & Woodward, 2002; Dreher &Berman, 2002; Dreisbach et al., 2002; Hübner et al, 2003; Koch, Gade & Philip, 2004; Mayr, 2001, 2002; Mayr & Keele, 2000; Schuch & Koch, 2003; Gillbert & Shallice, 2002). Particularly, it has been argued that there must be a mechanism that reduces activation of the current task set representation in order to enable the cognitive system to switch to a different task. This deactivation of the task set could possibly take place in the form of unspecific activation decay (e.g., Altmann & Gray, 2008) or in the form of inhibition, which is presumably a faster process that is triggered by some specific event (e.g., Mayr & Keele, 2000).

Previously, Allport et al. (1994) already suggested that switch costs arise from proactive interference resulting from having previously performed a competing task (Yeung et al, 2006). According to Allport & Wylie (1999), the nature of this proactive interference can be as "continued priming of the previous task (competitor priming) and suppression (negative priming) of the currently intended task" (see page 293 in their article, see also general introduction in the thesis). Thus, inhibitory processes (i.e., 'suppression') could contribute to switch costs in a simple way. Presumably, the inhibition of an irrelevant task set persists over time, so that it is more difficult to perform this task when it becomes relevant again. Thus, persisting inhibition could produce 'inertia' (see the general introduction) on the level of task sets (Allport et al., 1994; Allport & Wylie, 1999).

Goschke (2000) also suggested a similar contribution of inhibitory processes in task switching. He argued that the degree of inhibition is adjusted depending on the amount of response conflict evoked by a stimulus. Likewise, Gilbert & Shallice (2002) proposed that lateral inhibition of 'task demand units' to reduce or prevent the simultaneous activation of two competing task sets.

However, it is noteworthy that persisting activation accounts could explain switch costs as well as could persisting inhibition accounts. In other words, persisting activation accounts predict a performance benefit from N-2 trial repetition (alternating switch trials) relative to N-2 trial switch (double switch trials), whereas persisting inhibition accounts predict a performance

cost (alternating switch cost) in the alternating switch trials. In fact, many studies reported alternating switch costs (e.g., Arbuthnott & Frank, 2000; Lien & Ruthruff, 2008; Mayr & Keele, 2000; Philip et al., 2007;Schuch & Koch, 2003), suggesting that alternating switch costs for backward inhibition is the good measure to study the inhibitory control in task switching. Since these costs can be observed for a large variety of different tasks, alternating switch costs occur when subjects switch between tasks that differ in stimulus-related aspects (e.g., different stimulus dimensions) as well as in response-related aspects (e.g., different response inhibition).
However, it is still ambiguous what kind of inhibitory control involved in task switching. Tentatively, I proposed that at least three different types of inhibitory control involved in task switching.

Inhibition of the just-performed response (response-related inhibition)

Aron et al (2003) argued that RT and error rate are reduced when the response is the same as the response produced on the previous trial, providing the time-lag between stimulus and next response is short. However, Roger and Monsell (1995) showed the reverse effect on the switch trials. The response alternations were actually faster than response repetitions. Roger and Monsell (1995) suggested that the normal interaction between switch cost and response repetition is due to inhibition of any ongoing response when a task changes. However, alternating hyphotheses for this effect have been suggested, 'associative' (Rogers & Monsell, 1995) and 'change signal' (Thomas & Allport, 2000) accounts. The 'associative' hypothesis suggests that the response most recently produced in the context of a particular task becomes associated with that task, and this 'binding' has to be overcome when the task changes (cf. Allport & Wylie, 1999; Aron, 2003). This hypothesis would attribute to the current congruency effect throughout the experiments in the thesis. The 'change signal' hypothesis, by contrast, maintains that detecting any change between n-1 and trial n biases the participants toward performing the difference response and the presentation of a different task cue (as happens with a switch) is a salient change (cf. Aron, 2003). On this account, effect of previous congruency effect in the thesis indicates that participants are more susceptible to such a bias (possibly because of weaker endogenous control of task set); hence they have difficulty on switch trials that are incongruent to the previous trials. There is another evidence for inhibition associated with response-related aspects of task set. For example, using a numerical judgement task that remained constant across the entire experiment, Philipp & Koch (2005) had their subjects switch among different responses (manual, vocal and foot-pedal responses). The results of alternating switch costs suggested that inhibition can also be observed for task sets that differ in terms of the response modality. Moreover, Koch et al. (2004) had participants switch among three tasks: two of them were numerical judgement tasks (i.e., parity and magnitude), whereas the third task was a simple-response task that required pressing both response keys simultaneously upon stimulus onset. They also found the alternating switch costs even for the simple-response tasks.

Taken together, these studies show that inhibition can be targeted also at output-related aspects of processing. Hence, it appears that inhibition can occur at many different levels of task processing (Houghton et al, 2009).

Inhibition of irrelevant task set on current trial (task-set inhibition)

Arbuthnott (2005) argued that backward inhibition is to be an inhibitory mechanism of sequential control and has been observed across a range of perceptual and semantic judgement tasks (Arbuthnott & Frank, 2000; Koch etal., 2004; Mayr, 2002; Mayr & Keele, 2000; Schuch & Koch, 2003), indicating that it is not specific to one particular cognitive processing. In the context of sequential choice behaviour, people sometimes entertain a heuristic of expecting that all possible events are about equally distributed even in short runs of events (e.g., Kahneman & Tversky, 1972). This hypothesis suggests that participants would develop some kind of expectancy that a CBA sequence is more representative and thus more likely to occur than an ABA sequence, which in turn might cause an expectancy-based performance benefit in CBA sequences relative to that in ABA sequences. However, if this is the case, alternating switch costs would be due to the violation of expectancies rather than task inhibition.

However, the current results revealed the evidence that alternating switch costs is not explained by sequential expectancy.

The alternating switch costs in the current experiments were different depending on the task type (e.g., arrow task) and the level of congruency (e.g., single incongruent 2), suggesting that inhibition is more sensitive to the type of task and the strength of interference from irrelevant task sets. If the sequential control is the account for the current results, all three tasks should show the alternating switch costs consistently regardless of the congruency condition on the current trials. In other words, the expectancy bias account would probably predict that alternating switches of cue and thus participants knows exactly what they expect for the task.

Probably, participants failed to inhibit the other task sets during performing the arrow task only when it was incongruent to the previous trial N-1 whereas they managed to inhibit the other irrelevant task sets during performing either location or word task no matter how strong interference from the other tasks are (e.g., different congruent conditions).

Inhibition of Stimulus-Response mapping of irrelevant task on current trial (S-R inhibition)

In addition to examining how the entire task set may be activated by the irrelevant task set, the suppression of competing Stimulus-Response (S-R) would play a role in overcoming the persistent and remaining activation of the other task sets, especially when it activates a response that is different (incongruent) from the response activated by the new upcoming task set (current task set). In the current experiments, the congruency on the current trial N might be related to the inhibition of S-R mapping of irrelevant task because the current task stimulus always includes the irrelevant task information of the other tasks.

One possible functional trigger of backward inhibition is conflict/interference at the level of stimulus-attribute selection (e.g., Arbuthnott & Woodward, 2002; Hübner et al,, 2003; Sdoia & Ferlazzo, 2008). What they argued is in line with my previous accounts that stimulus-feature congruency also influenced the size of alternating switch costs. Sdoia & Ferlazzo (2008) found that conflict at stimulus selection during intentional encoding of stimuli into short-term memory in trial N-1 can cause alternating switch costs. This finding suggests that stimulus conflict (interference from stimulus feature in the current results) could play a role in alternating switch costs.

In conclusion, these three types of inhibition play an important role in task switching and I suggest that the main trigger of task set inhibition is interference from the stimulus as well as response. Thus, it will be worthwhile to disentangle two levels of congruency and see the different conflict processing then examine their influence on backward inhibition. For example, if they have functionally similar role in showing alternating switch costs or if these can be dissociated depending on the stimulus feature on the task.

C. Neurological components in cognitive control

During the last decade, substantial effects have been made to evaluate functional-neuroanatomical models of higher cognitive functions by combining behavioural methods from cognitive psychology with new neuroimaging techniques (Gruber & Goschke,2004). A large number of studies suggests that the different executive processes like maintenance of task-set information, conflict-monitoring, inhibition of prepotent responses, and task switching may not be attribute to a single unitary brain system which is against the earlier theories of cognitive controls that postulated a unitary 'central executive' that controls, coordinates, and supervises task-specific processing modules (e.g., Baddeley, 1986; Norman & Shallice, 1986). Gruber & Goschke (2004) also assumed that the mainly two brain systems have different functional roles in the cognitive control of goal-directed action. The first of these working memory systems relies on prefronto-parietal and prefronto-temporal cortical networks and appears to be also involved in the top-down modulation of domain-specific sensory association areas towards task-relevant information. The second system comprises mainly left hemispheric premotor and parietal brain regions which also underlie language functions, including inner speech and verbal rehearsal. The authors proposed that the second system plays a central role in the retrieval and maintenance of verbal representations of goals and task rules during the advance preparation for a novel task. According my model in chapter 9, mediator plays an important role to connect between cue-target mapping stage and LTM and it is assumed that inner speech and/or verbal rehearsal are the function of mediator as an internal self-cuing device (cf. Goschke, 2000). Taking up earlier suggestions by Luria (1961) and Vygotski (1962), who stressed the significant role of inner speech and verbal self-instructions in self-control and voluntary action, it would be possible to think that the underlying mechanism of preparation effect will be the retrieval of a verbal task or goal representation into working memory (Goschke, 2000, 2003). Especially when subjects must switch between novel and unpracticed tasks with arbitrary stimulus-response mappings, it appears that a verbal representation of the to-be-performed task must be retrieved before a response can be selected (Goschke, 2003; cf. Emerson & Miyake, 2003). Mecklinger et al. (1999) also found that patients with left-hemispheric brain damage suffering from central speech disorders showed disproportionally large switch costs, compared to patients without speech orders, suggesting that retrieval of a verbal task representation or 'self-instruction' play an important role in advance preparation for a task switch (Goschke, 2003). These results suggest that the brain region for verbal working memory is particularly important for task switching.

On the other hand, Dreher & Berman (2002) investigated two control processes: overcoming the inhibition of a previously performed task when re-engaging it, and restarting a sequence of tasks after a period of interruption by using event-related fMRI. Behaviorally, these processes were reflected in the facts that: 1) switching to a recently performed task, that is thus unlikely to have fully recovered from inhibition, takes longer than switching to a task less recently performed- 'backward inhibition' and 2) re-engaging in a sequence of tasks after a period of interruption transiently increases response time. The authors found that these behavioral effects were accompanied by a double dissociation: the right lateral prefrontal cortex was more activated when switching to a task recently performed compared to a task less recently performed, while anterior cingulated cortex was recruited when a sequence of tasks was initiated. Their results provided insights into functional organization of the frontal lobe and its role in distinct processes involved in cognitive control.

Recently, Sinai et al. (2007) used event-related potential (ERP) to determine whether backward inhibition (BI) was exerted preferentially in high interference environments, and whether ERPs locked to critical time points reflects BI during cue preparation and/or response stages. High interference and low interference were created by manipulating task difficulty. A reaction time BI effect (i.e., BI > control trials) was shown only during high interference task. For high interference tasks, BI versus control trial differences were reflected in a response-locked ERP negativity only after response selection (indexed by the response locked lateralized readiness potential), indicating that BI was a lateral inhibition mechanism- whereby the activation of one task causes the suppression of competing tasks- exerted during response preparation. Their results were in line with the current results that backward inhibition was only at present when the interference was high. Note that backward inhibition was quite big at the single incongruent 1 condition only for the arrow task in most experiments.

Another issue related to the current results in the thesis is about the congruency effect. Although there is no imaging study to investigate the congruency effect solemnly, it is assumed that the dynamic interactions between the brain systems allow adjusting the balance between maintenance and shifting of goals in a context-sensitive way depending on the presence of response conflicts. In other words, it should be more difficult to switch from one task to a different task, if the new task requires responding to a stimulus dimension that on the preceding trial elicited a response conflict (and thus had to be inhibited). Goschke (2000) demonstrated that switch costs were significantly increased on trials that were preceded by response-incongruent trials (i.e., trials on which the two stimulus dimension were mapped to incompatible responses). This effect of incongruence of the previous trial was not attenuated by advance preparation for the next task, but persisted until the next stimulus was processed. These results demonstrated that the degree of goal shielding is adjusted in a context-sensitive way depending on the presence of response conflicts. There is evidence that region of the medial prefrontal cortex, including anterior cingulated cortex (e.g., Carter et al., 1998; Carter et al., 2000; MacDonald et al., 2000) and/or adjacent regions (BA 8m) (Gruber et al., 2003; Ullsperger & von Cramon, 2001) are involved in this kind of conflict-induced goal shielding, presumably by signaling the demand for increased goal maintenance an/or intensified top-down modulation of task-relevant processing systems.

Yeung et al, (2006) also provided support for theories that propose a control hierarchy comprising regions responsible for maintaining task-specific information about rules or goals and, regions involved in coordination of these goals. They used functional magnetic resonance imaging (fMRI) to investigate the nature of the interaction between brain regions and the role of prefrontal cortex (PFC) in cognitive control as subjects switched between simple face and word categorization tasks. They found that activity in brain regions selective for the currently irrelevant task predicted the behavioral costs associated with switching tasks. Task switching was also associated with increased activity in a network of regions implicated in cognitive control, including lateral PFC and parietal cortex. Within this network of regions, they also observed dissociations between task-selective and general purpose mechanisms.

However, the current results in here showed the inconsistent pattern: Switch costs on the reaction time were not interacted with congruent conditions. However there was some interaction effect with congruent conditions on the error, depending on the manipulation of the experiments. This suggests that the mechanism underlying congruency effect in the current results is more complicated because there were two levels of congruency: 1) response level, 2) stimulus level. Thus, it will be worthwhile to investigate the congruency effect on the response and stimulus level to see any sub-hierarchical neurological components.

Conclusion

It is important to question what the relationship between switch cost and backward inhibition effect is as they are observed in task switching paradigm, yet they appears to have different underlying mechanisms. Obviously, switch cost is from comparing repeating single task and switching different tasks. In most task switching literature, it was robust finding that switching two tasks required extra effort to reconfigure the upcoming task while there is no need for extra effort when repeating only one task. Thus, the cost was more substantial and obvious and it was reduced by long preparation interval on the assumption that advance preparation for a certain amount of time helps the switching performance.

Theoretically, one can simply argue that switching tasks require two processes of activation:1) activation of the current task set 2) inhibition of the previous task set. A task set is typically assumed to include a representation of a task goal (e.g., attend to stimulus colour), a set of task-relevant stimuli (e.g., press a left or a right key), and a mapping of stimuli- or stimulus categories-to responses (see, e.g., Monsell, 1996).

In order to investigate the particular inhibitory control in task switching, backward inhibition phenomena enables to measure the inhibition on the basis of the assumption that alternating tasks have more difficulties overcoming the residual inhibition from the previous task which has been just abandoned, yet has to switch back again. These were compared to switching three tasks continuously when there is less need to overcome the residual inhibition from the previous task as it has to be changed with another different task. Thus, comparing between alternating switch and

double switch trials may cause the smaller size of backward inhibition which was measured by alternating switch costs in the thesis and there might be another inhibitory mechanism related to the response selection.
Backward inhibition of a no-longer relevant task has been proposed to be automatically triggered by competition between cognitive demands during task disengagement because it occurs even when subjects know that the inhibited task will become relevant again in the immediate future (Mayr & Keele, 2000). This effect is an important result since inhibition has been proposed to be a component process of executive control, yet it has been difficult establish empirically (Mayr & Keel, 2000; Tipper, 2001).

In the present thesis, I reviewed the traditional debate on the interpretation of switch costs in task switching and empirical evidence on backward inhibition and congruency effect. Although backward inhibition as inhibitory control mechanism is seemingly rather disputable and ambiguous, the current results on backward inhibition provided the evidence that it is present only when the inference from the other task sets are strong and it is influenced by the level of congruency on the previous trials N-1. It appears that inhibitory control mechanism is a diverse complex of processes rather than a unitary concept and it suggests that there might be another type of inhibitory control for overcoming the conflict (interference) from the irrelevant information of the other task sets. In addition, it is also likely to assume that backward inhibition is independent and separate process from task switching because it is clearly observed in other experimental paradigms such as go-no/go signals, flanker tasks. However, it is noteworthy that these paradigms are particularly focused on inhibition of competing responses, in other words, response inhibition.

Compared to these paradigms, the current experimental paradigm attempted to provide the evidence for different level of processing: preparation processing, cue processing, stimulus processing and response processing. It would be advisable to manipulate the response choices and modality of response execution to overcome this. The results suggested that backward inhibition was more sensitive to stimulus and response processing when participants had to *overcome the high* conflicts from previous trial N-1. The next research aim will be to data implementation for computational modelling and dissociate backward inhibition on the level of congruency (i.e., stimulus level/ response level). Furthermore, the ERP study for the timing of these separate control processes and fMRI study for the brain region will be helpful, yet it has to be carefully designed and measured in the near future.

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APPENDIX

• 5-Way ANOVA TABLE for group analysis

(CTI x trial type x task x congruency x group, and CTI x switch type x task x congruency x group)

Group Analysis results by mean data

1. task-oriented cue experiment between Young and Old (Exp 1 and 2)
2. task-oriented cue vs. all verbal cue experiment (Exp 1 and 3)
3. all verbal cue experiment vs. all arbitrary cue experiment (Exp 3 and 4)
4. word information inside the arrow vs. word information outside the arrow when both cues are verbally presented (Exp 3 and 5)
5. cue-target joint vs. cue-target separate when both cues are verbally presented (Exp 3 and 6a)
6. cue-target joint vs. cue-target separate when both cues are arbitrarily presented (Exp 4 and 6b)
7. all verbal cue vs. all arbitrary cue when both cue and target are separately presented (Exp 6a and 6b)

Note> the aim of the group comparison between experiments are shown in Table 2 in the chapter 2, page 58. Mean of median reaction time (ms) was used for all the group comparison analysis and mean of error percentage (%) was excluded except for chapter 4.

1. Exp 1 and 2 old control

CTI x Trial type x Task x Congruency By Group	CTI x Switch type x Task x Congruency By Group
1.*CTI*: F (1, 38)=267, p<.001 *x Group: F (1, 38)= 22, p<.001*	**1.*CTI***: F(1, 36)= 393, p<.001 *x Group: F(1, 36)= 19, p<.001*
2.*Trial type*: F(1, 38)=34, p<.001 *x Group: F (1,38)= 3.3, p =.07*	**2.*Switch type*** :F (1, 36)= 3.3, p =.08 *x Group: F (1, 36)= 2.5, p=.12*
3.*Task*: F (1, 43)=6.8, p=.01 *x Group: F (1, 43)=6.6, p=.01*	**3. *Task***: F(2, 58)= 19, p <.001 *x Group: F (2, 58)= 7.5, p=.002*
4. *Congruency*: F (1, 48)=19, p =.01 X Group: F (1, 48)= 2.7, P=1.0	**4.*Congruency***: F (2, 84)= 25, p <.001 *X Group: F (2, 84)= 1.7, p=.18*
5.*CTI x Trial type*: F(1, 38)=1.7, p =.19 *x Group: F(1, 38)= .75, p =.39*	**5.*CTI x Switch type***: F(1, 36)= .50, p=.48 *x Group: F(1, 36)= .59, p= .45*
6.*CTI x task*: F(2, 72)= 28, p<.001	**6.*CTI x task***: F(1, 55)= 42, p<.001

x Group: F(2, 72)= 8.6, p=.001

7.Trial type x task: F(2, 68)= 2.9, p=.07
x Group: F(2, 68)= .02, p=.97

8.CTI x Trial type x task: F(1,43)=.72, p=.41
X Group: F (1, 43)= .88, p=.37

9. CTI x congruency: F (2,85)= 3.7, p=.025
X Group: F (2, 85)=1.2, p=.30

10. *Trial type x congruency*: F (2, 77)= 1.9, p=.15
X Group: F (2, 77)= 1.0, p=.35

11. *CTI x Trial type x congruency* : F (1, 50)= 3.8, p=.04
X Group: F (1, 50)=1.7, P=.16

12. *Task x congruency*: F (2, 88)=9.4, p <.001
X Group: F (2, 88)= 1.9, p=.15

13. CTI x task x congruency: F (2, 63)= 3, p=.08
X Group: F (2, 63)= 1.3, p=.28

14. *Trial type x task x congruency*: F (2, 86)=4.5, p=.011
x Group: F (2, 86)= 2.3, p=.09

15. CTI x trial type x task x congruency: F (2, 62)= 2.5, p=.10
X Group: F (2, 62)= 1.7, p=.19

Between subject effect: F (1, 38)=24, p<.001

x Group: F(1, 55)= 42, p=.005

7.Switch type x task: F(2, 71)= 2.0, p=.14
x Group: F(2, 71)= 1.6, p =.21

8.CTI x Switch type x task: F (2, 62)= .80, p=.44
X Group: F (2, 62)=.02, p=1.0

9.CTI x congruency: F(2, 87)=6.2, p =.002
X Group: F (2, 87)= 1.0, p=.38

10. Switch type x congruency: F (2,91)= 2.8, p=.06
X Group: F (2,91)= 2.9, p=.05

11. CTI x Switch type x congruency: F (2,95)= 4, p =.012
X Group: F (2, 95)= .78, p=.49

12. Task x congruency: F (3, 138)= 9.3, P <.001
X Group : F (3, 138)= 1.7, p=.15

13. CTI x task x congruency: F (4, 146)= 4.1, p=.003
X Group: F (4, 146)=1.3, p=.25

14. Switch type x task x Congruency: F(4, 141)=3.6, p=.008
x Group: F (4, 141)= 1.9, p=.12

15. CTI x switch type x task x congruency: F (3, 121)= 5.5, p=.001
X Group: F (3, 121)= .64, p=.61

Between subject effect: F (1, 36)= 22, p <.001

2. Exp1 vs. Exp 3 (task-oriented cues vs. all verbal cues) *(see the chapter 5, page 165)*

CTI x Trial type x Task x Congruency By Group

1. ***CTI***: F (1, 40)=250, p<.001
x Group: F (1, 40)= 2, p=.17

2. ***Trial type***: F(1, 40)=66, p<.001
x Group: F (1,40)= 4.5, p =.04

3. ***Task***: F (2, 72)=46, p<.001
x Group: F (2, 72)=1.2, p=.31

4. ***Congruency***: F (2, 89)=53, p <.001
X Group: F (2, 89)= .55, P=.59

5. ***CTI x Trial type***: F(1, 40)=39, p <.001
x Group: F(1, 31)= .31, p =.58

6. ***CTI x task***: F(2, 73)= 17, p<.001
x Group: F(2, 73)= .35, p=.68

CTI x Switch type x Task x Congruency By Group

1. ***CTI***: F(1, 40)= 314, p<.001
x Group: F(1, 40)= 5.5, p=.02

2. ***Switch type*** :F (1, 40)= 2.2, p =.15
x Group: F (1, 40)= 1, p=.31

3. ***Task***: F(2, 72)= 34, p <.001
x Group: F (2, 72)= 1.0, p=.35

4. ***Congruency***: F (2, 97)= 62, p <.001
X Group: F (2, 97)= .08, p=.95

5. ***CTI x Switch type***: F(1, 40)= .10, p=.92
x Group: F(1, 40)= .00, p= .10

6. ***CTI x task***: F(1, 59)= 27, p<.001
x Group: F(1, 59)= 1.7, p=.20

7. ***Trial type x task***: F(2, 76)= 1.1, p=.32 *x Group: F(2, 76)= 3.2, p=.05*	**7.** ***Switch type x task***: F(2, 71)= .09, p=.89 *x Group: F(2, 71)= .18, p =.81*
8. ***CTI x Trial type x task***: F(2,75)=2.8, p=.07 X Group: F (2, 75)= 4.8, p=.012	**8.** ***CTI x Switch type x task:*** F (2, 77)= 2.5, p=.08 *X Group: F (2, 77)=.91, p=.40*
9. ***CTI x congruency***: F (2,98)= 3.2, p=.03 X Group: F (2, 98)=.15, p=.90	**9.** ***CTI x congruency:*** F(2, 99)=2.8, p =.05 *X Group: F (2, 99)= .54, p=.62*
10. ***Trial type x congruency***: F (3, 104)=.48, p=.67 *X Group: F (3, 104)= .41, p=.72*	**10.** ***Switch type x congruency:*** F (3,112)= 1.2, p=.32 *X Group: F (3,112)= 1.2, p=.32*
11. ***CTI x Trial type x congruency*** : F (3, 110)= 1.8, p=.16 *X Group: F (3, 110)=1.1, P=3.5*	**11.** ***CTI x Switch type x congruency:*** F (3,112)= 7.7, p <.001 *X Group: F (3, 112)= 2.2, p=.09*
12. ***Task x congruency***: F (4, 174)=14, p <.001 *X Group: F (4, 174)= 2.8, p=.03*	**12.** ***Task x congruency:*** F (4, 170)= 13, P <.001 *X Group : F (4, 170)= 1.7, p=.14*
13. CTI x task x congruency: F (4, 176)= 4.5, p=.001 *X Group: F (4, 176)= .60, p=.68*	**13.** ***CTI x task x congruency:*** F (3, 144)= 1.3, p=.26 *X Group: F (3, 144)=1.7, p=.17*
9. ***Trial type x task x congruency***: F (5, 195)=3.6, p=.004 *x Group: F (5, 195)= .64, p=.67*	**14.** ***Switch type x task x Congruency***: F(4, 169)=1.5, p=.20 *x Group: F (4, 169)= 1.7, p=.21*
15. CTI x trial type x task x congruency: F (5, 188)= 2.4, p=.04 *X Group: F (5, 188)= 1.2, p=.33*	**15.** ***CTI x switch type x task x congruency***: F (3, 135)= 5.6, p=.001 *X Group:* F (3, 135)= 1.6, p.19
Between subject effect: F (1, 40)=.08, p=.78	*Between subject effect: F (1, 40)= .08, p=.77*

4. Exp 3 vs. Exp 4 (all verbal cues vs. all arbitrary cues) *(see the chapter 6, page 206-208)*

CTI x Trial type x Task x Congruency By Group	CTI x Switch type x Task x Congruency By Group
1.*CTI*: F (1, 38)=560, p<.001 *x Group: F (1, 38)= 44, p<.001*	***1.CTI***: F(1, 38)= 279, p<.001 *x Group: F(1, 38)= 25, p<.001*
2.*Trial type*: F(1, 38)=57, p<.001 *x Group: F (1,38)= 7.5, p =.009*	***2.Switch type*** :F (1, 38)= 6.8, p =.02 *x Group: F (1, 38)= 1.2, p=.28*
3.*Task*: F (1, 60)=44, p<.001 *x Group: F (1, 60)=1.8, p=.17*	***3. Task***: F(2, 70)= 30, p <.001 *x Group: F (2, 70)= .24, p=.77*
4. *Congruency*: F (2, 86)=28, p <.001 X Group: F (2, 86)= .47, P=.65	***4.Congruency***: F (2, 95)= 25, p <.001 *X Group: F (2, 95)= 1.1, p=.33*
5.*CTI x Trial type*: F(1, 38)=68, p <.001 *x Group: F(1, 38)= 3.0, p =.09*	***5.CTI x Switch type***: F(1, 38)= .16, p=.69 *x Group: F(1, 38)= .13, p= .72*
6.*CTI x task*: F(2, 74)= 8.2, p=.001 *x Group: F(2, 74)= .18, p=.83*	***6.CTI x task***: F(2, 68)= 11, p<.001 *x Group: F(2, 68)= 2.2, p=.12*
7.*Trial type x task*: F(2, 65)= .027,p=.96	***7.Switch type x task***: F(2, 69)= 1.7, p=.19

x Group: F(2, 65)= .83, p=.42

8.*CTI x Trial type x task*: F(2,66)=3.2, p=.05
X Group: F (2, 66)= 6.4, p=.004

9.*CTI x congruency*: F (3,102)= 6.2, p=.001
X Group: F (3, 102)=.12, p=.93

10. *Trial type x congruency*: F (2, 93)= 2.7, p=.06
X Group: F (2, 93)= 2.0, p=.14

11. *CTI x Trial type x congruency*
: F (2, 87)= 3.8, p=.02
X Group: F (2, 87)=2.5, P=.07

12. *Task x congruency*: F (4, 158)=11, p <.001
X Group: F (4, 178)= 1.1, p=.37

13. CTI x task x congruency:
F (3, 136)= 4.2, p=.004
X Group: F (3, 136)= .68, p=.59

14. *Trial type x task x congruency*:
F (5, 190)=7.5, p<.001
x Group: F (5, 190)= 1.4, p=.20

15. CTI x trial type x task x congruency:
F (4, 163)= 3.9, p=.003
X Group: F (4, 163)= 2.5, p=.04

Between subject effect: F (1, 38)= 4.1, p=.05

x Group: F(2, 69)= 1.3, p =.27

8.CTI x Switch type x task: F (2, 65)= .45, p=.60
X Group: F (2, 65)= .77, p=.45

9.CTI x congruency: F(2, 92)= 1.9, p =.13
X Group: F (2, 92)= 1.0, p=.36

10. Switch type x congruency: F (3,104)= .42, p=.72
X Group: F (3,104)= 1.7, p=.17

11. CTI x Switch type x congruency:
F (2,84)= 3.4, p =.03
X Group: F (2, 84)= 1.7, p=.19

12. Task x congruency: F (4, 140)= 11, P <.001
X Group : F (4, 140)= 1.3, p=.28

13. CTI x task x congruency: F (4, 146)= 2.3, p=.06
X Group: F (4, 146)=1.1, p=.36

14. Switch type x task x Congruency:
F(3, 104)=1.3, p=.27
x Group: F (3, 104)= .91, p=.43

15. CTI x switch type x task x congruency: F (4, 164)= 3.4, p=.008
X Group: F (4, 164)= 1.4, p.23

Between subject effect: F (1, 38)= 6.3, p=.016

5. Exp 3 vs. Exp 5 (all verbal cues vs. response information out)

(see the chapter 7, page 246-247)

CTI x Trial type x Task x Congruency By Group

1.*CTI*: F (1, 38)=265, p<.001
x Group: F (1, 38)= .35, p=.55

2.*Trial type*: F(1, 38)=51, p<.001
x Group: F (1,38)= 5.9, p =.02

3.*Task*: F (2, 71)=87, p<.001
x Group: F (2, 71)= 4.1, p=.02

4. *Congruency*: F (2, 66)=30, p <.001
X Group: F (2, 66)= 1.6, P=.21

5.*CTI x Trial type*: F(2, 82)=48, p <.001
x Group: F(2, 82)= .53, p =.61

6.*CTI x task*: F(2, 64)= 13, p<.001
x Group: F(2, 64)= 1.5, p=.23

7.*Trial type x task*: F(2, 71)= .63,p=.52
x Group: F(2, 71)= .47, p=.61

CTI x Switch type x Task x Congruency By Group

1. CTI: F(1, 38)= 303, p<.001
x Group: F(1, 38)= 1.6, p=.21

2.Switch type :F (1, 38)= 13, p =.001
x Group: F (1, 38)= 2, p=.17

3. Task: F(2, 67)= 61, p <.001
x Group: F (2, 67)= 1.1, p=.34

4.Congruency: F (2, 86)= 35, p <.001
X Group: F (2, 86)= 2.0, p=.13

5.CTI x Switch type: F(1, 38)= .34, p=.56
x Group: F(1, 38)= .24, p= .62

6.CTI x task: F(2, 71)= 17, p<.001
x Group: F(2, 71)= 3.0, p=.06

7.Switch type x task: F(2, 76)= .76, p=.47
x Group: F(2, 76)= .18, p =.83

8.*CTI x Trial type x task*: F(2,65)=1.6, p=.22
X Group: F (2, 65)= 2.4, p=.10

9.*CTI x congruency*: F (3,107)= 3.3, p=.03
X Group: F (3, 107)=.88, p=.45

10. *Trial type x congruency*: F (3, 100)= 1.2, p=.30
X Group: F (3, 100)= .43, p=.71

11. *CTI x Trial type x congruency* : F (3, 110)= 1.2, p=.30
X Group: F (3, 110)=.46, P=.70

12. *Task x congruency*: F (4, 150)=18, p <.001
X Group: F (4, 150)= 1.7, p=.16

13. CTI x task x congruency: F (5, 188)= 4.2, p=.001
X Group: F (5, 188)= .31, p=.90

14. *Trial type x task x congruency*: F (4, 171)= 3.1, p=.012
x Group: F (4, 171)= 1.7, p=.13

15. CTI x trial type x task x congruency: F (5, 192)= 1.6, p=.16
X Group: F (5, 192)= .52, p=.77

Between subject effect: F (1, 38)= 3.8, p=.06

8.CTI x Switch type x task: F (2, 72)= 1.2, p=.31
X Group: F (2, 72)= .70, p=.49

9.CTI x congruency: F(2, 88)= 2.6, p =.07
X Group: F (2, 88)= .18, p=.86

10. Switch type x congruency: F (3,102)= 1.2, p=.31
X Group: F (3,102)= .58, p=.61

11. CTI x Switch type x congruency: F (2,96)= 3.1, p =.04
X Group: F (2, 96)= 1.8, p=.15

12. Task x congruency: F (4, 155)= 7.4, P <.001
X Group : F (4, 155)= 3.0, p=.02

13. CTI x task x congruency: F (4, 152)= 2.4, p=.05
X Group: F (4, 152)=.78, p=.54

14. Switch type x task x Congruency: F(4, 171)=.72, p=.59
x Group: F (4, 171)= 1.3, p=.27

15. CTI x switch type x task x congruency: F (4, 164)= 1.4, p=.23
X Group: F (4, 164)= 2.5, p.04

Between subject effect: F (1, 38)= .67, p=.47

6. Exp 3 vs. Exp 6a (cue-target joint vs. cue-target separate with verbal cues)

CTI x Trial type x Task x Congruency By Group

1. CTI: F (1, 38)=250, p<.001
x Group: F (1, 38)= .004, p<.94

2. *Trial type*: F(1, 38)=59, p<.001
x Group: F (1,38)= .14, p =.71

3. *Task*: F (2, 68)=46, p<.001
x Group: F (2, 68)=.30, p=.72

4. *Congruency*: F (2, 66)=30, p <.001
X Group: F (2, 66)= 1.6, P=.21

9.*CTI x Trial type*: F(1, 38)=63, p <.001
x Group: F(1, 38)= 1.1, p =.29

10. *CTI x task*: F(2, 66)= 9.2, p<.001
x Group: F(2, 66)= 4.3, p=.02

11. *Trial type x task*: F(2, 66)= 3.1,p=.05
x Group: F(2, 66)= .79, p=.44

12. *CTI x Trial type x task*: F(2,71)=2.9, p=.06
X Group: F (2, 71)= .79, p=.45

CTI x Switch type x Task x Congruency By Group

1. CTI: F(1, 38)= 261, p<.001
x Group: F(1, 38)= .58, p=.45

2. Switch type :F (1, 38)= 4.2, p =.05
x Group: F (1, 38)= .09, p=.76

3. Task: F(2, 73)= 86, p <.001
x Group: F (2, 73)= 1.2, p=.31

4. Congruency: F (2, 92)= 65, p <.001
X Group: F (2, 92)= 1.2, p=.30

5. CTI x Switch type: F(1, 38)= .16, p=.69
x Group: F(1, 38)= .24, p= .62

6. CTI x task: F(2, 73)= 13, p<.001
x Group: F(2, 73)= 4.5, p=.015

7. Switch type x task: F(2, 75)= .42, p=.65
x Group: F(2, 75)= 1.1, p =.34

8. CTI x Switch type x task: F (2, 67)= 1.4, p=.24

9. *CTI x congruency*: F (3,107)= 4.5, p=.006
X Group: F (3, 107)=.51, p=.66

10. *Trial type x congruency*: F (3, 108)= .78, p=.50
X Group: F (3, 108)= .60, p=.61

11. *CTI x Trial type x congruency* : F (3, 108)= 1.4, p=.24
X Group: F (3, 108)=.25, P=.85

12. *Task x congruency*: F (4, 156)=7.1, p <.001
X Group: F (4, 156)= 2.6, p=.03

13. CTI x task x congruency: F (5, 181)= 2.8, p=.02
X Group: F (5, 181)= .95, p=.45

15. *Trial type x task x congruency*: F (5, 185)=.75, p=.58
x Group: F (5, 185)= .75, p=.58

15. CTI x trial type x task x congruency: F (5, 193)= 2.2, p=.05
X Group: F (5, 193)= 1.1, p=.37

Between subject effect: F (1, 38)= .73, p=.40

X Group: F (2, 67)= .83, p=.42

9. CTI x congruency: F(2, 89)= 3.8, p =.02
X Group: F (2, 89)= .758, p=.49

10. Switch type x congruency: F (2,89)= 3.8, p=.02
X Group: F (2,89)= .75, p=.49

11. CTI x Switch type x congruency: F (3,105)= 8.8, p <.001
X Group: F (3, 105)= .38, p=.75

12. Task x congruency: F (5, 181)= 14, P <.001
X Group : F (5, 181)= .99, p=.42

13. CTI x task x congruency: F (5, 185)= 1.8, p=.11
X Group: F (5, 185)=.55, p=.73

14. Switch type x task x Congruency: F(4, 176)=.24, p=.94
x Group: F (4, 176)= .77, p=.56

15. CTI x switch type x task x congruency: F (5, 190)= 4.9, p<.001
X Group: F (5, 190)= 1.3, p=.27

Between subject effect: F (1, 38)= 4.3, p=.044

7. Exp 4 vs. Exp 6b (cue-target joint vs. cue-target separate with arbitrary cues)

CTI x Trial type x Task x Congruency By Group

1. CTI: F (1, 31)=435, p<.001
x Group: F (1, 31)= 2.3, p=.14

2. *Trial type*: F(1, 31)=40, p<.001
x Group: F (1,31)= 2.0, p =.17

3. *Task*: F (2, 49)=28, p<.001
x Group: F (2, 49)=1.7, p=.20

4. *Congruency*: F (2, 75)=19, p <.001
X Group: F (2, 75)= 1.3, P=.26

5. *CTI x Trial type*: F(1, 31)=76, p <.001
x Group: F(1, 31)= .97, p =.33

6. *CTI x task*: F(2, 55)= 1.8, p=.18
x Group: F(2, 55)= .92, p=.40

7. *Trial type x task*: F(2, 56)= .21,p=.79
x Group: F(2, 56)= .23, p=.77

8. *CTI x Trial type x task*: F(2,61)=5.5, p=.006
X Group: F (2, 61)= .86, p=.43

9. *CTI x congruency*: F (2,82)= 3.0, p=.04
X Group: F (2, 82)=.68, p=.55

CTI x Switch type x Task x Congruency By Group

1. CTI: F(1, 33)= 225, p<.001
x Group: F(1, 33)= .20, p=.65

2. Switch type :F (1, 33)= 4.7, p =.04
x Group: F (1, 33)= .06, p=.80

3. Task: F(2, 58)= 20, p <.001
x Group: F (2, 58)= .26, p=.74

4. Congruency: F (3, 90)= 13, p <.001
X Group: F (3, 90)= .13, p=.92

5. CTI x Switch type: F(1, 33)= .77, p=.39
x Group: F(1, 33)= .12, p= .73

6. CTI x task: F(2, 56)= 7.9, p=.002
x Group: F(2, 56)= .35, p=.67

7. Switch type x task: F(2, 62)= .95, p=.39
x Group: F(2, 62)= .10, p =.37

8. CTI x Switch type x task: F (2, 64)= 16, p=.85
X Group: F (2, 64)= .13, p=.87

9. CTI x congruency: F(3, 91)= 3.5, p =.02

	X Group: F (3, 91)= .30, p=.81
10. *Trial type x congruency*: F (2, 66)= 4.3, p=.02 *X Group: F (2, 66)= .70, p=.50*	***10. Switch type x congruency:*** F (3,89)= .48, p=.67 *X Group: F (3,89)= .48, p=.67*
11. *CTI x Trial type x congruency* : F (2, 76)= 4.3, p=.01 *X Group: F (2, 76)= 1.1, P=.33*	***11. CTI x Switch type x congruency:*** F (2,82)= 3.5, p =.02 *X Group: F (3, 91)= .30, p=.81*
12. *Task x congruency*: F (4, 140)=7.1, p <.001 *X Group: F (4, 140)= 1.3, p=.28*	***12. Task x congruency:*** F (4, 147)= 8.7, P <.001 *X Group : F (4, 147)= .71, p=.60*
13. CTI x task x congruency: F (3, 104)= 2.5, p=.06 *X Group: F (3, 104)= .86, p=.47*	***13. CTI x task x congruency:*** F (4, 134)= 2.5, p=.04 *X Group: F (4, 134)=.71, p=.58*
16. *Trial type x task x congruency*: F (4, 137)=4.8, p=.001 *x Group: F (4, 137)= 1.4, p=.22*	***14. Switch type x task x Congruency***: F(3, 109)= 1.5, p=.20 *x Group: F (3, 109)= .45, p=.73*
15. CTI x trial type x task x congruency: F (4, 133)= 5.4, p<.001 *X Group: F (4, 133)= 1.5, p=.21*	***15. CTI x switch type x task x congruency***: F (5, 156)= 2.4, p=.04 *X Group:* F (5, 156)= .95, p=.45
Between subject effect: F (1, 31)= 2.1, p=.16	*Between subject effect: F (1, 33)= 2.5, p=.12*

8. Exp 6a vs. Exp 6b (verbal cues vs. arbitrary cues when both cue-target are separately displayed) *(see the chapter 8, page 314-315)*

CTI x Trial type x Task x Congruency By Group	CTI x Switch type x Task x Congruency By Group
1. CTI: F (1, 31)=237, p<.001 *x Group: F (1, 31)= 14, p=.001*	***1. CTI***: F(1, 33)= 185, p<.001 *x Group: F(1, 33)= 25, p<.001*
2. *Trial type*: F(1, 31)=32, p<.001 *x Group: F (1,31)= 7.1, p =.01*	***2. Switch type*** :F (1, 33)= 2.8, p =.10 *x Group: F (1, 33)= 1.1, p=.31*
3. *Task*: F (2, 58)=57, p<.001 *x Group: F (2, 58)=2.2, p=.12*	***3. Task***: F(2, 55)= 43, p <.001 *x Group: F (2, 55)= .30, p=.70*
4. *Congruency*: F (2, 66)=40, p <.001 X Group: F (2, 66)= .29, P=.76	***4. Congruency***: F (2, 84)= 33, p <.001 *X Group: F (2, 84)= .04, p=.98*
9. *CTI x Trial type*: F(1, 31)=58, p <.001 *x Group: F(1, 31)= 7.9, p =.009*	***5. CTI x Switch type***: F(1, 33)= .41, p=.52 *x Group: F(1, 33)= 1.1, p= .29*
10. *CTI x task*: F(2, 60)= 2.1, p=.13 *x Group: F(2, 60)= .45, p=.63*	***6. CTI x task***: F(2, 57)= 5.7, p=.008 *x Group: F(2, 57)= 1.7, p=.19*
11. *Trial type x task*: F(2, 60)= .52,p=.59 *x Group: F(2, 60)= .003, p=.99*	***7. Switch type x task***: F(2, 65)= .34, p=.70 *x Group: F(2, 65)= .56, p =.57*
12. *CTI x Trial type x task*: F(2,62)=3, p=.06 X Group: F (2, 62)= 1.2, p=.31	***8. CTI x Switch type x task:*** F (2, 65)= .15, p=.86 *X Group: F (2, 65)= .10, p=.90*
9.CTI x congruency: F (3,84)= 1.3, p=.27 X Group: F (3, 84)=.39, p=.74	***9. CTI x congruency:*** F(3, 96)= 4.3, p =.008

10. *Trial type x congruency*: F (2, 80)= 3.2, p=.03
X Group: F (2, 80)= 1.2, p=.30

11. *CTI x Trial type x congruency* : F (3, 88)= 2.5, p=.07
X Group: F (3, 88)= 1.2, P=.30

12. *Task x congruency*: F (4, 129)=14, p <.001
X Group: F (4, 129)= .62, p=.65

13. CTI x task x congruency: F (4, 131)= 2.7, p=.03
X Group: F (4, 131)= .48, p=.76

17. *Trial type x task x congruency*: F (4, 136)=2.7, p=.03
x Group: F (4, 136)= .43, p=.80

15. CTI x trial type x task x congruency: F (5, 145)= 3.2, p<.001
X Group: F (5, 145)= 2.9, p=.02

Between subject effect: F (1, 31)= 4.1, p=.05

X Group: F (3, 96)= 1.5, p=.20

10. *Switch type x congruency:* F (3,87)= .23, p=.85
X Group: F (3,87)= .45, p=.69

11. *CTI x Switch type x congruency:* F (3,92)= 5.1, p =.003
X Group: F (3, 92)= .38, p=.75

12. *Task x congruency:* F (5, 162)= 9.7, P <.001
X Group : F (5, 162)= 1.1, p=.37

13. *CTI x task x congruency:* F (4, 132)= 2.5, p=.05
X Group: F (4, 132)=1.2, p=.33

14. *Switch type x task x Congruency*: F(4, 148)= 1.2, p=.31
x Group: F (4, 148)= .84, p=.51

15. *CTI x switch type x task x congruency*: F (4, 140)= 1.9, p=.11
X Group: F (4, 140)= 2, p=.13

Between subject effect: F (1, 33)= 8.6, p=.13

Chapter 4. Old controls vs. Patients with early Parkinson's disease

a) Reaction time (ms)

CTI x Trial type x Task x Congruency By Group

1. ***CTI***: F (1, 32)=172, p<.001
x Group: F (1, 32)= .48, p=.49

2. ***Trial type***: F(1, 32)=23, p<.001
x Group: F (1,32)= .12, p =.57

3. ***Task***: F (1, 38)=16, p<.001
x Group: F (1, 38)=.12, p=.78

4. ***Congruency***: F (1, 43)=23, p <.001
X Group: F (1, 43)= .21, P=.72

5. ***CTI x Trial type***: F(1, 32)=8.3, p =.007
x Group: F(1, 32)= 1.4, p =.24

6. ***CTI x task***: F(1, 45)= 17, p<.001
x Group: F(1, 45)= .82, p=.41

7. ***Trial type x task***: F(2, 61)= 3.3, p=.05
x Group: F(2, 61)= 1.4, p=.87

8. ***CTI x Trial type x task***: F(1,37)=.86, p=.37
X Group: F (1, 37)= .18, p=.71

9. ***CTI x congruency***: F (2,58)= 14, p<.001

CTI x Switch type x Task x Congruency By Group

1. ***CTI***: F(1, 31)= 2.3, p=.14
x Group: F(1, 31)= .94, p=.34

2. **Switch type** :F (1, 31)= 303, p <.001
x Group: F (1, 31)= 61, p=.44

3. ***Task***: F(1, 47)= 24, p <.001
x Group: F (1, 47)= 2.6, p=.10

4. ***Congruency***: F (2, 72)= 29, p <.001
X Group: F (2, 72)= .75, p=.49

5. ***CTI x Switch type***: F(1, 31)= 1.2, p=.28
x Group: F(1, 31)= .06, p= .80

6. ***CTI x task***: F(2, 52)= 1.3, p=.27
x Group: F(2, 52)= .69, p=.48

7. ***Switch type x task***: F(2, 60)= 33, p<.001
x Group: F(2, 60)= 2.1, p =.13

8. ***CTI x Switch type x task:*** F (2, 56)= .23, p=.77
X Group: F (2, 56)=.04, p=.95

9. ***CTI x congruency:*** F(3, 90)=6.4, p

X Group: F (2, 58)=.15, p=.84

10. *Trial type x congruency*: F (2, 53)= 4.8, p=.02
X Group: F (2, 53)= 4.8, p=.02

11. *CTI x Trial type x congruency* : F (2, 60)= 7.9, p=.001
X Group: F (2, 60)=.42, P=.65

12. *Task x congruency*: F (2, 77)=12, p <.001
X Group: F (2, 77)= .05, p=.97

13. CTI x task x congruency: F (2, 52)= 3.2, p=.06
X Group: F (2, 52)= .52, p=.56

14.Trial type x task x congruency: F (3, 103)=11, p<.001
x Group: F (3, 103)= 1.1, p=.37

15. CTI x trial type x task x congruency: F (2, 59)= 4.4, p=.02
X Group: F (2, 59)= .34, p=.69

Between subject effect: F (1, 32)=.53, p=.47

=.001
X Group: F (3, 90)= .02, p=.10

10. Switch type x congruency: F (2,71)= 5.3, p=.005
X Group: F (2,71)= .40, p=.70

11. CTI x Switch type x congruency: F (2,77)= 2.7, p =.06
X Group: F (2, 77)= .15, p=.90

12. Task x congruency: F (4, 119)= 9.0, P <.001
X Group : F (4, 119)= .85, p=.49

13. CTI x task x congruency: F (4, 129)= 3.5, p=.009
X Group: F (4, 129)=1.8, p=.13

14. Switch type x task x Congruency: F(4, 122)=5.8, p<.001
x Group: F (4, 122)= .50, p=.73

15. CTI x switch type x task x congruency: F (4, 133)= 4.1, p=.003
X Group: F (4, 133)= .77, p=.55

Between subject effect: F (1, 31)= 1.9, p=.18

b) Error (%)

CTI x Trial type x Task x Congruency By Group	CTI x Switch type x Task x Congruency By Group

1. CTI: F (1, 32)=195, p<.001
x Group: F (1, 32)= .55, p=.46

9. *Trial type*: F(1, 32)=9.7, p=.004
x Group: F (1,32)= 1.9, p =17

10. *Task*: F (1, 40)=12, p<.001
x Group: F (1, 40)=.15, p=.76

4. *Congruency*: F (1, 32)=314, p <.001
X Group: F (1, 32)= .74, P=.40

5. *CTI x Trial type*: F(1, 32)=.94, p =.34
x Group: F(1, 32)= .18, p =.68

6. *CTI x task*: F(2, 58)= 10, p<.001
x Group: F(2, 58)= .83, p=.43

7. *Trial type x task*: F(2, 58)= 1.1, p=.33
x Group: F(2, 53)= .47, p=.61

8. *CTI x Trial type x task*: F(2,55)=.07, p=.95
X Group: F (2, 55)= .85, p=.42

9. *CTI x congruency*: F (1,32)= 195, p<.001
X Group: F (1, 32)=.56, p=.46

10. *Trial type x congruency*: F (1, 32)=

16. CTI: F(1, 32)= .007, p=.94
x Group: F(1, 32)= .69, p=.41

17. Switch type :F (1, 32)= 8.1, p <.001
x Group: F (1, 32)= .08, p=.78

18. Task: F(2, 60)= 7.7, p =.001
x Group: F (2, 60)= .07, p=.92

19. Congruency: F (1, 35)= 10, p =.002
X Group: F (1, 35)= .54, p=.48

20. CTI x Switch type: F(1, 32)= 1.4, p=.24
x Group: F(1, 32)= .06, p= .81

21. CTI x task: F(2, 56)= 16, p=.83
x Group: F(2, 56)= .003, p=.99

22. Switch type x task: F(2, 62)= .47, p=.62
x Group: F(2, 62)= .25, p =.77

23. CTI x Switch type x task: F (2, 56)= 1.1, p=.33
X Group: F (2, 56)=.05, p=.93

24. CTI x congruency: F(2, 60)=2.5, p = 1.0
X Group: F (2, 60)= 1.2, p=.30

25. Switch type x congruency: F

9.7, p=.004 *X Group: F (1, 32)= 1.9, p=.17*	(2,60)= 1.7, p=.19 *X Group: F (2,60)= .28, p=.74*
11. ***CTI x Trial type x congruency*** : F (1, 32)= .94, p=.34 *X Group: F (1, 32)=.18, P=.67*	***26. CTI x Switch type x congruency:*** F (2,45)= .13, p =.80 *X Group: F (2, 45)= .23, p=.72*
12. ***Task x congruency***: F (1, 40)=12, p <.001 *X Group: F (1, 40)= .15, p=.76*	***27. Task x congruency:*** F (2, 73)= 6.7, P =.001 *X Group : F (2, 73)= .12, p=.91*
13. CTI x task x congruency: F (2, 57)= 10, p<.001 *X Group: F (2, 57)= .83, p=.43*	***28. CTI x task x congruency:*** F (2, 70)= .64, p=.55 *X Group: F (2, 70)=.50, p=.63*
14.Trial type x task x congruency: F (2, 57)=1.1, p=.33 *x Group: F (2, 57)= .47, p=.61*	***29. Switch type x task x Congruency***: F(2, 82)=2, p=.12 *x Group: F (2, 82)= 1.2, p=.30*
15. CTI x trial type x task x congruency: F (2, 55)= .07, p=.90 *X Group: F (2, 55)= .85, p=.42*	***30. CTI x switch type x task x congruency***: F (2, 58)= 1.3, p=.85 *X Group:* F (2, 58)= .34, p=.67
Between subject effect: F (1, 32)=.74, p=.40	*Between subject effect: F (1, 32)= .39, p=.53*

c) Effect of Previous congruency (Error data)

Switch/Repeat (Trial type)

	CTI=100		CTI=1200	
	Switch	Repeat	Switch	Repeat
Arrow	*Previous congruency* : F (1, 32)=.07, p=.80	F (1, 32)=.003, P=.96	*Previous congruency*: F (1, 32)=.11, p=.74	F (1, 32)=.00 P=1.0
	X group: F (1, 32)= 2.04, p=.16	F (1, 32)=.97, p=.33	*X group*: F (1, 32)= 2.6, p=.12	F (1, 32)= .60, p=.44
	Between subject effect: F (1, 32)=.04	F (1, 32)=.49, p=.49	*Between subject effect:* F (1, 32)=.10, p=.75	F (1, 32)=.84, p=.37
Location	*Previous congruency*: F (1, 32)= .36, p=.55	F (1, 32)= 3.4, p=.07	*Previous congruency*: F (1, 32)= 1.3, p=.26	F (1, 32)= 5.2, p=.03
	X Group: F (1, 32)=.36, p=.55	F (1, 32)=.08, p=.77	*X group*: F (1,32)= 2.6, p=.12	F (1, 32)= 1.3, p=.26
	Between subject effect: F (1, 32)= .44, p=.51	F (1, 32)= .50, p=.48	*Between subject effect*: F (1, 32)=.10, p=.75	F (1, 32)=.30, p=.59
Word	*Previous congruency*:		*Previous congruency*:	

	F (1, 32)= .23, p=.64 *X Group*: F (1, 32)= 4.3, p=.05 *Between subject effect*: F (1, 32)= .41, p=.53	F (1, 32)= 3.4, P=.07 F(1,32)= .08,p= .77 F (1, 32)=.50, P=.48	F (1, 32)= 1.3, p=.25 *X Group*: F (1, 32)= 1.3, p=.25 *Between subject effect:* F (1, 32)=.65, p=.42	F (1, 32)= 3.7, p=.09 F (1,32)=.34, p=.56 F (1, 32)= .34, p=.56

Alternating switch/Double switch (switch type)

	CTI=100		CTI=1200	
	Alternating switch	Double switch	Alternating switch	Double switch
Arrow	*Previous congruency* : F (1, 32)= 1.3, p=.26 *X group*: F (1, 32)= 2. 4, p=.13 *Between subject effect*: F (1, 32)=.18 P=.67	F (1, 32)=.99, P=.33 F (1, 32)=.05, p=.82 F (1, 32)=.05, p=.82	*Previous congruency*: F (1, 32)=1.7 p=.20 *X group*: F (1, 32)= 1.3, p=.26 *Between subject effect:* F (1, 32)=.87, p=.36	F (1, 32)=.14 P=.71 F (1, 32)= .91, p=.35 F (1, 32)=.39, p=.54
Location	*Previous congruency*: F (1, 32)= .26, p=.61 *X Group*: F (1, 32)=.87, p=.36 *Between subject effect*: F (1, 32)= .05, p=.83	F (1, 32)= .45, p=.51 F (1, 32)=.03, p=.86 F (1, 32)= .50, p=.48	*Previous congruency*: F (1, 32)= 1.9, p=.17 *X group*: F (1,32)= 1.8, p=.18 *Between subject effect*: F (1, 32)=.68, p=.41	F (1, 32)= 1.9, p=.18 F (1, 32)= .31, p=.58 F (1, 32)=.79, p=.38
Word	*Previous congruency*: F (1, 32)= .22, p=.64 *X Group*: F (1, 32)= 4.0, p=.05 *Between subject effect*: F (1, 32)= .22,	F (1, 32)= .76, P=.39 F(1,32)= .38,p= .54 F (1, 32)=.28,	*Previous congruency*: F (1, 32)= .01, p=.91 *X Group*: F (1, 32)= .17, p=.68 *Between subject effect:* F (1, 32)=.20, p=.66	F (1, 32)= 2.1, p=.15 F (1, 32)=.81, p=.37 F (1, 32)= 1.1,

p=.64	P=.50	p=.29

• 4-Way ANOVA TABLE for each chapter (note: chapter 4 was presented previously)

Chapter 3 (Experiment 1)

1. Effect of Trial type (Switch/Repeat), CTI, Task and Congruency *(see the chapter 3, page 73)*

a) On Reaction Time (ms)

Effect	*Df*	*F*	*P*
CTI	1, 20	156	P <.001
Trial type	1, 20	30	P<.001
Task	2, 37	22	P<.001
Congruency	2, 40	32	P<.001
CTI x trial type	1, 20	32	P<.001
CTI x task	2, 35	7.7	P=.002
Trial type x task	2, 33	1.6	P=.209
CTI x trial type x task	2, 37	4.1	P=.026
CTI x Congruency	2, 34	.98	P=.37
Trial type x Congruency	3, 57	.37	P=.76
CTI x Trial type x Congruency	2, 43	2.1	P=.12
Task x Congruency	3, 70	6.7	P<.001
CTI x task x Congruency	4, 75	2.4	P=.06
Trial type x task x Congruency	4, 86	1.4	P=.23
CTI x trial type x task x congruency	4, 93	2.4	P=.05

b) On Error (%)

Effect	*Df*	*F*	*P*
CTI	1, 20	.65	P =.43
Trial type	1, 20	15	P=.001
Task	2, 37	.24	P=.77
Congruency	2, 35	29	P<.001
CTI x trial type	1, 20	.26	P=.62
CTI x task	2, 38	2.9	P=.07
Trial type x task	2, 35	3.3	P=.05
CTI x trial type x task	2, 38	.64	P=.54
CTI x Congruency	2, 35	5.2	P=.02
Trial type x Congruency	2, 40	3.1	P=.06
CTI x Trial type x Congruency	2, 40	.45	P=.63
Task x Congruency	3, 68	1.5	P=.21
CTI x task x Congruency	3, 61	2.5	P=.07
Trial type x task x Congruency	3, 71	1.9	P=.12
CTI x trial type x task x	3, 72	.51	P=.71

congruency

2. **Effect of Switch type (Alternating/Double switch), CTI, Task and Congruency** *(see the chapter 3, page 87)*

a) On Reaction time (ms)

Effect	*Df*	*F*	*P*
CTI	1, 20	193	p <.001
Switch type	1, 20	.09	P=.76
Task	2, 34	12	P <.001
Congruency	2, 50	29	P <.001
CTI x switch type	1, 20	.007	P=.93
CTI x task	1, 27	14	P <.001
Switch type x task	1, 31	.09	P=.87
CTI x switch type x task	2, 37	1.6	p=.21
CTI x Congruency	2, 50	2	P=.13
Switch type x Congruency	2, 44	.89	P=.43
CTI x Switch type x Congruency	2, 49	6.1	P=.002
Task x Congruency	3, 69	8.1	P <.001
CTI x task x Congruency	3, 56	1.7	P=.17
Switch type x task x Congruency	3, 69	2.0	P=.10
CTI x switch type x task x congruency	2, 47	3.6	P=.03

b) On Error (%)

Effect	*Df*	*F*	*P*
CTI	1, 20	1.0	p =.33
Switch type	1, 20	.40	P=.53
Task	2, 35	.18	P =.80
Congruency	1, 30	17	P <.001
CTI x switch type	1, 20	1.5	P=.23
CTI x task	2, 39	2.3	P =.11
Switch type x task	2, 34	.42	P=.63
CTI x switch type x task	2, 38	.70	p=.50
CTI x Congruency	2, 46	3.3	P=.04
Switch type x Congruency	2, 47	.85	P=.45
CTI x Switch type x Congruency	2, 46	.63	P=.56
Task x Congruency	3, 66	1.4	P=.24
CTI x task x Congruency	4, 74	2.8	P=.03
Switch type x task x Congruency	4, 83	1.5	P=.20
CTI x switch type x task x congruency	3, 67	.58	P=.65

1. Effect of Trial type (Switch/Repeat), CTI, Task and Congruency *(see the chapter 5, page 141-142)*

a) On Reaction Time (RT)

Effect	*Df*	*F*	*P*
CTI	1, 20	116	P <.001
Trial type	1, 20	41	P<.001
Task	1, 30	23	P<.001
Congruency	2, 37	20	P<.001
CTI x trial type	1, 20	22	P<.001
CTI x task	2, 32	10	P=.001
Trial type x task	1, 29	.52	P=.54
CTI x trial type x task	1, 30	4.6	P=.03
CTI x Congruency	3, 56	2.7	P=.06
Trial type x Congruency	2, 53	.56	P=.62
CTI x Trial type x Congruency	3, 55	.10	P=.40
Task x Congruency	4, 72	7.4	P<.001
CTI x task x Congruency	4, 88	2.2	P=.07
Trial type x task x Congruency	4, 81	2.6	P=.04
CTI x trial type x task x congruency	4, 90	.63	P=.66

b) On Error (%)

Effect	*Df*	*F*	*P*
CTI	1, 19	.05	P =.82
Trial type	1, 19	10	P=.005
Task	1, 29	1.1	P=.32
Congruency	1, 28	26	P<.001
CTI x trial type	1, 19	.47	P=.50
CTI x task	2, 37	1.2	P=.32
Trial type x task	2, 32	.49	P=.58
CTI x trial type x task	2, 43	2.2	P=.12
CTI x Congruency	2, 43	2.2	P=.12
Trial type x Congruency	3, 50	4.9	P=.006
CTI x Trial type x Congruency	2, 44	3.4	P=.04
Task x Congruency	3, 56	46	P=.006
CTI x task x Congruency	3, 59	1.7	P=.18
Trial type x task x Congruency	3, 56	1.0	P=.38
CTI x trial type x task x congruency	4, 77	1.0	P=.38

2. **Effect of Switch type (Alternating/Double switch), CTI, Task and Congruency** *(see the chapter 5, page 153)*

a) On Reaction time (RT)

Effect	*Df*	*F*	*P*
CTI	1, 20	124	p <.001
Switch type	1, 20	.36	P=.07
Task	2, 35	30	P <.001
Congruency	2, 41	32	P <.001
CTI x switch type	1, 20	.004	P=.95
CTI x task	2, 37	16	P <.001
Switch type x task	2, 39	.19	P=.82
CTI x switch type x task	2, 35	1.8	p=.18
CTI x Congruency	2, 44	1.2	P=.30
Switch type x Congruency	2, 48	2	P=.18
CTI x Switch type x Congruency	3, 53	3.7	P=.02
Task x Congruency	4, 80	6.2	P <.001
CTI x task x Congruency	4, 83	1.1	P=.35
Switch type x task x Congruency	4, 86	.56	P=.70
CTI x switch type x task x congruency	4, 92	3.5	P=.007

b) On Error (%)

Effect	*Df*	*F*	*P*
CTI	1, 19	.33	p =.57
Switch type	1, 19	.007	P=.93
Task	2, 31	.12	P =.87
Congruency	2, 31	29	P <.001
CTI x switch type	1, 19	.00	P=.99
CTI x task	2, 32	4.3	P =.03
Switch type x task	2, 32	1.8	P=.17
CTI x switch type x task	1, 29	.34	p=.66
CTI x Congruency	2, 38	.78	P=.47
Switch type x Congruency	2, 39	.04	P=.97
CTI x Switch type x Congruency	2, 45	3.1	P=.05
Task x Congruency	3, 61	3.5	P=.02
CTI x task x Congruency	3, 63	23	P=.08
Switch type x task x Congruency	3, 62	1.2	P=.33
CTI x switch type x task x congruency	4, 75	.37	P=.82

Chapter 6 (Experiment 4)

1. Effect of Trial type (Switch/Repeat), CTI, Task and Congruency *(see the chapter 6, page 182)*

a) On Reaction Time (ms)

Effect	Df	F	P
CTI	1, 18	674	P <.001
Trial type	1, 18	28	P<.001
Task	1, 28	22	P<.001
Congruency	2, 37	20	P<.001
CTI x trial type	2, 40	22	P<.001
CTI x task	2, 32	10	P=.001
Trial type x task	2, 32	.37	P=.67
CTI x trial type x task	2, 32	4.5	P=.021
CTI x Congruency	2, 45	3.5	P=.03
Trial type x Congruency	2, 35	2.9	P=.07
CTI x Trial type x Congruency	2, 34	3.7	P=.04
Task x Congruency	4, 73	5.2	P=.001
CTI x task x Congruency	3, 47	2.4	P=.09
Trial type x task x Congruency	4, 77	5.5	P<.001
CTI x trial type x task x congruency	3, 65	3.9	P=.008

b) On Error

Effect	Df	F	P
CTI	1, 18	3.4	P =.08
Trial type	1, 18	9.1	P=.007
Task	1, 20	1.6	P=.22
Congruency	1, 19	5.9	P=.02
CTI x trial type	1, 18	.19	P=.66
CTI x task	2, 33	.38	P=.67
Trial type x task	2, 32	1.0	P=.36
CTI x trial type x task	2, 32	3.1	P=.06
CTI x Congruency	2, 40	1.1	P=.34
Trial type x Congruency	2, 42	1.2	P=.33
CTI x Trial type x Congruency	2, 33	.78	P=.45
Task x Congruency	1, 21	1.4	P=.26
CTI x task x Congruency	3, 61	1.2	P=.30
Trial type x task x Congruency	2, 40	1.6	P=.21
CTI x trial type x task x congruency	4, 66	1.3	P=.29

2. Effect of Switch type (Alternating/Double switch), CTI, Task and Congruency

a) On Reaction time (RT)

Effect	*Df*	*F*	*P*
CTI	1, 18	153	p <.001
Switch type	1, 18	3.8	P=.07
Task	2, 33	9.9	P =.001
Congruency	2, 46	5.8	P =.003
CTI x switch type	1, 18	.15	P=.70
CTI x task	2, 31	4.9	P =.02
Switch type x task	2, 30	1.7	P=.21
CTI x switch type x task	1, 28	.20	p=.76
CTI x Congruency	2, 42	1.5	P=.23
Switch type x Congruency	2, 44	.81	P=.47
CTI x Switch type x Congruency	2, 31	2.1	P=.15
Task x Congruency	3, 50	6.1	P=.002
CTI x task x Congruency	3, 58	1.7	P=.17
Switch type x task x Congruency	2, 40	1.1	P=.35
CTI x switch type x task x congruency	4, 71	2.0	P=.10

b) On Error (%)

Effect	*Df*	*F*	*P*
CTI	1, 18	7.5	p =.02
Switch type	1, 18	1.2	P=.28
Task	1, 23	1.7	P =.20
Congruency	1, 21	6.5	P =.01
CTI x switch type	1, 18	4	P=.06
CTI x task	2, 34	.18	P =.82
Switch type x task	2, 31	2.5	P=.10
CTI x switch type x task	2, 32	1.9	p=.16
CTI x Congruency	2, 29	2.4	P=.12
Switch type x Congruency	2, 32	1.2	P=.31
CTI x Switch type x Congruency	2, 42	3.4	P=.03
Task x Congruency	1, 22	1.1	P=.31
CTI x task x Congruency	3, 49	1.9	P=.15
Switch type x task x Congruency	3, 63	.57	P=.66
CTI x switch type x task x congruency	4, 67	2.1	P=.10

1. Effect of Trial type (Switch/Repeat), CTI, Task and Congruency *(see the chapter 7, page 224-225)*

a) On Reaction Time (RT)

Effect	*Df*	*F*	*P*
CTI	1, 18	141	P <.001
Trial type	1, 18	22	P<.001
Task	2, 33	23	P<.001
Congruency	1, 28	12	P<.001
CTI x trial type	1, 18	45	P<.001
CTI x task	2, 32	3.6	P=.04
Trial type x task	2, 32	2.9	P=.08
CTI x trial type x task	2, 36	.30	P=.74
CTI x Congruency	2, 44	2.4	P=.09
Trial type x Congruency	2, 45	.95	P=.41
CTI x Trial type x Congruency	2, 41	.67	P=.54
Task x Congruency	4, 66	2.8	P=.04
CTI x task x Congruency	3, 66	1.5	P=.20
Trial type x task x Congruency	4, 71	2.9	P=.03
CTI x trial type x task x congruency	4, 83	28	P=.03

b) On Error

Effect	*Df*	*F*	*P*
CTI	1, 18	.88	P =.36
Trial type	1, 18	11	P=.003
Task	1, 29	1.4	P=.26
Congruency	2, 30	11	P=.001
CTI x trial type	1, 18	.22	P=.64
CTI x task	2, 29	.48	P=.02
Trial type x task	2, 32	.64	P=.52
CTI x trial type x task	2, 33	.14	P=.85
CTI x Congruency	2, 32	27	P<.001
Trial type x Congruency	3, 47	.47	P=.68
CTI x Trial type x Congruency	2, 39	.96	P=.40
Task x Congruency	3, 63	.75	P=.54
CTI x task x Congruency	3, 48	3.6	P=.02
Trial type x task x Congruency	4, 67	1.1	P=.38
CTI x trial type x task x congruency	4, 77	.59	P=.68

2. **Effect of Switch type (Alternating/Double switch), CTI, Task and Congruency** *(see the chapter 7, page 235-236)*

a) On Reaction time (RT)

Effect	*Df*	*F*	*P*
CTI	1, 18	197	p <.001
Switch type	1, 18	12	P=.003
Task	2, 31	36	P <.001
Congruency	2, 42	17	P <.001
CTI x switch type	1, 18	1.1	P=.31
CTI x task	2, 34	2.8	P =.07
Switch type x task	2, 35	.14	P=.86
CTI x switch type x task	2, 35	.37	p=.68
CTI x Congruency	3, 50	2.1	P=.11
Switch type x Congruency	2, 42	.34	P=.75
CTI x Switch type x Congruency	3, 50	1.4	P=.25
Task x Congruency	3, 58	3.3	P=.024
CTI x task x Congruency	4, 65	1.8	P=.14
Switch type x task x Congruency	3, 64	1.3	P=.28
CTI x switch type x task x congruency	3, 61	1.1	P=.34

b) On Error (%)

Effect	*Df*	*F*	*P*
CTI	1, 18	.61	p =.45
Switch type	1, 18	.10	P=.75
Task	2, 34	2.4	P =.11
Congruency	1, 28	16	P <.001
CTI x switch type	1, 18	5.8	P=.03
CTI x task	2, 29	2.9	P =.08
Switch type x task	1, 26	4.7	P=.03
CTI x switch type x task	2, 34	2.8	p=.08
CTI x Congruency	2, 35	3.5	P=.04
Switch type x Congruency	2, 41	.69	P=.52
CTI x Switch type x Congruency	3, 51	.89	P=.45
Task x Congruency	3, 60	2.8	P=.04
CTI x task x Congruency	3, 64	2.1	P=.10
Switch type x task x Congruency	4, 73	1.2	P=.31
CTI x switch type x task x congruency	4, 69	.74	P=.54

1. Effect of Trial type (Switch/Repeat), CTI, Task and Congruency *(see the chapter 8, page 269)*

a) On Reaction Time (ms)

Effect	*Df*	*F*	*P*
CTI	1, 18	173	P <.001
Trial type	1, 18	14	P=.002
Task	2, 30	91	P<.001
Congruency	3, 49	39	P<.001
CTI x trial type	1, 18	24	P<.001
CTI x task	2, 31	3.3	P=.06
Trial type x task	2, 34	.55	P=.57
CTI x trial type x task	2, 33	.57	P=.55
CTI x Congruency	3, 50	1.3	P=.30
Trial type x Congruency	2, 42	1.2	P=.32
CTI x Trial type x Congruency	3, 50	.70	P=.54
Task x Congruency	3, 51	14	P<.001
CTI x task x Congruency	4, 74	2.4	P=.05
Trial type x task x Congruency	4, 74	2.4	P=.05
CTI x trial type x task x congruency	4, 73	1.5	P=.22

b) On Error

Effect	*Df*	*F*	*P*
CTI	1, 18	9.2	P =.007
Trial type	1, 18	35	P<.001
Task	1, 26	20	P<.001
Congruency	2, 38	15	P<.001
CTI x trial type	1, 18	.09	P=.76
CTI x task	2, 33	3	P=.06
Trial type x task	2, 34	1.6	P=.21
CTI x trial type x task	2, 343	.35	P=.69
CTI x Congruency	2, 36	24	P<.001
Trial type x Congruency	3, 48	7.7	P<.001
CTI x Trial type x Congruency	2, 36	8.6	P=.001
Task x Congruency	3, 52	7.3	P<.001
CTI x task x Congruency	3, 58	14	P<.001
Trial type x task x Congruency	3, 61	1.7	P=.15
CTI x trial type x task x congruency	3, 64	1.9	P=.12

2. Effect of Switch type (Alternating/Double switch), CTI, Task and Congruency *(see the chapter 8, page 280-281)*

a) On Reaction time (ms)

Effect	*Df*	*F*	*P*
CTI	1, 18	149	p <.001
Switch type	1, 18	1.2	P=.30
Task	2, 33	85	P <.001
Congruency	3, 49	38	P <.001
CTI x switch type	1, 18	.49	P=.49
CTI x task	2, 33	1.8	P =.18
Switch type x task	2, 34	1.6	P=.22
CTI x switch type x task	1, 27	.17	p=.78
CTI x Congruency	2, 46	4.1	P=.014
Switch type x Congruency	2, 40	.81	P=.46
CTI x Switch type x Congruency	2, 46	6.7	P=.001
Task x Congruency	5, 88	10	P<.001
CTI x task x Congruency	4, 69	1.3	P=.27
Switch type x task x Congruency	4, 76	.45	P=.78
CTI x switch type x task x congruency	4, 79	2.6	P=.04

b) On Error (%)

Effect	*Df*	*F*	*P*
CTI	1, 18	6.9	p =.02
Switch type	1, 18	.19	P=.67
Task	2, 30	5.3	P =.02
Congruency	2, 39	24	P <.001
CTI x switch type	1, 18	.98	P=.33
CTI x task	2, 35	2.2	P =.12
Switch type x task	2, 35	.012	P=.98
CTI x switch type x task	2, 31	.69	p=.48
CTI x Congruency	3, 50	2.8	P=.05
Switch type x Congruency	1, 27	1.6	P=.21
CTI x Switch type x Congruency	2, 41	4.4	P=.01
Task x Congruency	3, 64	5	P=.002
CTI x task x Congruency	4, 71	2.8	P=.03
Switch type x task x Congruency	3, 54	1.4	P=.26
CTI x switch type x task x congruency	4, 70	.99	P=.41

1. Effect of Trial type (Switch/Repeat), CTI, Task and Congruency *(see the chapter 8, page 292)*

a) On Reaction Time (ms)

Effect	*Df*	*F*	*P*
CTI	1, 13	91	P <.001
Trial type	1, 13	16	P=.001
Task	2, 21	9.8	P=.002
Congruency	2, 24	12	P<.001
CTI x trial type	1, 18	29	P<.001
CTI x task	2, 22	.57	P=.54
Trial type x task	2, 24	13	P=.86
CTI x trial type x task	2, 25	2.2	P=.13
CTI x Congruency	2, 30	5.8	P=.59
Trial type x Congruency	2, 33	2.6	P=.08
CTI x Trial type x Congruency	2, 34	2.0	P=.13
Task x Congruency	3, 50	3.5	P=.01
CTI x task x Congruency	3, 46	1.1	P=.36
Trial type x task x Congruency	3, 45	1.1	P=.38
CTI x trial type x task x congruency	4, 57	3.8	P=.007

b) On Error

Effect	*Df*	*F*	*P*
CTI	1, 16	18	P =.001
Trial type	1, 16	5.2	P=.04
Task	2, 31	1.0	P=.36
Congruency	1, 19	18	P<.001
CTI x trial type	1, 16	.01	P=.92
CTI x task	2, 28	3.3	P=.05
Trial type x task	2, 28	.06	P=.93
CTI x trial type x task	2, 28	1.2	P=.32
CTI x Congruency	2, 37	2.8	P=.06
Trial type x Congruency	2, 37	2.1	P=.13
CTI x Trial type x Congruency	2, 36	.44	P=.67
Task x Congruency	1, 25	1.2	P=.30
CTI x task x Congruency	4, 60	.99	P=.42
Trial type x task x Congruency	3, 47	.85	P=.47
CTI x trial type x task x congruency	4, 63	1.6	P=.19

2. Effect of Switch type (Alternating/Double switch), CTI, Task and Congruency *(see the chapter 8, page 408 table 2b)*

a) On Reaction time (ms)

Effect	*Df*	*F*	*P*
CTI	1, 14	110	p <.001
Switch type	1, 14	.19	P=.66
Task	1, 22	5.7	P =.015
Congruency	2, 26	10	P =.001
CTI x switch type	1, 14	3.2	P=.10
CTI x task	2, 33	1.8	P =.18
Switch type x task	2, 27	.04	P=.96
CTI x switch type x task	2, 27	.55	p=.58
CTI x Congruency	2, 30	2.4	P=.10
Switch type x Congruency	2, 37	.16	P=.90
CTI x Switch type x Congruency	3, 38	3.4	P=.03
Task x Congruency	4, 56	3.1	P=.02
CTI x task x Congruency	4, 61	2.2	P=.08
Switch type x task x Congruency	4, 61	1.7	P=.6
CTI x switch type x task x congruency	3, 45	.96	P=.42

b) On Error (%)

Effect	*Df*	*F*	*P*
CTI	1, 16	9.1	p =.008
Switch type	1, 16	.31	P=.59
Task	2, 30	1.3	P =.28
Congruency	1, 22	16	P <.001
CTI x switch type	1, 16	.51	P=.006
CTI x task	2, 29	6.4	P =.12
Switch type x task	1, 25	2	P=.16
CTI x switch type x task	2, 30	.69	p=.50
CTI x Congruency	2, 39	1.6	P=.21
Switch type x Congruency	2, 35	.90	P=.42
CTI x Switch type x Congruency	2, 28	4.1	P=.03
Task x Congruency	2, 32	1.0	P=.37
CTI x task x Congruency	4, 64	1.9	P=.11
Switch type x task x Congruency	3, 51	1.1	P=.34
CTI x switch type x task x congruency	2, 41	.40	P=.72