Task Switching in Predictable and Unpredictable Cases

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ABSTRACT

Fourteen experiments have been run in order to provide evidence regarding the cognitive processes that underlie the switching between simple cognitive tasks. Central to these experiments was the predictability factor; in half of the cases, the upcoming task could be predicted in advance with absolute certainty while in the other half no foreknowledge regarding the upcoming task was provided. In all of the experiments, switch costs were found to be smaller when no task foreknowledge was provided relative to when task foreknowledge was available. Chapter 2 provided evidence regarding the interplay of endogenous and exogenous control in task switching. Top-down and bottom-up processes are not completely insulated from one another. Chapter 3 revealed that both task difficulty and task expectancy play a central role in determining performance on unpredictable cases. Based on the results so far, a task switching model was developed and discussed. Chapter 4 concentrated on the effects of task similarity on performance. It seems that in some cases when tasks are similar at a conceptual level then this results to interference increasing switch costs. Finally, on Chapter 5 behavioral and neuroimaging data provided further evidence that expectancy (in the form of trial expectancy) has a central role on task switching performance. In addition, the neuroimaging data revealed brain regions that could be linked with central components of the proposed task switching model. Concluding, in contrast to many task switching approaches, evidence is provided in the thesis in favor of the presence of endogenous control on unpredictable cases. This control, in the form of expectancies regarding the upcoming task or trial, plays a central role on task switching performance.

CONTENTS

LIST OF FIGURES

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DECLARATION

I declare the research reported in this thesis to be my own. The research was completed between September 2006 and August 2009 in the Department of Psychology and the York Neuroimaging Research Center (YNiC), University of York, under the supervision of Dr. Philip Quinlan. Chapter 2 of the thesis was published in modified form from the Psychonomic Society as:

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1 LITERATURE REVIEW

1.1 'CORRESPONDENCES'

Τιμή σ' εκείνους όπου στην ζωή των
ώρισαν και φυλάγουν Θερμοπύλες.
Ποτέ από το χρέος μη κινούντες·
δίκαιοι κ' ίσιοι σ' όλες των τες πράξεις,
αλλά με λύπη κιόλας κ' ευσπλαχνία·
γενναίοι οσάκις είναι πλούσιοι, κι όταν
είναι πτωχοί, πάλ' εις μικρόν γενναίοι,
πάλι συντρέχοντες όσο μπορούνε·
πάντοτε την αλήθεια ομιλούντες,
πλην χωρίς μίσος για τους ψευδομένους.

Και περισσότερη τιμή τούς πρέπει
όταν προβλέπουν (και πολλοί προβλέπουν)
πως ο Εφιάλτης θα φανεί στο τέλος,
κ' οι Μήδοι επί τέλους θα διαβούνε.

(Θερμοπύλες - Κωνσταντίνος Π. Καβάφης, 1863-1933)

[Honour to those who in their lives are committed and guard their Thermopylae. Never stirring from duty; just and upright in all their deeds, but with pity and compassion too; generous whenever they are rich, and when they are poor, again a little generous, again helping as much as they are able; always speaking the truth, but without rancor for those who lie.

And they merit greater honor when they foresee (and many do foresee) that Ephialtes will finally appear, and in the end the Medes will go through.]

(Thermopylae - Constantine P. Cavafy, 1863-1933)

1.2 INTRODUCTION

From a cognitive psychological perspective, human beings are basically conceptualised as dynamic information-processing systems whose mental operations can be described in computational terms (Neisser, 1967). Within this framework, it is possible to make a general distinction between relatively permanent cognitive structures such as short- and long-term memory, and the cognitive processes that operate alongside them. In recent years, research has focused on studying these cognitive processes in experiments in which participants have to switch between different cognitive tasks under tightly controlled conditions. The so-called *task switching paradigm* has become a very popular tool for studying mental processes in simple cognitive tasks. Such popularity reflects the growing interest in attempting to understand attentional and other executive processes. Sound knowledge of these processes will eventually contribute to a better understanding of cognition and the brain in general.

In the first chapter of the thesis a review on the current progress in the task switching field will be presented along with an introduction of the relevant to the area aspects of the cognitive system. It will be shown that the task switching literature is mainly dominated by paradigms that involve experiments on task predictable and not task unpredictable switches. Following that, current problems in the area due to that fact will be presented and analyzed. Concluding the chapter, the way by which the thesis will provide further insights on the task switching field will be revealed.

But what is task switching? Let us consider the following everyday example: A secretary is sitting on her chair typing a letter, the phone rings, she picks it up, answers, chats and finally she notes down the caller's name and continues her work. Each cognitive task in this sequence (sentence-composing, phone-answering, conversation and writing) requires an appropriate configuration of mental resources, a procedural *schema* or *task-set*. External stimuli are partially responsible for the initiation of each task (the phone rings and the secretary picks it up) but certain executive functions are responsible for the intentional control exerted over the selection of the appropriate task in order to achieve current goals (suppression of the 'typing' task-activation of the 'answering the phone' task). In this case, the satisfaction of the typing goal has been intentionally put aside (switched-away task-set) in order for another more immediate goal to be completed that is, answering the call (switched-to task-set). The questions that arise at this point are: What are the cognitive components involved on the selection of the appropriate task-set and how are they organised? In what ways are external/internal influences exerted? The computer metaphor provides a useful framework for thinking about some of these issues. For instance, it provides a framework for thinking and elaborating on the nature and structure of the cognitive components involved in task switching.

In simple terms, there are two means by which a computer stores and uses information, the random-access memory (RAM) and the hard disk. The hard disk is where information is stored permanently in a stable and safe mode. In order for this information to be used, it has to be retrieved and loaded into the RAM - a temporary working space. Retrieval and loading of a program can be either initiated by external input (a command given by the user through the keyboard or mouse interface) or internally (initiation of an antivirus check when scheduled). All these processes are supervised by the central processing unit (CPU). The analogy to the cognitive components can be nicely described by the hard disk/long-term memory and similarly by the RAM/working memory analogy. Both cognitive components have been studied extensively over the years however focus on the latter will be made since, as it will become evident later, it is more central to the thesis.

1.3 WORKING MEMORY

A popular view of *working memory* is contained in the Baddeley & Hitch (1974) model of working memory, where it is suggested that working memory consists of two short-term stores and a control system. In this respect, the short-term stores provide temporary space in which complicated cognitive processes like integration, coordination, and manipulation of information can take place. Consider an arithmetic task (e.g., multiplication) as a simple example. Using a computational metaphor, the digits and the multiplication symbol are encoded and then stored temporarily in working memory (WM), consequently their corresponding meaning and task demands are retrieved from long-term memory (LTM), and finally the multiplication mentally occurs and the result is utilised (e.g., verbalised).

The Baddeley and Hitch WM model consists of at least two distinct components, the *visuospatial scratchpad* (visuospatial information is buffered here) and the *phonological loop* (buffering of verbal information takes place here). These components are considered to be further divided into two subcomponents each. The former consists of a *visual cache* in which information about shape and colour is stored, and the *inner scribe*, in which spatial and movement information is stored respectively. In addition, the inner scribe also rehearses information stored in the visual cache and transfers information to the central executive. The phonological loop contains a *phonological buffer* store in which phonologically coded information is held for very short periods only and a *subvocal rehearsal loop* where information is maintained by repeating it mentally (Logie, 1995). More recently, an additional component, *the episodic buffer*, has been discussed. This component is the place in which information from different perceptual domains are linked in order to form integrated units of visual, spatial and verbal information with chronological ordering such as a story or a movie scene (Baddeley, 2000). Due to the fact that the components are independent from each other, great flexibility is provided in memory processing and storage. Of some importance is the *central executive*, a mechanism that supervises what is processed, deposited and removed from the above mentioned short-term stores (Baddeley & Hitch, 1974).

Specifically, the central executive is responsible for, a) determining when information is stored in the two short-term stores, b) determining which of the two short-term stores is more appropriate for storing the currently available information according to their nature (verbal or visuospatial information), c) the integration and coordination of information between the two short-term stores and finally, d) for the inspection, transformation and manipulation of the information held in the two short-term stores. The central executive is responsible for controlling and allocating attention and it determines how to expend cognitive resources by suppressing irrelevant information that would otherwise consume these resources unnecessarily (Baddeley, 1986).

A different account of executive control has been put forward by Norman and Shallice (1986). According to their view, behaviour in already learned tasks is controlled by cognitive schemata/task-sets. These can be defined as an organization of mental resources in order to accomplish a particular goal given appropriate input. Schemata/task-sets can be acquired through trial and error, instruction or observation, are stored in our memories, and are responsible for the selection and coordination of the processes that take place during the execution of a task. For a response to occur, a schema/task-set must be first selected and activated.

The selection of the appropriate schema/task-set can occur in two ways. One is by external environmental stimuli in a bottom-up manner. The second takes place in a top-down fashion. Due to the fact that more than one schemata/task-sets can be activated by external environmental stimuli at a time, a process of *contention scheduling* takes place in which the schemata/task-sets compete and only one emerges as dominant and is finally executed. This central selection of a schema is possible when the *supervisory attentional system (SAS)* biases contention scheduling, through top-down activation, of the appropriate schema. Biasing is essential whenever the environmental cues are novel and fail to activate the appropriate schema and when prevention of automatic selection of an inappropriate schema/task-set must take place.

The schemata/task-sets can be conceived as a sequence of component cognitive functions that once initiated unfold in a serial fashion. In simple terms, the sequence may be conceptualized as stimulus-identification, response selection and movement production. For example, when signaled by a cue to name an object that is displayed in a picture, a person will scan the object, then identify and link it with appropriate abstract response codes. Finally, the abstract response codes will be converted to certain motor movements that will allow the person to respond according to the task's demands. As mentioned earlier, many of these schemata/task-sets when acquired through trial and error or through instruction are stored in our LTM and can be readily applied when necessary. Practice or recent use of a set, results in an easier retrieval and reapplication of a schema/task-set. Consequently, under excessive training or use, schemata/task-sets become habitually associated with a stimulus and become highly automatic processes (reading is a good example - drivers unintentionally read an advertisement while driving). Effective performance under these circumstances is, a) the ability to maintain control and protect an ongoing task from disruption (not looking every other second at your tachometer while driving) and simultaneously, b) to provide with flexibility for the rapid execution of other tasks when the circumstances arise (to step on the brake pedal when a traffic light turns to red).

It should be evident to this point that performance when someone has to complete a task is regulated by a complicated cognitive mechanism. Several general questions arise regarding key components of this mechanism, a) how easily the stimulus that triggers retrieval of the appropriate task-set is identified, b) how difficult it is for the appropriate task-set to be recognised and retrieved from LTM and finally, c) how complex is the motor response? In order to provide insights into these questions, cognitive psychologists evolved various versions of an experimental paradigm (task switching paradigm) that allowed them to study performance when participants had to respond between alternating simple cognitive tasks.

1.4 TASK SWITCHING PARADIGMS

Laboratory based experiments on task switching allow us to examine in detail the fundamental mental processes that underlie the switching between simple tasks. In the majority of these experiments, participants have to switch rapidly between two or more speeded simple cognitive tasks. *Task switches* are identified with trials in which the task is different from the one performed in the immediately preceding trial, whereas *task repetitions* are associated with trials in which the same task as the one in the previous trial is performed. In most of the cases, participants prior to the experiment undergo several training blocks of trials on the tasks to be performed during the experiment. The stimuli that are typically used can be either *univalent* or *bivalent* in nature. Univalent trials comprise stimuli that contain a single aspect that unambiguously signals the task to be performed (e.g., a single letter character ‘A’, ‘G’, ‘D’ is presented on a given trial and a ‘consonant’ or ‘vowel’ response is required via pressing the appropriate button).

On the other hand, bivalent trials comprise stimuli that contain more than one task relevant aspect. Each aspect signals a task to be performed according to the instructions or cue, so for each trial a distinction of the *relevant task* from the *irrelevant task* can be made. For example, a stimulus that contains both a letter and a digit (e.g., A3, B6, G2) may be presented. According to cue/instructions, one of the characters must be classified on a given trial while the other must be ignored. With bivalent stimuli and in the absence of further instructions, which task (alphabetic or arithmetic) to perform remains ambiguous. With univalent stimuli this is not the case – the presentation of a digit unambiguously signals the arithmetic task. On trials where an arithmetic task is required, the letter is considered as the irrelevant character and the digit is considered the relevant character of the stimulus. One important difference relative to univalent stimuli is that when bivalent stimuli are presented the irrelevant character may be unintentionally processed and activate automatically the irrelevant task causing some kind of interference with the relevant task. As a result performance on bivalent trials is impaired on both non-switch and switch trials relative to performance on univalent trials (Mayr, Diedrichsen, Ivry, & Kelee, 2006). But in what ways are these stimuli presented in task switching experiments?

In general, participants go through blocks of trials where they have to either repeat or switch tasks between trials. Performance is compared on switch relative to non-switch trials. In some studies however, participants go through blocks of trials where they have to perform the same task throughout the block. Their performance is relative to blocks where they have to switch tasks on every other trial. Typical findings in the first involve the *switch cost* - performance is poorer on task switch trials relative to task repetition trials while the latter involve *the mixing cost* - performance is poorer on blocks of trials where participants alternate tasks on every other trial relative to blocks where they have to repeat the same task throughout the block. The difference between the two costs is that mixing costs involve switch cost plus an additional memory load (keeping track of the task sequence). This confounding was first observed in the now classic task switching study of Jersild (1927). A number of different methodologies have been evolved since and these along with their findings will be considered shortly. The original study will be considered first.

1.4.1 Jersild's Method

In Jersild's experiments, participants had to complete lists of items in which they had either to repeat one task or to alternate between two different tasks. Individuals used a stopwatch to time themselves. Results indicated that performance was impaired in mixed blocks relative to pure blocks. Moreover, in some task pairs (adding 3 vs. subtracting 3 from numbers) the alternation costs were remarkable, whilst in others (adding 3 to a number vs. writing the antonym of an adjective) were not. Jersild attributed the findings to the expectations that are formulated by the participant for the upcoming trial (an *anticipatory component*) and managed to establish a sound paradigm even though his measurements lacked today's accuracy (he used a stopwatch). His alternating method has severe drawbacks as it confounds switch costs and mixing costs because the alternating blocks impose a great memory load (keep track of the task sequence and maintain two tasks in readiness concurrently). In order for these shortcomings to be avoided, a number of more recent methodologies have been developed. In the following pages, the more frequently used methodologies of the task switching literature will be described. The majority of these has been used in the studies discussed later on the current and the following chapters and will be discussed in further detail as the thesis progresses.

1.4.2 Alternating-Runs Paradigm

The alternating-runs paradigm developed by Rogers and Monsell (1995) avoids Jersild's methodological drawbacks. In this paradigm, switch and non-switch trials exist within the same block. This is achieved by alternating tasks every N trials in a predictable manner. For instance, in an experiment where the tasks A and B are tested then a possible presentation order is AABBAABB….

1.4.3 Prespecified Task Sequence Paradigm

An alternative to the alternating blocks paradigm is the prespecified task sequence paradigm, were participants are given short sequences of trials in a prespecified order. Therefore, instead of having to perform large blocks of trials as in the alternating runs paradigm, participants are instructed about a specific sequence of tasks that will be presented in the upcoming 'miniblock' of trials. This procedure is followed for every 'miniblock' (Monsell, 2003).

1.4.4 Explicit Task Cueing Paradigm

The explicit task cueing paradigm is another way to instruct participants which task they have to perform on a given trial. In that method, a cue is presented either before or upon the presentation of the stimulus while the task is unpredictable. In this paradigm, the cue-stimulus interval and the response-cue interval can be manipulated independently thus allowing different time to elapse for active task preparation and passive dissipation of task activation respectively (Mayr & Kliegl, 2003).

1.4.5 Intermittent Instruction Paradigm

In the intermittent instruction paradigm the series of trials is interrupted at various intervals by an instruction that indicates what task is to be performed in the upcoming trials. There is always impairment on performance after such an instruction even when the same task must be performed again. However, whenever the task changes this impairment is larger indicating clearly a switch cost (Gopher, Armony, & Greenshpan, 2000).

1.4.6 Voluntary Task Switching Paradigm

In this paradigm, participants are asked to randomly and equally often choose which task to perform on blocks of bivalent stimuli. Task cues are not provided therefore top-down control of task switching is required (Arrington & Logan, 2005).

1.4.7 Random Task Switching Paradigm

Finally, the random switching paradigm provides an alternative experimental method where no foreknowledge of the upcoming task is provided. Switching of tasks is completely unpredictable (e.g. the task is signaled by a cue upon the onset of the trial) and performance is in generally deprived relative to performance on predictable blocks of trials (Milan, Sanabria, Tornay, & Gonzalez, 2005; Monsell, Sumner, & Waters, 2003; Tornay & Milán, 2001).

1.5 TASK SWITCHING - MAIN EMPIRICAL FINDINGS

Task switching is studied from many perspectives and the available literature is characterized by a great number of diverse experiments. The results usually focus on different cognitive aspects and data is discussed revealing specific task switching factors. Nevertheless, whatever the experiment and its focus are, in the majority of cases results are aligned with some basic reliable and robust phenomena. The list includes but is not limited to, the switch cost, the preparation effect, the residual cost, the performance recovery, and finally the mixing cost.

1.5.1 Switch Cost (Task-Repetition Benefit)

As mentioned earlier, performance is in general poorer on a switch than on a non-switch trial. Typically, responses are substantially slower and the error rate is higher after a task switch (Figure 1). The difference between a switch and a non-switch trial in terms of reaction times constitutes the 'switch cost' (Ruthruff, Remington, & Johnston, 2001).

1.5.2 Preparation Effect

The average switch cost is usually reduced when enough time for preparation - a longer response-stimulus interval (RSI) is given and/or knowledge (by cueing or instructions) of the upcoming task is provided (Figure 1) (Altmann, 2004a). However, evidence for the preparation effect is quite complex to interpret. There are circumstances in which even when long RSIs or foreknowledge is provided there is no clear evidence for a preparation effect.

1.5.3 Residual Cost

It has been widely observed that even if enough time for preparation (above 600 ms RSI) is given the reduction in switch cost remains constant (Figure 1). This asymptote is observed even when 5 s or more is allowed for preparation (Meiran, Chorev, & Sapir, 2000).

1.5.4 Performance Recovery

Performance tends to recover rapidly after a task switch (Figure 1). For instance, performance of a switch trial will be significantly slower relative to the average non-switch trial RT; on the other hand, performance of the non-switch trial *n+1* will be equal to the average non-switch RTs and that will be the case for *n+2*, *n+3* and until a switch trial occurs again. This phenomenon applies only to blocks were advance preparation is available (e.g like in alternating runs blocks of trials) and not to blocks were such preparation is not feasible (e.g like in random task

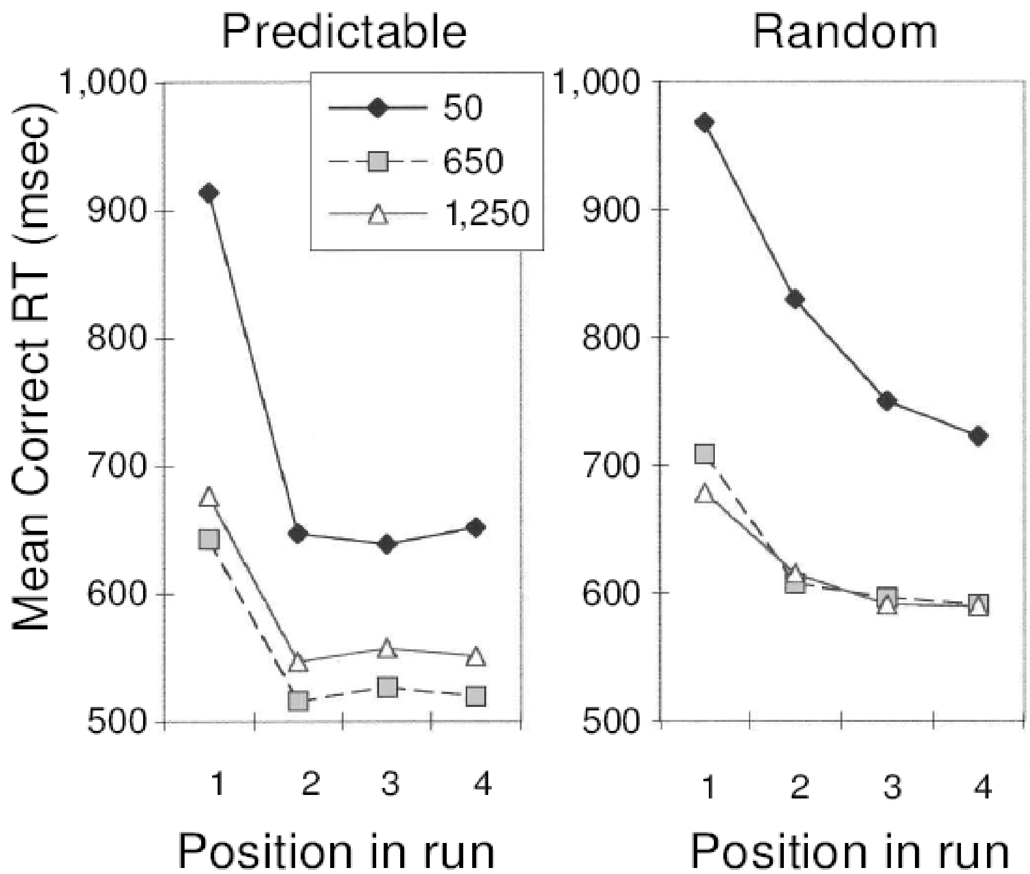


Figure 1: Task-set reconfiguration with predictable and unpredictable task switches. The 1st position in run indicates average RT of task switching trials while 2nd, 3rd and 4th positions in run indicate average RT of task repeat trials. Several typical task switching findings can be observed: a) Performance is in general poorer on a switch than on a repeat trial, b) average switch cost is usually reduced when advance preparation or a longer response-stimulus interval (RSI) is provided, c) even if enough time for preparation (above 600 ms RSI) is given switch cost remains constant (residual cost) and, d) recovery of performance is gradual after a task switch on unpredictable (random) sequences. In contrast, on predictable sequences only one trial is sufficient for a full recovery of performance to occur.
From "Task-Set Reconfiguration with Predictable and Unpredictable Task Switches" by Stephen Monsell, Petroc Sumner, and Helen Waters, 2003, *Memory & Cognition*, *31*, p. 336. Copyright 2003 Psychonomic Society, Inc.

switching blocks of trials). (Mayr & Kliegl, 2000; Monsell, et al., 2003; Rogers & Monsell, 1995).

1.5.5 Mixing Cost

As previously discussed, in blocks of trials where more than one task must be performed (mixed blocks), performance is impaired relative to performance in blocks where only one task must be performed (pure blocks) (Koch, Prinz, & Allport, 2005; Lupker, Kinoshita, Coltheart, & Taylor, 2003).

1.6 HISTORICAL BACKGROUND

Almost half a century after Jersild's pioneer study the paradigm was brought up to date by Spector and Biederman (1976). In one condition of their experiments, participants were instructed to add or subtract the number 3 alternatively on each trial on lists of two digit numbers (e.g., 47, 35, 18...). In another, participants had to follow exactly the same procedure with the only difference being that the mathematical operations were cued (e.g., 47 + 3, 35 - 3, 18 + 3...).

Results revealed that switch costs were substantially affected by the presentation of visual cues. Specifically, switch costs were found to be smaller when a visual cue that signaled the task to be performed accompanied the stimulus than when no such cue was present. This effect was interpreted as evidence for the existence of an executive component in which cues are used along with other stored information to identify and prepare for tasks.

In detail, Spector and Biederman (1976) gave participants columns with two-digit numbers. In one case, participants had to subtract or add the number 3 to every stimulus and report the sum verbally. In another instance, they had to alternate between adding and subtracting the number 3 to the alternate stimuli. Results showed that there was impairment on performance when participants had to alternate between tasks as Jersild (1926) found. In another experiment however, they added explicit visual cues to their stimuli (the '+3', '-3' cue indicated which task is to be performed). Impairment was still evident on alternating columns but the switch cost was significantly lower than when participants were not cued.

Despite these interesting results, further substantial development in the field did not take place until around 1995 with the publication of the works by Allport, Styles, & Hsieh (1994) and Rogers and Monsell (1995) which revived the scientific interest for the subject.

1.7 THEORETICAL INTERPRETATION OF MAIN EMPIRICAL FINDINGS

Allport, Styles, & Hsieh (1994) did not agree with the notion that Jersild's (1926) and Spector and Biederman's (1976) findings are a result of an anticipatory component of executive task control. Instead, they proposed that switch costs result from *task-set inertia (TSI)*. TSI is a kind of proactive interference among conflicting stimulus-response (S-R) mappings that exists for successive tasks.

Specifically, performance on a task switch trial requires activation of a task different from the one that has been performed on the preceding trial. By the time that this activation occurs, some residual activation of the task associated with the immediately preceding trials remains. This residual activation interferes with the activation of the new task for many trials in succession. Moreover, this interference is expected to be much stronger when a task-set has been performed often and in such cases where a strong S-R mapping has been developed (Wylie & Allport, 2000). However, some of the results reported by Allport, Styles, & Hsieh (1994) were not that straightforward. In some cases where the TSI account predicts that there must not be switch costs, such costs occurred. This was true even when excessive RSIs were provided (e.g., over 1000 ms). According to the TSI hypothesis, it should be expected that there should not be any switch costs because residual activation, the source of switch cost, has completely dissipated at this point.

A study by Rogers and Monsell (1995) tried to provide further light on such issues that cannot be explained adequately by the TSI account. In their series of experiments, they used the alternating-runs paradigm. In this paradigm switch and non-switch trials are contained within the same block of trials. In their experiments, a character pair was presented on a quadrant of four square boxes. On most trials, the pair of characters contained one letter and one digit. Participants had to classify the letter character as consonant/vowel and the digit as odd/even.

When the letter and the digit character of the pair fell into the same response then the character pair was considered as a congruent character pair (e.g., consonant and even responses where both assigned on the left response button). In cases were the opposite was true, the character pair was considered as an incongruent character pair. On neutral trials, though, either a letter or a digit was presented together with a symbol not assigned to a response (for instance, '#'). Depending on which quadrant the characters were presented, participants had to classify either the letter or the digit character. The critical thing was that the stimulus position was perfectly predictable following the first trial because the location of the stimulus pair was determined sequentially in a clockwise fashion - the sequence was AABBAABB…. Trials within such a sequence can be divided into two main types, a) on a non-switch trial the task is repeated from the immediately prior trial and, b) on a switch trial the task on that trial is changed from the task on immediately prior trial.

Finally, stimuli were presented on various RSIs ranging from 150 ms to 1200 ms. Two findings are of interest at this point, a) results in their experiment 3 revealed that performance was improved as the RSI increased from 150 ms to 600 ms. Nevertheless, (in contrast to what the TSI account predicts) a residual cost remained showing no reduction when the RSI was increased from 600 ms to 1200 ms and, b) average RT was facilitated for the neutral character pair relative to the other two cases (crosstalk effect) and, c) average RT was facilitated for the congruent character pair relative to the incongruent character pair (congruency effect).

Based on these results, the researchers concluded that TSI is not an adequate explanation for switch costs. Thus, they proposed that two executive control processes could explain efficiently what they called *task-set reconfiguration (TSR)*: *endogenous control* and *exogenous control*.

In the researchers' terms, a person's effort to choose intentionally a task over another less appropriate task is achieved by a flexible top-down process (endogenous control) that executes the necessary operations of the upcoming task when the task to be performed is known in advance. When enough time for preparation is allowed the effect of these operations is more marked. However, processes that occur during endogenous control are not enough to complete TSR resulting in a residual cost showing no reduction on RTs even when enough time for preparation is allowed. The human cognitive system is believed to have a substantial limitation that constitutes it incapable of reconfiguring itself completely for a new task in the absence of an exogenous component.

Exogenous control therefore, is the final stage and is triggered by the onset of the upcoming task's imperative stimulus (Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, 2001). Upon task presentation, the stimulus can by itself activate the tendency to perform a task that is habitually associated with it, regardless of previous intention and usually in conflict with current intention. For instance, in cases of incongruent character pairs the irrelevant character will elicit unintentionally the tendency to give a response that is inappropriate for the current trial resulting in response conflict. Top-down resolution of this conflict is essential in order for an appropriate response to be given giving rise to additional performance costs. Therefore, context, like availability, frequency and recency of an alternative task, can influence TSR to a great extent.

Meiran (1996) supported Rogers and Monsell's (1995) ideas. By presenting a visual precue prior to each task, participants were explicitly informed about the upcoming task. Results revealed that on trials were a task switch was necessary, the precues attenuated task switching costs more at long (1423 ms) than short (203 ms) cue-target intervals. Thus, the idea of endogenous executive control was supported by showing that advance TSR exists and when provided with a long RSI is more complete.

Arrington and Logan (2005) attempted to define the degree of the effect that exogenous and endogenous control processes have on the switching of tasks. In their experiments, participants had to undergo blocks of bivalent stimuli in which they had to choose which task to perform on each trial. They were instructed to perform each of the tasks equally often while their performance was relative to the one obtained from blocks of trials in which an explicit cue signaled what task should be performed on the upcoming trial.

The main issue that was addressed was whether participants are told to choose their tasks (endogenous control) or whether these are exerted by the environmental influence (exogenous control). In their study, it was evident that choice behaviour was uninfluenced by external stimuli suggesting that choice of task occurs in a top-down manner. For example in one of their experiments, the participants had to choose which task to perform on each trial under several experimental conditions. In all conditions, a warning box preceded each trial. However, in the first condition the warning box was always black while in the second the warning box randomly changed colour (red or blue) cueing the upcoming task. In both cases, participants were allowed to voluntarily choose which of the two tasks to perform on the upcoming trial regardless of whether or not the cue signaled a task. In the third condition, the warning box randomly changed colour (red or blue) cuing the upcoming task but participants this time had to perform the task that was cued (explicit cueing).

Analysis of the results of the first two conditions revealed that the proportion of task repetitions and task alternations was uninfluenced by the presence of an external cue that signaled the upcoming task. Moreover, in terms of switch costs, it was found that these were smaller when participants had to choose which task to perform rather than when the task was signaled by an explicit cue. The above results demonstrate that endogenous executive control has, under some circumstances, a large effect on task switching. These findings support accounts that view task switching costs primarily as a result of top-down processes, like Rogers and Monsell's (1995) TSR, and not the ones that favor bottom-up processes like Allport, Styles, & Hsieh (1994) TSI account. In the latter case, switch costs are viewed primarily as the result of the difficulty to switch away from a recently performed task due to residual activation.

The quest for understanding this endogenous executive control process has also been carried out from the perspective of self-instruction using inner speech. Inner speech is associated with Baddeley's (1986) phonological loop which is regarded to be a peripheral, independent system in WM specialised for the short-term storage and processing of verbal-phonological information.

More specifically, one of its subsystems, the articulatory control process, is responsible for the generation and maintenance of inner speech. Because executive control is considered to be managed by a specialised component of WM, the central executive, it would be rather difficult to conclude that inner speech plays a significant role in task switching since the phonological loop is probably not directly related to executive control processes.

Nevertheless, recent studies that used *articulatory suppression* on task switching experiments, demonstrated that disruption of inner speech clearly has a negative effect on performance. Articulatory suppression is a task that requires the subjects to utter a speech sound. Uttering a speech sound interferes with inner speech and thus reduces its potential to act as an aiding device when circumstances arise. More specifically, the presented cue (either no cue, colour cue, or symbol cue) was manipulated under control and articulatory suppression conditions. Results revealed that the *articulatory effect* (the overall improvement on performance when articulatory suppression was not present) was modulated most under the no cue condition and least under the symbol cue condition suggesting that inner speech acts as a self-cuing aid (top-down control), when circumstances demand, by activating a phonological representation of the upcoming task (Emerson & Miyake, 2003).

The role of the central executive and an involvement of the phonological loop when cues were absent were also demonstrated in an earlier study conducted by Baddeley, Chincotta, and Adlam (2001). Among others, they have found that the role of articulatory suppression affected primarily the switching trials supporting the notion that inner speech acts as a self-cuing device.

According to Mayr and Kliegl (2000) another memory component namely LTM, is linked to task switching. It has been suggested that switch costs would, at least to some extent, reflect the retrieval of the appropriate ‘task-set rules’ when circumstances arise (task-switch). This hypothesis was tested and the results demonstrated that switch costs were higher when the switched-to task involved high retrieval demands such as episodic information than in the opposite case of semantic information. However, when a chance for advance preparation was provided (long RSI or explicit cuing of the task rules) the retrieval-demand effect was eliminated. Hence, it was suggested that the intentional switch cost component reflects the time that is necessary for efficient retrieval of the appropriate task rule for LTM (Mayr & Kliegl, 2000).

The main empirical findings of the task switching area discussed so far have been derived from experiments that have used a wide array of experimental paradigms. The results reveal that the TSI account fails to explain some task switching effects (e.g., residual costs) that can be better explained by the TSR account. The TSR account does not reject the TSI idea but includes its effect through what Rogers and Monsell name ‘exogenous control’. This component however, is under the strong influence of endogenous control. Switch costs result from the interplay of endogenous and exogenous control. Further support for the existence of an endogenous component comes from studies that investigate the contribution of inner speech and LTM retrieval in task switching.

A commonality between these experiments is that in the majority of them participants knew in advance what task they had to perform on the upcoming trial. This was achieved mainly by instructions – for instance, participants knew in an alternating runs experiment that the tasks would alternate every two trials. In these cases however, participants used internal cues in order to keep track of the task sequence and that might have affected switch costs. In order to provide foreknowledge to the participants by avoiding the necessity of internal cues the explicit-task cueing paradigm has been evolved. A further explanation of its design and use will be discussed in the following section.

1.8 EXPLICIT TASK CUEING PARADIGM

One of the most popular procedures to investigate task switching costs is the *explicit task-cuing* procedure which includes the presentation of a cue that indicates what task is to be performed to the target stimulus. In this case, a task switch is indicated by a cue change. Task-switch costs therefore, can be considered as the difference between performance on a cue-switch trial and a cue-repetition trial. In the simplest case however, task transitions and cue transitions are confounded maximising the possibility that task-switch costs represent cue-transitions effects rather than task-transition effects. (Schneider & Logan, 2007).

This problem can be partially resolved by using two cues per task leading to three types of trials, task repetitions along with cue repetitions, task repetitions along with cue-switch and task-switch with cue-switch. Task-switch cost in that case resembles the difference between the latter two trial types (Schneider & Logan, 2007). Results indicate that these switch-costs are smaller than the switch costs obtained from the task repetition-cue repetition minus task-switch-cue-switch. This suggests that previously task-switch costs obtained with one cue per task were contaminated with cue transition effects (Mayr & Kliegl, 2003).

Similar findings were revealed in a study that allowed a partial deconfounding of cue transitions and task sequences (REPEAT and AGAIN indicated task repetitions - SWITCH and CHANGE indicated task switches), robust sequential effects were revealed. Performance was affected by higher order task transitions when cue transitions were constant and with cue transitions affecting performance when task sequences were held constant (Schneider & Logan, 2007).

These findings so far indicate that cue transitions directly affect switch costs and researchers should be aware of that if they are to make implications about executive control from switch costs in explicit task cueing experiments.

In a similar manner, an attempt to separate cue encoding from target processing was made in a series of experiments where participants were required to respond to the cue either by indicating the presented cue or by indicating which task was cued. This separation was successful when the cue response indicated which task was cued but not when it indicated which cue was presented. The results revealed that there are ‘true’ task-switch effects that are independent of cue encoding. Further analysis of the conditions required for this separation suggested that cue encoding is performed not in a verbal or phonological representation but rather in a categorical manner of the task to be performed (Arrington, Logan, & Schneider, 2007).

It is clear that under certain circumstances, response selection occurs in such a way that the cue and the target are used in a compound way in the retrieval process of the response selection. This mechanism (mediator retrieval) is proposed as the possible explanation accounting for the confounding effects occurring in conditions where only a single cue is used to indicate a specific task (Schneider & Logan 2005). As stated before, experiments using that task-cuing paradigm must be conducted with caution in order for the limitations and problems of the specific procedure to be identified and resolved on time.

Finally, it has been shown that when a cue is presented for a short time (instead of the whole RSI) and then removed during the RSI then advance preparation is enhanced. More interesting is the fact that the residual cost is diminished under these circumstances. This was found to be true for several cue types. In that case, it can be concluded that under conditions of short cue presentations, subjects are encouraged to complete advance preparation which in turn leads to the elimination of the residual cost (Verbruggen, Liefooghe, Vandierendonck, & Demanet, 2007). The question is how this advance preparation is accomplished in the advance foreknowledge conditions described so far. It seems that a possible answer is that a modulation of the task-set’s activation takes place when preparation is available.

1.9 TASK-SET ACTIVATION

In broad terms, task switch costs can be viewed as the time required for the executive component to manage task-set activation. Support for this claim comes from studies that have investigated the effects of a response on a previous trial on the current trial. Specifically, responses are facilitated when they are the same (congruent) with the response given on the previous trial than when they are not (incongruent). This *response-congruency effect* probably reflects the fact that task-sets are simultaneously maintained in WM during task switching. If that is the case, then executive control perhaps modulates appropriately task-set activation, when advance foreknowledge of the upcoming task is provided, in order for the appropriate task-set to be enabled (Luria & Meiran, 2005; Rogers & Monsell, 1995).

However, a number of researchers argue that task-set activation occurs in LTM rather than in WM (Allport, Styles, & Hsieh, 1994; Mayr & Kliegl, 2000; Rubinstein, et al., 2001). From this perspective, executive control activates task-sets in LTM and switch costs reflect the additional time needed for retrieval of task-sets from LTM on switch trials vs. non-switch trials where such retrieval does not occur. Support for this idea comes from experiments that manipulated the task-set's retrieval demand. Under conditions were such demand was great (e.g., when retrieval of episodic vs. semantic information is required) switch costs were high. For instance, when the number of task-set rules was greater for one task relative to another, tasks switch costs were greater for that task (Rubinstein, et al., 2001). However, it is important to note that when other (irrelevant to retrieval demands) aspects of task difficulty are manipulated switch costs are not affected. In addition, Mayr and Kliegl (2003) demonstrated that when time for preparation is allowed then the retrieval effect on switch costs is substantially reduced. Endogenous control therefore, is taking place during preparation and involves to some extent retrieval of task-set rules from LTM.

Response-repetition effects can also arise from exogenous factors. If it is assumed that task-sets are activated and retrieved upon the presentation of the stimulus, then when stimuli that afford both tasks (bivalent stimuli) are presented then both task-sets should be activated and retrieved. In that case, activation on the currently relevant task will have an effect on performance on the subsequent trial. Specifically, if the currently relevant task is the irrelevant task on the succeeding trial then it can trigger unintentional activation and retrieval of its related task-set rules resulting in greater task-set interference that needs to be resolved by executive functions resulting in greater switch costs (Waszak, Hommel, & Allport, 2003). But is task-set activation the only means by which executive control processes control task switching?

1.10 TASK-SET INHIBITION

Executive control may also modulate interference caused by the unintentional activation of the currently irrelevant task-set by suppressing its activation. By that way, it is ensured that the two task-sets will not compete for behavioral control and that only the currently relevant task will elicit a behavioral response. The interference caused by two competing tasks has been studied extensively using the Stroop paradigm. Specifically, this paradigm has been partly used to examine the modulation of interference caused by the unintentional activation of the irrelevant to the current trial task-set.

Typically, in experiments using the Stroop paradigm a word such as blue, green, red, etc. is printed in a color differing from the color expressed by the word's semantic meaning (e.g., the word ‘red’ printed in blue ink). Participants have either to indicate the color font of the word (the non-dominant task) or indicate the color that is semantically represented by the word (the dominant task). Responding to the word usually is easier because reading is a highly trained and automatic task. However, indicating the color font of the word is usually slower and more error prone than indicating the color that the word represents.

In studies were Stroop stimuli were used, researchers observed that it was more difficult to switch to the dominant task than the other way around (Allport, Styles, & Hsieh, 1994, Allport & Wylie, 2000). Specifically, strong support for task-set inhibition comes from studies were bilingual participants were required to name numerals in either their dominant (easy automatic task) or non-dominant language (difficult non-automatic task). Results revealed a paradoxical finding, that switch costs were larger when participants switched to the dominant from the non-dominant language than the other way around.

These *asymmetrical switch costs* were attributed to the greater inhibition that the dominant task requires in order to effectively switch away from it. This inhibition is essential, because it diminishes the interference that is caused by the unintentional activation of the irrelevant task (naming numeral in the dominant language) and makes possible the relevant task (naming numerals in the non-dominant language). This inhibition is carried over across trials and must be overcome when the dominant task must be performed again giving rise to larger switch costs (Meuter & Allport, 1999).

However, studies demonstrated that under certain conditions this asymmetry effect can be reversed so that switch costs are larger when switching to the non-dominant task. Specifically, when the irrelevant attribute of the stimulus is presented with a delay in respect to the relevant attribute then inhibition of the irrelevant task is not necessary. In particular, unintentional activation of the irrelevant task due to exogenous control doesn't take place concurrently with the relevant task therefore there is no interference between the two task-sets. In that case, a reversal of the asymmetrical switch costs is observed (Monsell, Yeung, & Azuma, 2000; Rubinstein, et al., 2001). This pattern of switch costs is predicted by the TSR account that states that reconfiguration to a less well learned task will take longer relative to well learned task simply because its related task-set rules will need more activation in order to elicit a response.

Task-set inhibition was also clearly demonstrated in a study where participants had to respond to either ABA or ABC task sequences. Results demonstrated that responses on the 3rd trial of an ABA sequence were slower relative to that of an ABC sequence. This result, suggests according to the researchers, that task A was inhibited in order to switch away from it. However, this inhibition persists and must be overcome when task A must be performed again resulting to a slowdown in response. On the other hand, that is not necessary on an ABC sequence since inhibition on task A is not expected to affect performing task C. Therefore, as previously mentioned, responses are facilitated on the 3rd trial of an ABC sequence relative to that of an ABA sequence (Mayr & Kelee, 2000, experiment 5).

Concluding, it seems that in predictable cases executive control is exerted on task-sets either by means of top-down activation/inhibition of the appropriate task-set. The nature of the asymmetrical switch cost (greater switch costs when switching to the dominant task or vice versa) may depend on the amount of activation that is required on any given moment. Thus, if it was necessary to inhibit a task-set in order to switch away from it (dominant, well learned task), then it will require a greater amount of activation in order to elicit a response on subsequent trial giving rise to large switch costs. On the other hand, if inhibition was not required, then switching to less well learned task will give rise to larger switch costs because its related task-set rules will require greater activation in order to elicit a response.

Having reviewed some of the fundamental cognitive processes that underlie the switching of tasks on cases where advance foreknowledge was provided it should now be explored how the cognitive system manages switching between tasks under conditions were no foreknowledge of the upcoming task is provided.

1.11 UNPREDICTABILITY: A CRUEL REALITY

Many studies to date have focused on paradigms and procedures that aimed to reveal the executive processes that underlie the switching of tasks under conditions in which either complete (e.g., alternating runs paradigm) or partial (e.g., precueing) foreknowledge of the upcoming task was provided. However, outside of the laboratory the conditions under which task switching occurs vary significantly from what is manipulated inside it. Most of the times, there is a complete lack of predictability of the upcoming task; there are no precues, no intermittent instructions and no prespecified task sequences to prepare us for what is coming next. Task switching paradigms therefore, can be classified into two broad categories. In one, task switches that are predictable occur (e.g., by using runs in which the participant can memorize the sequence of task presentation, by using precues or by providing instructions during a run), and in the other, unpredictable task switches where there is complete lack of foreknowledge of the upcoming task exist.

A principal difference between the two is that in predictable blocks of trials (alternating-runs) participants have to keep track of the task sequence in order to decide which task is to be performed. In contrast, in unpredictable blocks there is no such demand. It is believed that a more adequate picture of the nature of switch costs can be obtained if this WM demand is not present because the additional memory load of keeping a task sequence in mind will not be present in WM (Meiran, 1996). In general, it is observed that foreknowledge has a general effect (preparation effect) on RTs and it is not restricted to switch trials. In cases where foreknowledge is provided, a reduction in RTs is evident for both the switch and the non-switch trials (Sohn & Carlson, 2000).

Some attempts in which the manipulation of predictability was central to the experiment have provided very interesting results. In one of these studies, Monsell, Sumner and Waters (2003) investigated TSR with predictable and unpredictable task switches. Participants had to switch between the high/low and odd/even classification tasks. The interval between the task cue and the presentation of the stimulus was varied between blocks of trials. In their first experiment, the task switched predictably every two, four or eight trials. In their second experiment, the task switched every four trials and was relative to random switching.

Their aim was to support the idea that TSR is responsible for task switch costs and not TSI. They hypothesized that if decay of TSI accounts for task switch cost then the more trials that have elapsed since the use of Task A the more difficult it would be to switch to it. Moreover, the effect would be enhanced by the accumulation of activation of the competing Task B during these trials while there would also be a gradual improvement on RT across trials after a task switch. If the above trends were absent then that would imply that either TSI decays rapidly, or that one trial is sufficient to erase it, or finally TSI decays so slowly that two, four or eight trials are not sufficient to demonstrate the effect.

Results revealed that, after a task switch, there was a substantial decrease in RT between the first and the second trial of a run of similar size. No further improvement in RTs was observed in the consequent trials. It seems therefore, that only one trial was needed in order to recover from a task switch and that was true for all run lengths. This was also observed in an experiment using a cuing paradigm with predictable runs of eight trials (Kelee & Rafal, 2000).

However, the above-mentioned results have not been found in every study. Mayr (2001) in a task cuing experiment with older participants showed a more gradual recovery of performance. A slower approach to asymptote was also found by Salthouse, Fristoe, McGuthry, and Hambrick (1998) by using a cuing paradigm with unpredictable task switches. In the latter study, it was suggested that this was the true pattern of performance recovery (a clear support for TSI) and that Rogers and Monsell (1995) had insufficient power on their experiment to detect it. Similarly, a small linear improvement in RT was found in an experiment that used a task-cuing paradigm with 33% task switches (Meiran, 2000). A reduction in RT switch cost was also seen in Monsell et al. (2003) study with increasing RSI. This reduction reached an asymptote still giving rise to a residual cost when an RSI of more than 600 ms was provided.

In their second experiment, predictable vs. unpredictable sequences were compared. Monsell et al. (2003) found that performance was in general poorer when advance knowledge of tasks (predictability) was not provided than when it was. Despite this though, switch costs were smaller on the unpredictable sequences than on the predictable one.

An interesting finding was that in the unpredictable sequences performance, in contrast to the predictable trials, did not recover immediately after the switch trial but gradually in a negatively accelerated manner (Figure 1). Similarly, later experiments, that used the explicit-cueing paradigm, revealed the same pattern of results indicating that TSR clearly depends on upon the predictability of the task (Milan, et al., 2005). The theoretical interpretation of this finding suggested that the additional activation that has been induced on a task that has just been performed, is intentionally suppressed to a certain extent by the participant if a further task switch is probable. Finally, a longer RSI produced a decrement on RTs and the residual component was also evident (Monsell, et al., 2003).

Regarding this exogenous, residual component that is found in the form of residual RT costs, some researchers have argued that, given the appropriate circumstances, it vanishes. In a study conducted by Tornay and Milán (2001), several differences between switching in predictable sequences and switching in unpredictable ones have been found. In their experiments, they used a task-cueing paradigm in which bivalent stimuli (e.g., 5A, A7, 2B, P4, ...) were presented in both predictable and unpredictable blocks of trials when a variety of RSIs (200 ms, 800 ms, and 1200 ms) were used.

Relative to performance on predictable sequences, performance on unpredictable sequences was generally poorer, while switch costs were smaller. Moreover, the effect of advance preparation was apparent, the longer the RSI the faster the RTs. What was of some significant importance though, was that in the unpredictable blocks of trials switch costs were eliminated (non-switch trials average RT = switch trials average RT) when a long RSI (1200 ms) was provided. Furthermore, while in the predictable sequences performance recovered sharply following a task switch, this was not evident for the unpredictable sequences. There was only a slight gradual improvement between the switch trial *n* and the following non-switch trial *n+1*, *n+2*, trial.

Such a result is in accord with those of Rogers and Monsell's (1995) and Monsell et al. (2003). Based on the finding that the residual cost vanishes under certain circumstances, Tornay and Milán (2001) suggested that the exogenous factors are of lesser importance on unpredictable than in predictable switch conditions. In the first case, exogenous factors are not detectable while in the second are necessary for preparation to complete (Tornay & Milán, 2001). On their later study, Monsell et al. (2003) did not replicate this finding.

A methodological implication derived from results using these paradigms is that switch costs obtained from unpredictable task cueing experiments fail to demonstrate the 'true' cost of a task switch. That is mainly because the predictable switch cost reflects the difference between the level of performance on a switch trial and the asymptotic performance level of the subsequent non-switch trial. Nevertheless, on unpredictable task switching experiments, due to the gradual recovery of performance after a task switch, the subsequent non-switch trial does not reflect a full recovery to the asymptotic performance level. It is suggested that whenever a cueing paradigm is utilised data must be analyzed by position in run over at least three or four trials of a run. In other occasions, the predictable-switching paradigm has several advantages over the unpredictable: fuller preparation is encouraged, it is quite efficient in runs where only two trials are sufficient to estimate the switch cost, trials per position in run are equal and it is not necessary to control for equal run-length distributions (Monsell, et al., 2003).

Overall, the principal differences between the predictable and unpredictable cases can be summarized as follows, a) RTs in predictable switch and non-switch trials are smaller relative to the respective unpredictable RTs, b) switch costs are larger on predictable cases, c) only one non-switch trial after a task switch is enough for performance to reach an asymptotic level in predictable cases whereas a more gradual approach to asymptote is observed in unpredictable cases and, d) in some experiments and at long RSIs switch costs were eliminated in unpredictable but not in predictable cases (residual cost).

On a theoretical level, the explanation of the differences between performance on predictable runs and performance on unpredictable tasks vary. Some researchers view the results as a modulation of task-set activation/inhibition along a continuum. Specifically, switch costs are a result of, a) inappropriate states of activation and inhibition of task-controlling representations that are persistent and, b) associative learning that result in stimuli's tendency to activate tasks that have recently been associated (Gilbert & Shallice, 2002). Others suggest that the influence of one task's performance on task readiness is depending on the strategic modulation by expectation of the probability of a further task switch (if after one trial after a task switch a further switch is probable, the increment in readiness that resulted from performance to the task is intentionally suppressed (Monsell et al., 2003). Finally, some argue that the probability of success of discreet preparation is altered. For example, it is assumed that participants attempt TSR, when possible, prior to the onset of the stimulus but only a proportion of these attempts are successful. Whenever these attempts are successful, TSR is completed prior to the stimulus' onset and performance equals the performance on a non-switch trial. On the other hand, if they fail, TSR must occur after the onset of the stimulus giving rise to a decrement on performance (DeJong, 2000).

One explanation for this 'all or none' account is that TSR is characterised by an attempt to retrieve and load the appropriate task-set rules from LTM to WM. This attempt either succeeds or fails (Mayr & Kliegl, 2000). Whatever the answer may be, what is certain is that this exercise of control is quite fragile because after two or three repetitions of the same task performance reaches an asymptotic level even in cases where the probability of a task change remains the same (Monsell, et al., 2003).

As it has been shown to this point, a number of experiments with a variety of methodologies have investigated the cognitive processes that control the switching of tasks. These experiments have provided the task switching literature with diverse results that sometimes contradict each other on a theoretical level. Attempts to provide more holistic and detailed accounts regarding the cognitive processes that control task switching have been made occasionally with the use of cognitive models. The more influential of these attempts will be discussed in the following section. Common components across the models, along with any possible omissions, will be sought and discussed further in regard to their efficiency to explain performance on predictable and unpredictable cases. This will conclude the overall review on the task switching literature and constitutes the final step prior to the introduction of the task switching cognitive architecture that is proposed in the thesis.

1.12 MODELING TASK SWITCHING

Several models have been developed over the years in an attempt to provide a coherent account of the interplay of the cognitive functions that underlie the switching of tasks. Three such models will be considered in detail here.

1.12.1 Sohn and Anderson (2001)

First, there is the model described by Sohn and Anderson (2001). Figure 2 provides in summary form the set of productions included in the model together with a brief account of the actions associated with the rules.

Critically in the current context, the model does provide some insights into how task certainty influences processing. In being a production system model, there is a basic distinction between declarative chunks that are held in declarative memory and productions that are held in procedural memory. The declarative chunks provide basic facts about the task at hand such as stimulus-to-task mappings and stimulus-to-response mapping. In contrast, the procedures define the cognitive operations that underlie task performance.

In declarative memory, the chunks themselves have associated activation levels. Chunk activation acts as an index of retrieveability such that highly active chunks will be retrieved more quickly than less active chunks. As Sohn and Anderson (2001) noted, “All other things being equal, the more frequently or the more recently a chunk has been retrieved the higher the activation.” (p. 772). Time to retrieve a chunk will be reflected in the overt RTs.

It is through chunk activation that the model accounts for the task repetition benefits – a recently activated task will result in faster responding if it is immediately repeated. Hence, RTs are shorter on non-switch than switch trials. As noted above, although Sohn and Anderson (2001) refer to these effects as reflecting “exogenous factors” their intended meaning is automatic processes. Such automatic processes are taken to explain the various task-set inertia effects discussed at length in the literature (Monsell, 2003). Moreover, the definition of chunk activation includes a decay parameter such that as the time since last chunk retrieval increases, chunk activation decreases in a negatively decelerating fashion. In this way, the model can simulate changes in performance as a function of RSI.

Production	Actions
1. Start-Task	Encode colour
2. Encode-Task	Set Task appropriately and encode stimulus
3. Task-Prepared	Encode stimulus
4. Identify-Symbol	Identify the symbol for the task
5. Judge-Symbol	Categorize symbol
6. Map Response	Set the response accordingly
7. Respond	Respond
8. Prepare-Switch	Set task to next task if known
9. Think	Think

Figure 2**:** Sohn & Anderson (2001) model's set of productions.

On each trial and once a stimulus is presented the model simulates mental processes as its works its way down the list of production shown in Figure 2. In accounting for the overall patterns of performance, the basic idea is that, "Normally no task-relevant productions apply during the RSI." (p. 772). Under predictable cases where the task is to be repeated, the participant is already prepared, but under unpredictable cases, the participant cannot prepare. In these cases, performance will reflect to large measure the relative strengths of the various chunks. However, in the predictable cases where the participant must enact a task switch the Prepare-Switch production is 'fired' such that the system is now in an appropriate state prior to the next trial.

The other major difference between predictable and unpredictable cases is that once the stimulus has been presented and the participant already knows which task to perform then the Encode-Task production is by-passed and the Task-Prepared production is applied. Such operations are taken to reflect endogenous control. Given this, within the model there is a clear separation between (so-called) exogenous and endogenous processes. Indeed, in an earlier paper, a stronger case was built for both the *functional* and *neural* separation of exogenous and endogenous mechanisms (see Sohn et al., 2000).

1.12.2 Yeung and Monsell (2003)

The second model to be considered in detail is that reported by Yeung and Monsell (2003b). This again is a computational model and at the heart of the model lies the equations presented in Figure 3:

$$\text{input}_i = \text{strength}_i + \text{priming} + \text{control}_i + \text{noise} \quad (1)$$

$$\text{activation}_i = 1 - e^{(-c*\text{input}[i])} \quad (2)$$

$$\text{generation-rate}_i = \text{activation}_i / \Sigma\text{activation} \quad (3)$$

$$\text{generation-time}_i = \text{THRESHOLD} / \text{generation-rate}_i \quad (4)$$

$$\text{resolution-time} = r + f\left(r-\left(\text{generation-time}_j - \text{generation-time}_i\right)\right) \quad (5)$$

$$\text{RT} = P + (\text{generation-time} + \text{resolution-time}) + R \quad (6)$$

Figure 3: Yeung and Monsell (2003) model's equations.

Assume here, that there are two tasks indexed by *i* and *j*, respectively. The activation of a given task-set depends on the parameter *input* and as with the Sohn and Anderson model, the overall level of activation of task-set fundamentally determines how quickly a response is made. The *input* of a given task-set is a simple linear addition of several factors. *Strength* refers to, in a sense, baseline activation with familiar or easy tasks having higher baseline values than less familiar or more difficult tasks; priming is used to convey ideas about TSI. *Priming* takes on a higher value if a task has most recently been used than if it has not. *Control* reflects endogenous factors and is used to simulate in part task certainty - levels of control for a particular task are boosted if that task is expected. Finally, *noise* refers to a random variable that introduces variability into the models responses and allows it to produces response errors. P, R, c, THRESHOLD, and f are free parameters. Free parameters are also used to compute priming, control and strength. r is sampled randomly from an Ex-Gaussian distribution in a bid to model a typical RT distribution.

Once the activation has been computed for each task, response selection is simulated via Equations 3 - 5. The generation rate for each task is computed as a proportion of the tasks activation expressed as function of the total activation of both tasks. These values are then used to compute the generation time for each task. The bigger the difference between the generation rate and the threshold, the larger the generation time for a given task will be.

Equation 5 now crystallises the ideas about response interference so that the more the two tasks generation times are similar the more overall interference will ensue. The eventual RT reflects, in part, the overall response interference and generation time for the task being responded to.

As Yeung and Monsell (2003b) and Yeung, Nystrom, Aronson and Cohen (2006) have demonstrated, the model is capable of providing good fits with the data from various task switching cases.

1.12.3 Gilbert and Shallice (2002)

The final model to be considered is the connectionist model described by Gilbert and Shallice (2002). The model comprises collections of simple processing units that are grouped into different pools such that within each pool, all of the units have the same functional role. The model was configured to simulate task switching performance in tasks in which Stroop stimuli (i.e., colored words) were used. Switching performance relates, in this case, to instances of where participants either name the color of the word's ink (the color naming task) and then name the word (the word naming task) or vice versa.

The input layer of units in the model is divided into two pools, namely, *word input units* and *color input units*. A stimulus is defined relative to a distributed pattern of activation across the input units. So the word RED printed in green ink would be represented via the RED word unit being switched ON and the green color unit being switched ON - all other input units remain OFF. Activation from the input layer feeds directly into the next layer of units (i.e., the output unit layer) that again is divided into two pools, *word output units* and *color output units*, respectively.

The final layer of units contains two *task demand units*: a *word naming unit* and a *color naming unit*. Connections to this layer of units exist directly from both the input and output layers. In addition, feedback connections exist between the task demand units and the output layer and in this way the model aims to simulate top-down control. Both excitatory and inhibitory connections are posited. Essentially, the model responds once a particular output unit has reached a critical level of activation determined by a response threshold. Output units' activation is a function of both bottom-up activation from the input units and top-down activation from the task demand units.

In broad terms, the model is an elaborate interactive management of activation and competition mechanisms as described in the Stroop task switching literature. For instance, the model provides interesting insights into cognitive networking and Gilbert and Shallice wrote extensively about how the model is able to simulate various effects like the so-called reverse Stroop interference (Allport, Styles, & Hsieh, 1994; Allport & Wylie, 2000). Incongruent stimuli are cases where the ink and the word are linked with different responses (as with 'RED' in green ink). Neutral cases come in two forms for the color naming task, 'XXXX' would be used; for the word naming task the color word would be printed in black. The critical comparisons involve performance on switch and non-switch trials for the two different task separated out for both incongruent and neutral trials.

The pattern of effects is as follows: For the word naming task, switch costs are substantial for both neutral and incongruent cases. However, whereas there is a congruence effect on switch trials with incongruent responses being longer than neutral responses, there is no congruence effect on non-switch trials. In contrast, in the data for the colour naming task switch costs are reduced but the congruence effect is pronounced on both switch and non-switch trials.

In general terms, the data reflect that in the word naming task the color naming task-set only interferes on switch trials, whereas for the color naming task the word naming task interferes on both non-switch and switch trials. The standard Stroop effect is that colour naming is impeded when there is a disparity between the named colour and the colour of the ink. Word naming is generally unaffected by variation in ink colour. However, the fact that the data do show a congruency effect in the word naming task on switch trials is an instance of the reverse Stroop effect.

In the model switch costs reflect the fact that the previous task-set has just been activated and this is realised as higher levels of activation for the associated task units and connections (i.e., the task pathway) and suppression or inhibition of the alternative task pathway. So even in the word naming case the immediately prior activation of the colour naming pathway is reflected on the switch trials when an incongruent stimulus is presented.

In concluding this survey on modelling, several commonalities as well as differences in the models are discussed and linked to major theoretical ideas regarding task switching. All models include an initial activation level for a given task. This level can reflect how easy or difficult a task is. The initial level of activation can be affected by the recency of retrieval for the task (priming). Priming affects the time taken to respond so that non-switch trials are always faster than switch trials (switch cost). In addition, an endogenous component has a direct effect on the activation of a task prior to the onset of the trial (advance preparation). Through that component, the models aim to account for differences between predictable and unpredictable cases where advance preparation is thought not to be feasible (predictability effect).

An exogenous component that can account for congruency and/or crosstalk effects is included in all models. Especially, a conflict resolution (Yeung & Monsell) and an inhibitory component (Gilbert & Shallice) seem to manage the automatic activation of a competing to the trial task-set. The time taken for a task to reach the threshold of activation and consequently to a response is a parameter that is included on all models. This parameter can explain in part RSI effects.

Another parameter that could account for RSI effects, a decay parameter, is found only on Sohn and Anderson's model. Finally, it is slightly concerning to note the large number of free of parameters in all models. Sohn and Anderson (2001) reported 18 free parameters and there is a comparable number (if slightly more) in the model discussed by Yeung and Monsell (2003b). Gilbert and Shallice (2002) list 17 free parameters. In addition, the structure of the network was handcrafted.

It is clear that task switching, even in simple laboratory cases, draws upon many cognitive processes but with all the computational models discussed here there are many more free parameters than there are effects to explain. In this regard, the concern is not that the field lacks computational models but that such models are only loosely constrained.

1.13 SETTING THE COGNITIVE ARCHITECTURE

Overall, the cognitive system seems to be managing task switching by utilizing an executive component that controls the selection and the management of task-sets (Baddeley & Hitch, 1974; Norman & Shallice, 1986). Task-sets are cognitive schemata that are stored in LTM and consist of several subcomponents.

From LTM they are selected in a top-down manner and then are loaded into WM where they are manipulated in order for an adequate to the circumstances response to be given (endogenous control).

However, selection of a task-set can occur in bottom-up fashion as in cases where a stimulus activates a task-set unintentionally (exogenous control). The executive component seems to be supervising constantly the whole process and intervenes (e.g., when interference from the irrelevant to the trial task occurs) by biasing the task-sets either by activating further or by suppressing their activation according to the circumstances (Norman & Shallice, 1986). The crosstalk and congruency effects seem to support the notion that such an intervention occurs giving rise to increased switch costs on trials where exogenous control is strong and causes interference (bivalent or incongruent trials) than on when it is absent or weak (univalent or congruent/neutral trials) and causes no interference (Mayr, Diedrichsen, Ivry, & Keele, 2006; Rogers & Monsell, 1995).

Up to this point, it is clear that exogenous control can affect the selection of tasks-sets (endogenous control) (see also Stroop effect, Sohn & Anderson and Gillbert & Shallice task switching models). Therefore, in cases where task selection is not necessary a reduction or absence of a crosstalk/congruency effect can be expected. An example where task selection is not necessary is on predictable non-switch trials. This idea is supported by the fact that only one non-switch trial is enough in order for performance to reach an asymptote in predictable trials.

This is not the case for unpredictable non-switch trials where a more gradual recovery of performance is observed (Monsell, Sumner, & Waters, 2003). Therefore, it seems that on predictable non-switch trials the task is already loaded in WM for use in the current trial and only needs to be maintained there for further use on the upcoming trial(s). In that case, the presence or absence of an irrelevant aspect of the stimulus should make no notable difference on performance.

On switch trials however, where task selection and loading in WM occurs, crosstalk and congruency effects should be evident even when advance preparation is allowed. That is, because it should be easier relative to incongruent cases to prepare the relevant task when interference from the irrelevant task is weak or absent (as in congruent/neutral trials).

Interestingly, on unpredictable trials exogenous control should be evident on both switch and non-switch trials. This is derived from the assumption that under unpredictable conditions due to the lack of foreknowledge about the upcoming task the cognitive system should bias the two competing tasks in order for both to be equally ready for use on the next trial. Depending on the RSI provided this equilibrium might be achieved or not.

If the above assumptions are true then the following should be evident under unpredictable conditions, a) overall slower performance relative to predictable conditions – selection of the appropriate to the trial task-set occurs always after the onset of the stimulus, b) crosstalk/congruency effects in both non-switch and switch trials – due to the presence of task selection in both cases, c) smaller switch costs relative to predictable trials – the cognitive processes on both kinds of unpredictable trials are very similar therefore switch costs will solely depend on the relative activation of the relevant/irrelevant task at the moment of task selection.

Evidence for the latter speculation comes from the study that demonstrated that when a long RSI is provided switch costs on unpredictable cases are eliminated (Tornay & Milán, 2001). This finding provides strong support that the cognitive system biases the two competing tasks in order for both to be equally ready for use on the next trial under unpredictable conditions. Moreover, the idea stated in Monsell et al. (2003) of a strategic modulation of task readiness due to expectancy for a task switch seems to fit nicely with the previous belief that the cognitive system modulates accordingly the activation of the competing tasks in order to be optimally ready for the upcoming trial. If the cognitive system prepares tasks-sets according to expectancy then it should be expected that in cases where a specific task-set is more probable to be required on the next trial then this task-set should be favored by the cognitive system. Furthermore, if a certain type of trial is expected to occur more often, (e.g., a switch trial), then it can be expected that the cognitive system will bias the task-sets accordingly. For instance, if a switch is more probable to occur on trial $n+1$ than on trial n the irrelevant task-set will receive more bias than the relevant task-set. It has to be noted, that ideas such as the carry-over of inhibition and repetition priming should more evidently affect task switching performance under unpredictable conditions. Under these conditions, the modulation of the activation/inhibition of task-sets is relatively relaxed relative to predictable cases (in predictable trials there is complete foreknowledge regarding the upcoming trial allowing for a strong bias in favor of the upcoming task).

Finally, when two tasks share component(s) (e.g., an attentional component) then switching between them should result in smaller switch costs relative to switching cases where two tasks do not share components. In the first case, the common between task-sets component(s) will either be biased constantly or they will be maintained in WM for use on the next trial. In this case, fewer components need to be changed when switching between similar tasks relative to switching between dissimilar tasks resulting in smaller switch costs relative to the second case. However, there must be cases in which sharing a component should result in an increase on switch costs. In that case, bias in shared between task-sets components may unintentionally activate the irrelevant task-set causing interference that needs to be overcome prior to the response. A good example comes from cases where the same response set is used by both task-sets. Upon a switch trial *n+1* if the switch is incongruent relative to the trial *n* then additional costs arise (Rogers & Monsell, 1995).

1.14 THESIS OVERVIEW

The aim in the thesis is to provide an adequate explanation for the following general question: How the cognitive system modulates itself and manages to adapt effectively in a multidimensional environment such as everyday life. For that reason a variety of the task switching paradigm has been developed in which task switches are sometimes unexpected. In this paradigm, switch costs are obtained under a variety of circumstances for predictable and unpredictable cases and are compared and contrasted. As can be concluded therefore, the central manipulation of the thesis' experiments is predictability. Participants had to perform simple tasks with or without foreknowledge of the upcoming task. In every experiment in the thesis therefore, the general concern has to do with how non-switch/switch trials are affected by the lack of foreknowledge.

Moreover, it has been shown that under unpredictable conditions non-switch trials carry more performance losses in terms of RTs relative to switch trials when both are relative to the respective predictable trials (Dreher & Grafman, 2002; Dreher, Koechlin, Ali, & Grafman, 2002; Milan, Sanabria, Tornay, & Gonzalez, 2005). It is interesting to investigate this pattern throughout the thesis and uncover the reasons behind this phenomenon. Along these general concerns, interest will be focused on different dimensions of task switching effects in each chapter. Nevertheless, in order to maintain coherence between the different series of experiments, replication of the central findings as these were set in Chapter 2 was set as a prerequisite.

In particular, in Chapter 2 the basis for the rest of the thesis is established by replicating in general the main task switching effects found in the literature. Beside that, the particular role of competing task-set interference in task switching is investigated. In addition, the magnitude of the effect of advance preparation is studied in cases where the RSI provided was long vs. cases where the RSI was short. This set of experiments is thought to address the interplay of exogenous and endogenous control in task switching performance.

In Chapter 3, the focus is on the endogenous modulation of activation/inhibition in cases where tasks of unequal difficulty competed. Another issue that is addressed is how this modulation is affected by the unequal probability of presentation (expectancy) of the competing tasks. Is task-set priming in the form of activation, the carry over of inhibition, expectancy, or a combination of all of the above that determine task switching performance? By the end of the discussion in this chapter, the main assumptions of the thesis are formulated and explained. A task switching model is introduced.

In the following chapter (Chapter 4), the effect of task similarity on task switching is addressed. The aim is to realize further, how task-sets and specifically their components are managed by endogenous control. Does switching between tasks with similar components require less effort from the cognitive system? On which level of processing do similar components between two tasks facilitate task switching? Can switching between similar tasks result in larger switch costs relative to switching between dissimilar tasks?

In the final empirical chapter (Chapter 5), the role of endogenous control under unpredictable cases is studied. The questions addressed are: Does the cognitive system prepare endogenously when the probability for a task switch increases? Are there any neuroimaging data to provide further support that preparation actually occurs? Can these neuroimaging data provide support for the task switching model's components proposed on Chapter 3?

In Chapter 6, the thesis is concluded. The main empirical findings are drawn together and suggestions for further experimental work are provided.

2 TASK CONGRUENCY AND TASK CROSSTALK EFFECTS

2.1 GENERAL INTRODUCTION

A basic aim in Chapter 2 is to provide a detailed understanding as to why performance is impaired when people switch between different tasks relative to when they repeat a single task. Predominantly the work in the literature has focussed on performance in predictable conditions in which participants are fully informed about which task to engage with on the upcoming trial (see Monsell, 2003, for a recent review). Far less work, however, has examined cases where the requirement to switch is unpredictable in advance of the trial stimulus. This imbalance in the literature is somewhat surprising given that our every day activities are characterised by apparently random events that interrupt the task at hand and demand attention. It seems therefore, that large gaps in knowledge remain over the differences in performance that occur under predictable and unpredictable circumstances.

It is important to clarify one notable point at the outset and set the work properly in context. For present purposes, performance in unpredictable conditions will be examined in cases where participants do not know which task to engage with in advance of the presentation of the next imperative stimulus. Under these conditions, the appropriate task is signalled by some characteristic of the imperative stimulus itself. For instance, the color of the stimulus indicates which task to perform (see e.g., Sohn & Anderson, 2001). Such experimental conditions seem to mimic exactly the sorts of task switching that more normally takes place (e.g., there is normally no warning that the phone will ring). However, in the experimental literature there is a body of work in which unpredictable task switching is examined in a different way. Now something known as *explicit cuing* has been used (see Altmann, 2007). In these cases, participants without having completed the current trial, do not know what task will occur next. The next task is signalled by a cue that is presented prior to the presentation of the next imperative stimulus. The random nature of the trial order has lead investigators to claim that performance reflects task switching performance under conditions of unpredictability (see Monsell, Sumner & Waters, 2003), but some caution is warranted because once the cue is presented the next task is known with certainty.

It is important to set the scene for the present work in this manner because in the present case the phrase *unpredictable task switching* will be used in a very particular way. The phrase will be used to refer to cases where the task to perform is only signalled once the imperative signal is presented. In this respect, participants cannot prepare with certainty for what is expected of them next. Given that participants may be able to engage in some form of task preparation on the basis of an explicit task precue (Karayanidis, Mansfield, Galloway, Smith, Provost, & Heathcote, 2009; Meiran, 1996), then it seems incautious to use the term 'unpredictable' in such cases. Indeed, the degree to which switching performance is affected by the presence of an explicit task precue will be examined in detail later in the chapter.

As with other studies on task switching (Sohn & Anderson, 2001; Sohn & Carlson, 2000; Sohn, Ursu, Anderson, Stenger & Carter, 2000; Yeung & Monsell, 2003b), the basic starting point for the present chapter is the work by Rogers and Monsell (1995). Rogers and Monsell (1995) developed something known as the *alternating runs paradigm*. In the original experiment, the basic stimulus display contained a square divided into four quadrants and on each trial a pair of characters was positioned in the centre of one of these quadrants. There were two tasks that participants were required to engage in. For ease of exposition, Task A will be designated the *letter task* and here participants had to classify the letter as either a consonant or a vowel. With Task B (the *digit task*) participants had to classify the digit as either odd or even. Each task is assumed to be defined relative to its own *task-set*. As discussed in the previous chapter, according to Gilbert and Shallice (2002; p. 298) task-set refers to "the set of cognitive operations required to effectively perform the task". From this point of view, performance in task switching experiments is assumed to inform about the nature of different task-sets and how these are managed on a moment-to-moment basis.

In the original experiment reported by Rogers and Monsell (1995), on most trials, the pair of characters contained one letter and one number. On neutral trials, though, either a letter or a digit was presented together with a symbol not assigned to a response (for instance, '#'). Depending on which quadrant the characters fell, participants had to perform either Task A or B. The stimulus position was perfectly predictable following the first trial because the location of the character pair was determined sequentially in a clockwise fashion - the sequence was AABBAABB.... Trials within such a sequence can be divided into two main types, a) on a *non-switch* *trial* the task is repeated from the immediately prior trial, and, b) on a *switch trial* the task on that trial is changed from the task performed on the immediately prior trial.

Rogers and Monsell (1995) discussed performance in the tasks in terms of two general components, namely, *endogenous* and *exogenous factors*. The interplay of these two factors is the focus of the present series of experiments. Endogenous factors relate to the participant's intentions (e.g., adopting a particular task-set prior to the onset of a trial). In addition to such endogenous factors, there are exogenous factors that affect performance once the stimulus is present. To examine these, Rogers and Monsell (1995) discussed three different types of trials. On *congruent trials,* both characters were mapped to the same response. For instance, if the 'odd' and 'consonant' responses were mapped to the right key then '3K' would be known as a congruent stimulus. On *incongruent trials,* the different characters were mapped to different responses. For instance, '3A' is an incongruent trial because 'odd' is mapped to the right key but 'vowel' is mapped to the left key. Finally, on *neutral trials* only one task relevant character is presented so in the case '3 #' only '3' is mapped to a response. Similar manipulations of stimulus congruency occur frequently in the general attentional literature (see for instance the work on the Eriksen flanker effect, B. A. Eriksen & C. W. Eriksen, 1974), and a typical pattern of findings is that response benefits increase on congruent relative to neutral cases, and that response costs increase on incongruent relative neutral cases (Miller, 1991). It is important to draw a distinction though between such *congruency effects* and *crosstalk effects* (Rogers & Monsell, 1995).

In their first experiment, Rogers and Monsell (1995) found a basic crosstalk effect such that RTs were as long on congruent and incongruent trials and they were shorter on neutral trials. There was an overall cost in performance for cases where two task relevant characters were presented relative to the neutral baseline (i.e., when only one task relevant character was presented). This pattern of findings contrasts with congruency effects, as described, and seems to reflect instead the standard difference between responding to *bivalent stimuli* and responding to *univalent stimuli*. Bivalent stimuli invoke two different task-sets, for example, A3 invokes both the letter and digit task-sets. In contrast, univalent stimuli invoke only a single task-set, (e.g., A# invokes only the letter task-set). In the absence of additional information, there is uncertainty over which task-set is appropriate for a given bivalent stimulus. Bivalent stimuli therefore carry additional processing requirements to univalent stimuli and, consequently, there are performance costs associated with bivalent stimuli (see Quinlan & Dyson, 2008, Chapter 9 for review of such performance differences).

On these grounds, the phrase *crosstalk effects* will be used in cases where the data reveal costs on bivalent trials relative to the neutral (univalent) trials. The phrase *congruency effects* will be used in cases where differences arise across congruent and incongruent trials. Indeed, in the data reported by Rogers and Monsell (1995) crosstalk effects were common whereas effects of stimulus congruency were less evident. In their second experiment, although they did report some speeding on congruent relative to incongruent cases, responding on congruent and incongruent trials was notably slower relative to neutral trials. Such a pattern reveals both congruency and crosstalk effects. Nonetheless, the presence of both crosstalk and congruency effects reflects the fact that once the stimulus is presented, exogenous factors influence performance. More recently, Monsell et al. (2003) have used the term *task-set interference* in discussing crosstalk effects. The implication is that the different characters evoke the different task-sets associated with them and this results in some form of competition at the cognitive level. The problem is to decide which of the activated task-sets is appropriate for the current trial.

In attempting to examine endogenous control, Rogers and Monsell (1995) tested performance as a function of the interval between successive trials. In the task switching literature, it is typically the case that the inter-trial interval is varied by systematically changing the delay between the response on trial *n* and the presentation of the stimulus on trial *n+1*. This is known as the *response to stimulus interval* or *RSI*. The simple prediction is that the more time the participants have to prepare for the upcoming task then the more efficiently they will perform that task (see Altmann, 2004b, for a detailed discussion). One index of such preparation is known as *switch preparation* (Altmann, 2004b). In most of the cases, performance is impaired on switch trials relative to non-switch trials and it is possible to express this difference as a so-called *switch cost* (average switch trial RT – average non-switch trial RT). Evidence of switch preparation is where the size of the switch cost reduces as the RSI increases. Rogers and Monsell (1995) found the strongest evidence of switch preparation when RSI was blocked within sequences (Experiment 3) - there was no evidence of switch preparation when different RSIs were employed between blocks of trials (experiment 2).

The evidence for switch preparation was taken by Rogers and Monsell (1995) to reflect that certain reconfiguration processes can take place within the cognitive system prior to the next trial as long as participants have sufficient time and foreknowledge of the upcoming task. However, a substantial residual switch cost was still present at the longer RSIs (RSIs of 150, 300, 450, 600 and 1200 ms were used). This was taken to suggest that any so-called *task-set reconfiguration* (TSR) was not complete until after the next trial stimulus had been presented. The residual switch cost was taken to show additional processes that “can be triggered only exogenously by the arrival of stimulus” (Rogers & Monsell, 1995; p. 229). Interestingly, in neither their experiment 2 nor experiment 3 did changes in RSI alter the size of the crosstalk effects. In broad terms therefore, the effects of RSI, that are in some sense indicative of intentional control, are independent of the crosstalk effects that reflect exogenous factors relating to the nature of the stimulus.

Overall therefore, it seems that different variables can be used to examine the respective endogenous and exogenous components of switching. Indeed, one way in which the interplay of endogenous and exogenous factors could be examined further is by taking the crosstalk effects and seeing the degree to which these are insulated from other aspects of executive control. Based on that, an aim here was to examine task switching performance in cases where the trial sequence was predictable (as in the standard alternating runs case) and where the trials were essentially random.

A relevant series of experiments has been carried out by Sohn and Anderson (2001). They compared performance in what they termed *foreknowledge* and *no-foreknowledge* conditions. (In the present context, the terminology adopted labels these *predictable* and *unpredictable conditions,* respectively.) In the predictable cases, and as in the standard alternating runs paradigm, participants knew in advance of a trial which task would be the imperative task (i.e., the task to engage in). In the unpredictable cases, although participants were unable to predict the next task based on which task had just been performed. The relevant task was signalled by the color of the characters. In the experiments reported by Sohn and Anderson (2001), the types of transitions between trials were tested in blocks and trials were run in pairs. In predictable non-switch blocks, participants enacted either the letter task or the digit task. In predictable switch blocks, participants knew after the first trial of a pair what the next task would be on the second. In contrast, in the unpredictable blocks pairs of trials were randomised so that the nature of the first trial of a pair provided no information as to what trial the second would be. Furthermore, Sohn and Anderson (2001) varied RSI between, but not within, blocks.

Theoretical interest lays on the two aspects of performance that Sohn and Anderson termed *task preparation* and *task repetition.* They proposed that task preparation reflects endogenous factors as described above. However, the terminology becomes less clear because they also claimed that task repetition reflects *exogenous factors* and by this they meant that such effects are *automatic* and are beyond the control of the participant. It has to be noted here, that the more appropriate use of the term ‘exogenous’, that is preferred here, is used to refer to effects that are tied directly to the onset of the stimulus (see Rogers & Monsell, 1995). Sohn and Anderson (2001)use the term ‘exogenous’ as synonymous with ‘automatic’. In discussing task repetition, the basic idea is that participants' performance is facilitated if the task is repeated from the immediately previous trial because of an “activation boost that makes the repeated task performance more efficient” (p. 764). Such ideas can be linked from the *task-set inertia hypothesis* as proposed by Allport and colleagues (see e.g., Allport, Styles, & Hsieh, 1994) - the idea that there is persisting activation from a previous task and that this takes time to dissipate. In cases where the task is repeated, the persisting activation facilitates responding on the repeated trial.

Sohn and Anderson (2001) developed a production system model to account for performance in the basic task switching paradigm (similar ideas have been explored by Altmann & Gray, 2008). Central to this model, is the division between *declarative memory* that essentially holds facts about the different task-sets (such as stimulus-to-task mappings and stimulus-to-response mappings) and *procedural memory* in which production rules specify the basic cognitive processes. Information in declarative memory is governed by processes of activation such that the ease of retrieval of a given information chunk depends on its level of activation - higher levels of activation reflect easier retrieval. Any general task priming effects (such as on repetition trials) should decrease as a function of RSI as their activation in declarative memory decays.

In contrast, the different production rules compete with one another in procedural memory in a bid to determine which cognitive operation is invoked next.

Within the account, task preparation effects reflect the fact that when participants possess foreknowledge of the next task, they can avoid the need to retrieve information that is otherwise needed to determine the next task. In simple terms therefore, effects of task repetition are located within declarative memory and reflect chunk activation, whereas task preparation effects are located within procedural memory. This means that task repetition and task preparation reflect separate aspects of the cognitive system and should reveal effects that are selectively sensitive to different manipulations of performance.

In the present study, very specific predictions were tested regarding the influence of exogenous and endogenous factors, respectively. A first set of predictions concerned performance under unpredictable conditions. It was predicted that the facilitative nature of task repetition (i.e., task priming) would decrease as RSI is increased. Critically this effect would be revealed as slowing on non-switch trials as the delay increased. In addition, little benefit would accrue on switch trials because of lack of foreknowledge. Consequently, switch costs should diminish as RSI increases. Clear supporting evidence for these ideas was found in the data from the unpredictable conditions.

A second set of predictions concerned performance in the predictable conditions in which endogenous factors come into play. Now as with unpredictable cases, switch costs should also diminish with increases in RSI but for different reasons. Under these circumstances, there is both task repetition and task preparation. Repetition RTs again should increase as a function of delay as a reflection of task priming. In addition, RTs on switch trials should also shorten as a reflection of task preparation. Generally, the data were in line with these predictions. However, Sohn and Anderson (2001) also predicted that the pattern of effects should be more marked in the predictable than the unpredictable conditions but the critical higher order interaction failed to reach statistical significance. As will become clear, the present experiments provide additional tests of these particular predictions. Considering both the work of Rogers and Monsell (1995) and Sohn and Anderson (2001) a common assumption is that endogenous and exogenous control factors are independent from one another. A primary aim of the current work was to examine this assumption in detail.

2.2 EXPERIMENT 1

The aim of the first experiment was to examine task switching in variations of the standard alternating runs task. Two manipulations of endogenous control were undertaken. The first and primary manipulation involved task predictability. Participants were tested under both predictable and unpredictable conditions. The second concerned variation in RSI and intervals of 250, 600 and 1200 ms were tested as a between-groups variable. One aim was to test for the higher order interaction between task predictability, RSI and task switching described by Sohn and Anderson (2001). The primary aim though was to examine the pattern of congruency and crosstalk effects as a function of predictability, RSI and task switching. If the stimulus effects reflect automatic processes that are insulated from any changes in endogenous control, then these should remain relatively stable regardless of the manipulations of predictability and task delay (cf. Rogers & Monsell, 1995; and also Monsell et al., 2003, p. 338).

2.2.1 Method

2.2.1.1 Participants

The participants were 36 university students (29 females) with a mean age of 20.3 and standard deviation (SD) 1.9 years old. They took part for either course credit or payment (i.e., £4). All reported having normal or corrected to normal vision and hearing. Six were left-handed.

2.2.1.2 Design and stimuli

Central to the experiment were two character classification tasks (cf. Rogers & Monsell, 1995). In the letter classification task, and on each trial participants had to decide whether a target letter was a vowel (from the set A, U, I, E) or a consonant (from the set M, K, G, R). In the digit classification task, and on each trial, the participants had to decide whether the target digit was an odd number (from the set 3, 5, 7, 9) or an even number (from the set 2, 4, 6, 8). On each trial, a pair of characters was presented and participants had to make a speeded key press response. There was a left and a right response key, with 'consonant' and the 'even' responses assigned to the right key and the ‘vowel’ and ‘odd’ responses to the left key. Letters and digits appeared randomly either as the first (left) or second (right) character in the pair. On congruent trials, both characters were assigned to the same key response (e.g., A3, K6), on incongruent trials the characters were assigned to different key response (e.g., U4, G9). Neutral trials occurred when the imperative stimulus (i.e., the letter or digit) was presented together with a neutral character. The neutral character was taken form the set '?', '%', '*', '#' and was not associated with either response.

In the experimental trials, there were two main conditions - a predictable condition and an unpredictable one. In the predictable condition the sequence of trials started with a letter trial thereafter the sequence was a letter trial, digit trial, digit trial, letter trial and so on (i.e., LLDD). Every 3rd and 5th trial was a switch trial and every 2nd and 4th trial in the sequence was a non-switch trial. In the unpredictable condition, the sequence of trials was completely random. Each block comprised 48 trials and within a block there were equal numbers of switch and non-switch trials, equal numbers of congruent, incongruent and neutral trials, equal numbers of letter and digit trials, and finally equal numbers of left (consonant/even) and right (vowel/odd) key presses. In addition, a further constraint was that a character that appeared in trial *n* never appeared on the immediate subsequent trial *n+1*. In addition, conditions were tested in which the RSI varied.

Across the experimental trials, a mixed design was used containing four factors: RSI (250, 600 and 1200 ms) constituted a between-groups factor, and stimulus type (congruent, incongruent, neutral), trial transition (switch or non-switch), and predictability (predictable or unpredictable), were within-participants factors. To keep the testing sessions to a manageable duration the RSI factor was tested between-participants with participants being randomly assigned to the different RSI group.

2.2.1.3 Apparatus

The E-prime program, running on a Windows XP PC, was used for controlling the experiment. Moreover, an E-prime response box was used to collect the responses. A 15” SONY monitor was used throughout (model CPD-100ES).

2.2.1.4 Procedure

Participants were tested individually in a small quiet testing cubicle. The cubicle contained a table upon which a computer monitor and the response box were placed. Participants were sat facing the 15" monitor placed 57 cm away from a chinrest bolted to the edge of the table. Prior to the experimental trials, participants underwent training blocks of trials where only neutral trials were used. Blocks of trials were generated for the separate classification tasks. Each block of trials contained 24 cases and individual letters and digits were equally represented in each of their blocks (3 times each). The training session comprised 16 blocks (8 letter blocks and 8 digit blocks). The session was initiated by a letter classification block followed by a digit classification block and the presentation continued accordingly until the end. At the start of each trial, a central fixation plus sign (0.4° x 0.4° of visual angle) was presented. In the training tasks, the fixation plus sign was followed by a centrally presented pair of characters. Character pairs were presented as black, bold, courier new, size 18 font (0.5° x 0.5°). In contrast, on the experimental trials the fixation plus sign was followed by a display containing a large square (9° x 9°) divided into quadrants (4.5° x 4.5°). A pair of characters was presented centrally in one of the quadrants. Participant's task was to classify the letter (consonant-vowel) when the character pair appeared in either one of the two upper quadrants, and the number (odd-even) when the character pair appeared in one of the two lower quadrants. In the predictable condition, the task was presented into the quadrants in a clockwise manner starting from the upper left quadrant then to the upper right, lower right, lower left and so on until the end of the block. In the unpredictable condition, the task was presented in a completely unpredictable fashion. The main experiment required participants to proceed through two sequences of predictable and two of unpredictable trials. Each sequence consisted of four blocks of 48 trials each. Order of sequences was balanced across participants by using ABBA counterbalancing.

2.2.1.4.a Training trials

In the training trials, the sequence of events was as follows. A central fixation plus sign occurred for 250 ms, 600 ms, or 1200 ms depending on the participant's group. This was immediately followed by a centrally presented pair of characters for

3 s or until a response occurred. Immediately following this, the fixation returned for the corresponding RSI. At the beginning of the testing session, written instructions were presented on the monitor. Participants were asked to read the instructions carefully and when ready to press one of the response buttons to initiate the trials. At the start of each block of trials, the word 'Ready' was presented and after 3 s the fixation plus sign appeared in the middle of the screen followed a short time later (either 250 ms, 600 ms, or 1200 ms) by the first character pair. The end of a block of trials was signalled by the presentation of a display, “This is the end of that block. Press a button to continue”.

2.2.1.4.b Experimental trials

At the beginning of the experimental trials, new written instructions were presented on the monitor. Participants were asked to read carefully the instructions and proceed when ready. The fixation plus sign was followed by the target display that stayed on for 5 s or until a response occurred. Immediately following this, the fixation returned for the corresponding RSI. In case of an error, a sound (beep) occurred for 20 ms and an additional delay of 1.5 s was added to the RSI. Blocks were initiated in the same way as in the training trials. However, at the end of each block further feedback was given. A screen display provided the average RT, number of correct responses, number of errors and percentage of errors. Participants were advised to slow down if they found out that they were making many mistakes.

2.2.2 Results

Error responses, very fast responses (less than 100 ms) and responses that followed an error response were excluded from the analysis of the RT data. As a result, in total 9.3% of scores were removed prior to data analysis. Detailed percentage excluded scores for each type of trial for all experiments from now on will be provided on the Appendices section under the ‘Outliers’ column of the table of interest. Separate analyses were carried out for mean correct RTs and percentage errors. Detailed percentage error scores for each type of trial for all experiments from now on will be provided on the Appendices section under the ‘Errors’ column of the table of interest. The standard arcsine procedure was employed in the present experiment and it will be used throughout the thesis in order to transform error percentage rates prior to analysis (see Keppel & Wickens, 2004). For both data sets a split plot analysis of variance (ANOVA) was carried out in which the between participants grouping factor was the RSI (250 ms, 600 ms and 1200 ms) and the within participants factors were predictability (predictable vs. unpredictable), trial transition (switch vs. non-switch) and stimulus type (congruent, incongruent, neutral). All effects will be reported in the thesis as significant at the $\alpha = 0.05$ level.

2.2.2.1 RTs

The analysis revealed statistically significant main effects of trial transition [$F(1, 33) = 108.53$, $MS_e = 120812$, $p < .001$], stimulus type [$F(2, 66) = 235.63$, $MS_e = 7399$, $p < .001$], and predictability [$F(1, 33) = 175.64$, $MS_e = 31531$, $p < .001$]. The main effect of RSI failed to reach statistical significance. Indeed, the RSI factor did not produce any statistically significant effects in the original version of analysis. Generally speaking, responses were slower on switch than non-switch trials, they were slower overall on unpredictable than predictable cases and they were slower overall when the stimulus pair contained two task relevant characters than one - there was clear evidence of a crosstalk effect. However, these general patterns were modulated by a number of statistically significant interactions. Various statistically reliable interactions were uncovered; namely, the predictability x trial transition interaction [$F(2, 33) = 29.3$, $MS_e = 9344$, $p < .001$], the trial transition x stimulus type interaction [$F(2, 66) = 21.9$, $MS_e = 3104$, $p < .001$], and the predictability x trial transition x stimulus type interaction [$F(2, 66) = 6.20$, $MS_e = 3633$, $p < .01$]. In order to examine these interactions in more detail the data for predictable and unpredictable cases were analysed separately.

2.2.2.1.a Predictable trials

The data were now entered into a two-way within participants ANOVA in which trial transition and stimulus type were entered as fixed factors. Both the main effect of trial transition [$F(1, 35) = 104.72$, $MS_e = 82007$, $p < .001$], and stimulus type [$F(2, 70) = 150.57$, $MS_e = 4986$, $p < .001$], were statistically reliable as was the trial transition x stimulus type interaction [$F(2, 70) = 25.95$ $MS_e = 3256$, $p < .001$]. In order to specify the source of this interaction, the mean switch costs for the predictable congruent, incongruent and neutral trials were computed. A one-way ANOVA was run on the resulting switch costs. This revealed a statistically significant main effect of stimulus type [$F(2, 70) = 25.95$, $MS_e = 6513$, $p < .001$]. A Tukey' s HSD test indicated that switch costs on congruent and incongruent trials were reliably larger from those on neutral trials, but not from each other ($p < .05$, both comparisons).

2.2.2.1.a Unpredictable trials

For the data from the unpredictable trials, only the main effects of trial transition [$F(1, 35) = 88.76$, $MS_e = 54052$, $p < .001$], and stimulus type [$F(2, 70) = 163.19$, $MS_e = 6138$, $p < .001$], were statistically significant. Figure 4 provides a graphical illustration of summary RT and error rate averaged over the RSI factor.

2.2.2.2 Error rates

Error rates were analysed in the same way as the RTs. The associated ANOVA revealed that the main effects of trial transition [$F(1, 33) = 73.00$, $MS_e = .044$, $p < .001$], stimulus type [$F(2, 66) = 14.35$, $MS_e = .039$, $p < .001$], and predictability [$F(1, 33) = 10.37$, $MS_e = .019$, $p < .01$] all reached statistical reliability. In addition, the interactions between predictability x stimulus type [$F(2, 66) = 7.19$, $MS_e = .02$, $p < .01$], and that between trial transition x stimulus type [$F (2, 66) = 10.22$, $MS_e = .024$, $p < .001$], were also found to be statistically significant. In the case of the predictability x stimulus type interaction, simple main effects analyses revealed that the stimulus type effect was evident in both the predictable [$F(2, 66) = 3.58$, $MS_e = .02$, $p < .05$], and the unpredictable conditions [$F(2, 66) = 17.38$, $MS_e = .04$, $p < .001$]. Visual inspection of the data (see Figure 5), however, revealed that the effect was more marked in the unpredictable than the predictable condition. In the case of the trial transition x stimulus type interaction, the stimulus type effect was statistically significant only in the switch trials [$F(2, 66) = 22.72$, $MS_e = .03$, $p < .001$]. Although the pattern of significance was different across the RT and accuracy analyses, there was no evidence of any systematic speed/error trade-offs in performance.

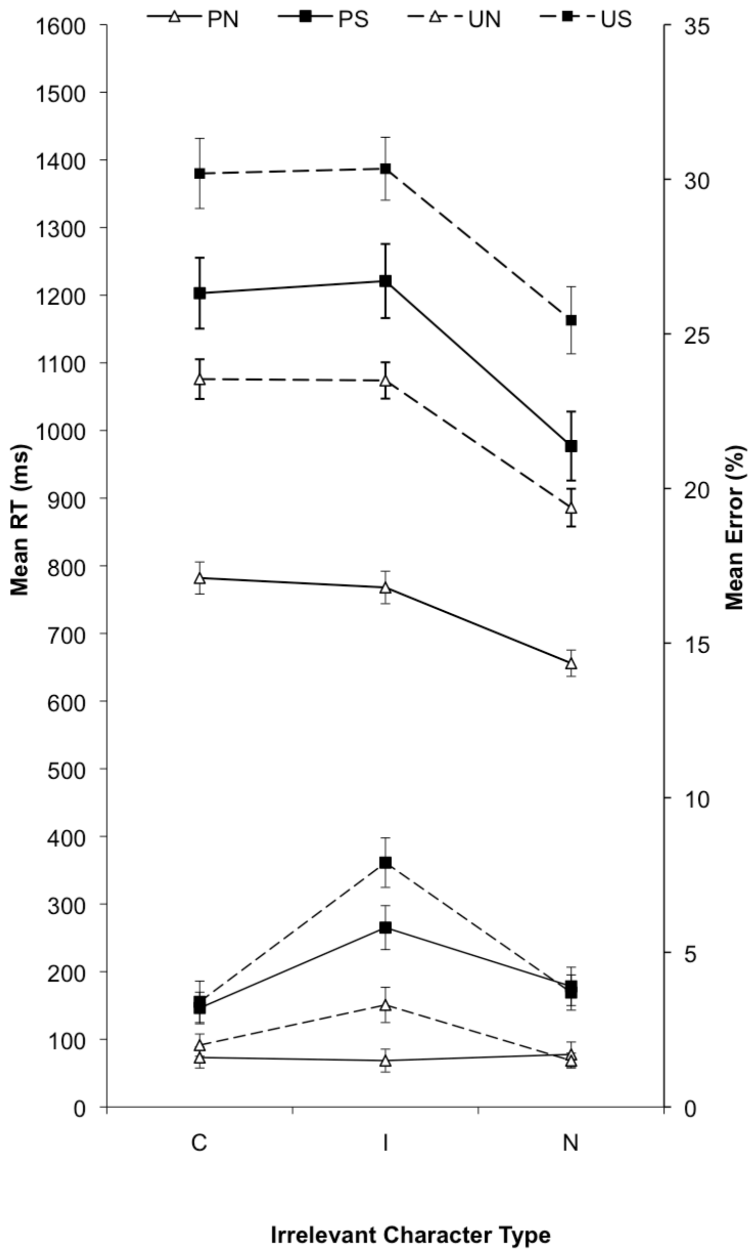


Figure 4: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 1. Means have been averaged over RSI. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials, C = Congruent, I = Incongruent, and N = Neutral.

It must be noted, that whereas in the RT data only a crosstalk effect is evident, in the error data there is evidence of both a crosstalk and congruency effect. In particular, more errors were made on incongruent than congruent trials. This same pattern is present in the data reported by Rogers and Monsell (1995; Figure 2). In this regard, it is important to note the following. On congruent trials both characters were mapped to the same response hence responses based on the irrelevant character would have produced 'correct' responses even though they were implicitly 'errors'.

	Stimulus Type		
Condition and Trial Transition	Congruent	Incongruent	Neutral
Predictable			
Non-Trial transition	1.6	1.5	1.7
Trial transition	3.2	5.8	3.9
Unpredictable			
Non-Trial transition	2.0	3.2	1.5
Trial transition	3.4	7.9	3.7

Figure 5: Mean percentage error rates for the conditions of interest in Experiment 1. The data have been averaged over RSI.

2.2.3 Discussion

In the predictable condition, the present data reveal all of the basic effects reported by Rogers and Monsell (1995; see their Figure 2, p. 215). Switch costs were greater in the congruent and incongruent cases relative to the neutral cases. Switch costs did not differ between the congruent and incongruent cases. Errors were greatest on incongruent cases. Errors were comparably less and equivalent on congruent and neutral cases. In addition, there were no statistically reliable effects of RSI in the data. As a consequence, the predicted higher order interaction between task predictability, RSI and task switching discussed by Sohn and Anderson (2001) was not found here. Although Sohn and Anderson (2001) also failed to find this interaction, the fact that RSI was manipulated between-participants in the present experiment is something to bear in mind. As Altmann (2004b) has documented, effects of RSI are most pronounced when this is manipulated as a within-participants factor and participants experience a range of delays. Most interesting though, are the contrasts between performance in the predictable and the unpredictable conditions.

As Figure 1 shows, generally performance was impaired in the unpredictable relative to the predictable conditions. Furthermore, the switch costs were smaller in the unpredictable than the predictable cases. Both of these general patterns replicate those reported by Sohn and Anderson (2001). It is also important to note how the effects of stimulus type varied as a function of predictability. For the predictable condition, the switch costs varied as function of stimulus type - switch costs were equivalent and large on the congruent and incongruent trials; they were significantly less on neutral trials. For the unpredictable condition, the switch costs were the same for all three trial types.

Participants were overall faster and more accurate in the predictable than the unpredictable cases. In the past, it has been accepted that such benefits are due to the fact that in the predictable condition participants are in a higher state of readiness for the upcoming trial than in the case in the unpredictable condition. In discussing such preparation effects, Altmann (2007) distinguished between switch preparation as discussed previously and *generic preparation* which is manifested when benefits accrue on both switch and non-switch trials. Generic preparation is taken to reflect benefits that accrue with respect to stimulus encoding processes that underpin performance on all trials. In the present data, there is no evidence for switch preparation because the present manipulation of RSI has been ineffective. Nonetheless, evidence for generic preparation is revealed in the comparisons between the predictable and unpredictable cases. When the appropriate comparisons are made, the current data reveal that RTs in the predictable condition are generally shorter than they are in the unpredictable condition.

However, as will be made clearer shortly, it is a mistake to attribute all of the benefits in the predictable cases to what goes on in preparation of and prior to the onset of the next trial. In contrast, the influence of one important exogenous factor is reflected in the crosstalk effects. The general slowing on the bivalent trials (those that contain congruent and incongruent stimuli) relative to the univalent (neutral) trials reflects the fact that competition for task execution occurs once the stimulus has been presented. Such competition does not arise when only a single task-relevant character is presented. Critically, the results indicate that the crosstalk effects are reduced under predictable non-switch cases - so when participants know that the same task is to be repeated, crosstalk is reduced relative to cases where, a) they have to switch tasks or where, b) they do not know which task to perform. This is a quite different effect to switch preparation in which reduced switch costs arise because of speeding on switch trials and reflects instead task priming on repetition trials.

To add further support for the claim that the effects have been carried on the non-switch trials with participants performing best on predictable non-switch trials, a further analysis of the RT data was undertaken. Now, the average of the mean RTs on the congruent and incongruent trials was computed and the mean RT on neutral trials was subtracted to give a difference score. Difference scores were computed on a participant-by-participant basis. These scores are assumed to reflect the amount of interference caused by the presence of two task-relevant characters relative to the case when only one such character is present. These difference scores were now entered into a split-plot ANOVA in which RSI (as before) was entered as the between-participants factor and the within participants factors were predictability (predictable vs. unpredictable) and trial transition (switch vs. non-switch).

This analysis revealed that the main effect of trial transition [$F(1, 33) = 36.64$, $MS_e = 5258$, $p < .001$] was statistically significant. The predictability effect [$F(1, 33) = 3.931$, $MS_e = 6891$, $p = .056$] marginally failed to reach statistical reliability. Finally, the predictability x trial transition interaction [$F(3, 99) = 11.18$, $MS_e = 5739$, $p < .01$], was found to be statistically significant. An HSD test revealed that the smallest difference scores (as described earlier) were present in the data for the predictable non-switch trials (119 ms). Comparisons with all other types of trial were statistically reliable (the mean difference scores were 189, 220 and 235 ms for the unpredictable non-switch, unpredictable switch, and predictable switch cases respectively). No other pair-wise comparison revealed any further statistical differences. What the additional analysis strongly suggests is that the crosstalk was minimal on the predictable non-switch trials. So when participants were aware that they had to maintain the current task-set for the next trial, they were less susceptible to interference from the character linked to the competing task.

2.3 EXPERIMENT 2

Experiment 1 has revealed that the size of the crosstalk effects are modulated by task predictability and as such the data have revealed an interesting interplay between exogenous and endogenous control. In an attempt to examine this in more detail, a second experiment was undertaken in which an additional task cue was presented. Now, the position of the letter and the number were fixed across all trials in a way that participants always knew which character position to process in order to carry out the task. The intention here was that an additional task cue would reduce the size of crosstalk and the aim was to see if such a reduction would be comparable for both the predictable and unpredictable cases.

From Experiment 1, it seems that under unpredictable circumstances irrelevant task information impacts considerably on performance and that filtering out such irrelevant information is more efficient when the appropriate task can be predicted to be repeated. However, from Experiment 1 it is not clear whether the crosstalk effects reflect an early encoding stage of processing or whether the effects arise later at a more central stage. In an attempt to examine this issue, Experiment 2 addresses the claim that the problems arise at an encoding stage of processing. If this is true, then providing an additional cue to character encoding ought to reduce crosstalk. The data ought then to reflect on whether the effects of task predictability also implicate stimulus encoding.

2.3.1 Method

2.3.1.1 Participants

Participants were 36 university students (28 females) with a mean age of 20.8 (3.9 SD) years old. They took part for either course credit or payment. All reported having normal or corrected to normal vision and hearing while two were left-handed.

2.3.1.2 Design and stimuli

Every aspect of the design of Experiment 2 was the same relative to the design of Experiment 1 except for the way the stimuli were configured. Whereas in Experiment 1 the position of the letter and the digit in each character pair was unpredictable, now the letter was always presented on the left and the digit was always on the right.

2.3.2 Results

Error responses, very fast responses (less than 100 ms) and responses that followed an error were excluded from the analysis of the RT data. As a result, 8.5% of scores in total were eliminated prior to data analysis.

2.3.2.1 RTs

As in Experiment 1, the main effects of trial transition [$F(1, 33) = 135.83$, $MS_e = 90431$, $p < .001$], stimulus type [$F(2, 66) = 90.81$, $MS_e = 8536$, $p < .001$], and predictability [$F(1, 33) = 135.83$, $MS_e = 71446$, $p < .001$], were all statistically reliable. The RSI factor failed to produce any statistically significant results. Moreover, four interactions were found to be statistically reliable. Specifically, the trial transition x stimulus type [$F(2, 66) = 18.73$, $MS_e = 3012$, $p < .001$], the predictability x stimulus type [$F(2, 66) = 3.80$, $MS_e = 4707$, $p < .05$], the predictability x trial transition [$F(2, 66) = 6.94$, $MS_e = 10690$, $p < .05$], and the trial transition x RSI [$F(2, 33) = 5.62$, $MS_e = 90431$, $p < .01$], interactions were found to be statistically reliable. In order to examine the trial transition x stimulus type interaction in more detail the switch costs for the three types of trials were entered into a one-way ANOVA in which stimulus type was a fixed factor. The main effect of stimulus type was statistically reliable [$F(2, 70) = 19.09$, $MS_e = 2961$, $p < .001$]. A further HSD test revealed that the switch costs were reliably smaller on neutral trials than congruent and incongruent trials ($p < .05$), but that the switch costs were equivalent on congruent and incongruent trials ($p > .05$). A similar ANOVA was also carried out on the predictability effects (i.e., the difference in mean RT between predictable and unpredictable trials) for the congruent (260 ms), incongruent (251 ms) and neutral trials (217 ms). The main effect of stimulus type was statistically reliable [$F(2, 70) = 3.43$, $MS_e = 4773$, $p < .05$], and the ensuing HSD test revealed that predictability effects were reliably larger on congruent trials when relative to neutral trials ($p < .05$) but not when relative to incongruent trials ($p > .05$). The corresponding mean difference of 33.7 ms between incongruent and neutral trials just failed to surpass the critical value of 39.1 ms.

Finally, in order to examine the trial transition x RSI interaction switch costs (switch – non-switch trials) were calculated and averaged over the congruent, incongruent and neutral trials on a participant-by-participant basis. The resulting scores were subsequently averaged over the predictable and unpredictable cases. The result was a single score for each participant that indicated his overall average switch cost. These scores were then entered into a one-way ANOVA in which RSI was the between participants factor. The main effect of RSI was statistically reliable [$F(2, 33) = 5.62$, $MS_e = 30144$, $p < .01$]. The ensuing HSD test revealed that switch cost (467 ms) for the 250 ms RSI were larger than that of the 1200 ms RSI (233 ms). The switch costs for the 600 ms RSI (312 ms) did not differ significantly from either the 250 ms or the 1200 ms condition.

2.3.2.2 Error rates

Analysis of the error data revealed statistically significant main effects of trial transition [$F(1, 33) = 5.63$, $MS_e = .040$, $p < .05$], and predictability [$F(1, 33) = 41.22$, $MS_e = .026$, $p < .001$]. Participants were generally more inaccurate on switch than non-switch trials and were generally more accurate in the predictable than the unpredictable cases. In addition to these main effects, three interactions, namely, the predictability x RSI [$F(2, 33) = 3.70$, $MS_e = .026$, $p < .05$], the trial transition x RSI [$F(2, 33) = 6.25$, $MS_e = .026$, $p < .05$], and the predictability x stimulus type [$F(2, 66) = 3.94$, $MS_e = .02$, $p < .05$], interaction were all statistically reliable. In addition, several three-way interactions, namely, the predictability x task transition x RSI interaction [$F(2, 33) = 6.52$, $MS_e = .034$, $p < .01$], the predictability x stimulus type x RSI interaction [$F(4, 66) = 3.36$, $MS_e = .02$, $p < .05$], and the task transition x stimulus type x RSI [$F(4, 66) = 3.21$, $MS_e = .03$, $p < .05$], interaction were also statistically reliable. Figure 6 provides a graphical illustration of summary RT and error rate averaged over the RSI factor.

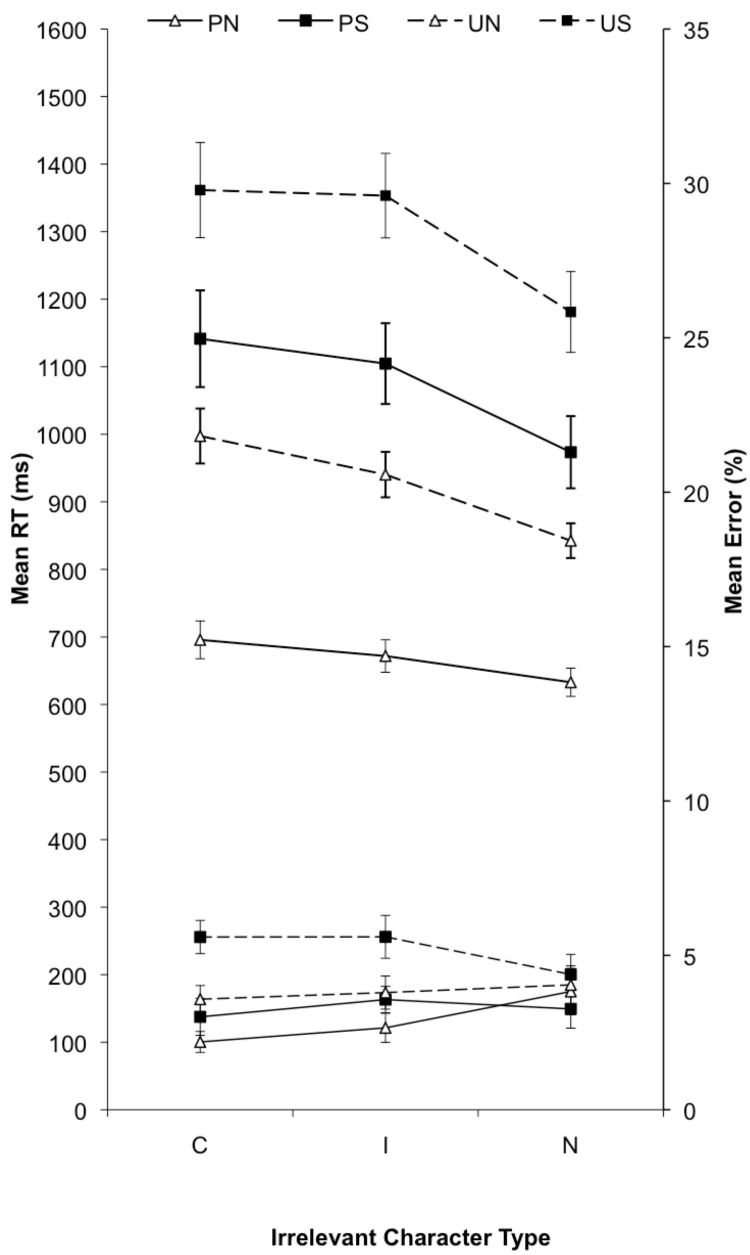


Figure 6: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 2. Means have been averaged over RSI. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials, C = Congruent, I = Incongruent, and N = Neutral.

Generally speaking, the predictability x task transition x RSI interaction reflects the relatively high numbers of errors on predictable switch trials at the 250 ms RSI; the predictability x stimulus type x RSI interaction reflects the relatively low number of errors on the incongruent trials at the 600 ms RSI in the unpredictable switch condition; and finally, the task transition x stimulus type x RSI interaction reflects the relatively high number of errors on the incongruent switch trials at the 250 ms RSI. These error patterns are complex and there is no obvious reason for their presence. Nevertheless, the data as a whole do not reveal any systematic speed/error trade-offs. Figure 7 provides the relevant summary statistics of the error data.

2.3.3 Discussion

The results are generally clear-cut, and, in different places, replicate or contrast with those reported in Experiment 1. In sum, performance was better in the predictable relative to the unpredictable cases - there was evidence of generic preparation. Moreover, switching costs were larger in the predictable than the unpredictable cases and this was mainly due to the good performance on the predictable non-switch trials. The important contrast with the results in Experiment 1 was that now there was no three-way interaction between predictability, trial transition and stimulus type. Specifically, the size of the switching costs varied as a function of stimulus type in a similar way in the data for the predictable and unpredictable conditions - costs were large and equivalent for the congruent and incongruent cases, they were significantly smaller on neutral trials.

Such effects reflect the fact that participants were able to use the position cue to focus attention on the task relevant character in both the predictable and unpredictable cases. Interestingly, fixing the character position across trials impacted the most on performance in the unpredictable cases. This indicates that at least a component of the task predictability effects reflect operations located at the stimulus encoding stage of processing. Moreover, it seems that now that the influence of the exogenous factor was reduced, the effect of endogenous control in the form of advance preparation surfaced. These results contrast with the idea that endogenous and exogenous factors are completely insulated from one another.

	Stimulus Type		
Condition and Trial Transition	Congruent	Incongruent	Neutral
		250 ms RSI	
Predictable			
Non-Trial transition	1.7	1.8	2.5
Trial transition	3.4	6.9	3.8
Unpredictable			
Non-Trial transition	3.1	2.7	4.6
Trial transition	4.0	6.0	4.7
		600 ms RSI	
Predictable			
Non-Trial transition	1.3	2.2	3.5
Trial transition	2.5	1.8	3.7
Unpredictable			
Non-Trial transition	3.5	4.5	3.7
Trial transition	6.3	4.8	6.4
		1200 ms RSI	
Predictable			
Non-Trial transition	3.5	3.9	5.5
Trial transition	3.1	2.0	2.3
Unpredictable			
Non-Trial transition	4.2	4.2	3.8
Trial transition	6.3	6.0	2.1

Figure 7: Mean percentage error rates for the conditions of interest in Experiment 2.

2.4 EXPERIMENT 3

The data reported in Experiment 2 clearly reveal that the crosstalk effects are affected by the positional uncertainty of characters - the effects are reduced when participants know which character position to attend to. Further support for such a link would be forthcoming if the previous modulation of crosstalk by task predictability could be reinstated by the reintroduction of positional uncertainty of the characters. Part of the rationale for Experiment 3 was just this - an attempted replication of the original three-way interaction found in Experiment 1 under different testing conditions.

However, in order to both replicate and generalize the findings, changes to the basic paradigm were introduced. Now, on every trial, the stimulus pair was presented centrally at fixation and the color of the characters signaled the task to be performed. Both changes bring the paradigm more in line with that employed in the experiments of Sohn and Anderson (2001). The next experiment therefore, allows for further comparison with the findings reported by Sohn and Anderson (2001).

2.4.1 Method

2.4.1.1 Participants

Participants were 36 university students (30 females) with a mean age of 20.7 (3.1 SD) years old and took part on this experiment for either course credit or payment. They all reported having normal or corrected to normal vision and hearing: Seven were left-handed.

2.4.1.2 Design and stimuli

Almost every aspect of the design of Experiment 3 was the same to the design of Experiment 1. The significant differences relate to the manner in which the stimuli were presented and means by which the tasks were cued. Now on each trial, the character pair was presented centrally on the screen and participants were instructed to classify the digit when the character pair was presented in green and the letter when the character pair was in red. As in Experiment 1, the position of the letter and digit within the pairs was now unpredictable. Moreover, three separate RSI conditions (i.e., 250 ms, 600 ms and 1200 ms) were run with separate groups of participants.

2.4.2 Results

Data analysis was the same as before. In total, 9.2% of scores were excluded prior to data analysis.

2.4.2.1 RTs

Statistically significant main effects of trial transition [$F(1, 33) = 121.05$, $MS_e = 85829$, $p < .001$], stimulus type [$F(2, 66) = 213.54$, $MS_e = 10046$, $p < .001$], and predictability [$F(1, 33) = 100.85$, $MS_e = 41180$, $p < .001$], were found. The statistically significant main effects though were modulated by various statistically reliable interactions.

Statistically significant interactions between predictability x task transition [$F(2, 33) = 14.90$, $MS_e = 21117$, $p < .01$], trial transition x stimulus type [$F(2, 66) = 3.68$, $MS_e = 3900$, $p < .05$], and between predictability x stimulus type [$F(2, 66) = 11.29$, $MS_e = 5066$, $p < .001$], were found. The trial transition x RSI interaction revealed a trend towards statistical significance [$F(2, 33) = 2.89$, $MS_e = 85829$, $p = .07$], that resembled closely the RSI effect of Experiment 2. The average 250 ms RSI switch costs (385 ms) were overall larger than the 600 ms (325 ms) and 1200 ms (221 ms) RSIs respectively.

Two three-way interactions are also noted; the predictability x stimulus type x RSI interaction just failed to reach statistical reliability [$F(4, 66) = 2.51$, $MS_e = 5066$, $p = .05$]. Whereas the predictability x trial transition x stimulus type interaction was found to be statistically reliable [$F(2, 66) = 15.66$, $MS_e = 3338$, $p < .001$].

Taking the latter first, this interaction was examined via the size of the predictability effects (i.e., the mean difference between RTs on predictable and unpredictable trials) for the different stimulus types for the three different RSIs. As with the data in Experiment 1, the general trend was for the size of the predictability effects to be larger on congruent and incongruent trials than neutral trials. This trend was repeated here for the 250 ms and 1200 ms RSI groups but not for the 600 ms

RSI group. The size of the predictability effect of the 600 ms RSI group was of the same size for all three trial types. There is no obvious reason for this finding and is difficult to interpret as the effects, such as they are, did not scale with RSI.

In order to examine the predictability x task transition x stimulus type interaction in more detail, the data for predictable and unpredictable cases were analysed separately.

2.4.2.1.a Predictable trials

Both the main effects of trial transition [$F(1, 35) = 96.05$, $MS_e = 74545$, $p < .001$], and stimulus type [$F(2, 70) = 140.76$, $MS_e = 5341$, $p < .001$], were statistically reliable as was the tria transition x stimulus type [$F(2, 70) = 16.28$, $MS_e = 3517$, $p < .001$], interaction.

To understand the nature of this interaction further, the switch costs for the three stimulus types were entered into a one-way within participants ANOVA in which stimulus type was the factor of interest. The main effect of stimulus type was statistically reliable [$F(2, 70) = 16.28$, $MS_e = 7033$, $p < .001$]. An ensuing HSD test revealed that as in Experiment 1 the resulting switch costs were equivalent on the congruent and incongruent trials, $p > .05$) but these costs were larger than that on neutral trials (both comparisons, $p < .05$).

2.4.2.1.b Unpredictable trials

On unpredictable trials only the main effects of trial transition [$F(1, 35) = 85.19$, $MS_e = 41602$, $p < .001$], and stimulus type [$F\ (2, 70) = 142.22$, $MS_e = 10199$, $p < .001$], were statistically significant. As before therefore, switch costs were additive with stimulus type.

Figure 8 provides a graphical summary of the RT and error rate data of the conditions of interest in Experiment 3.

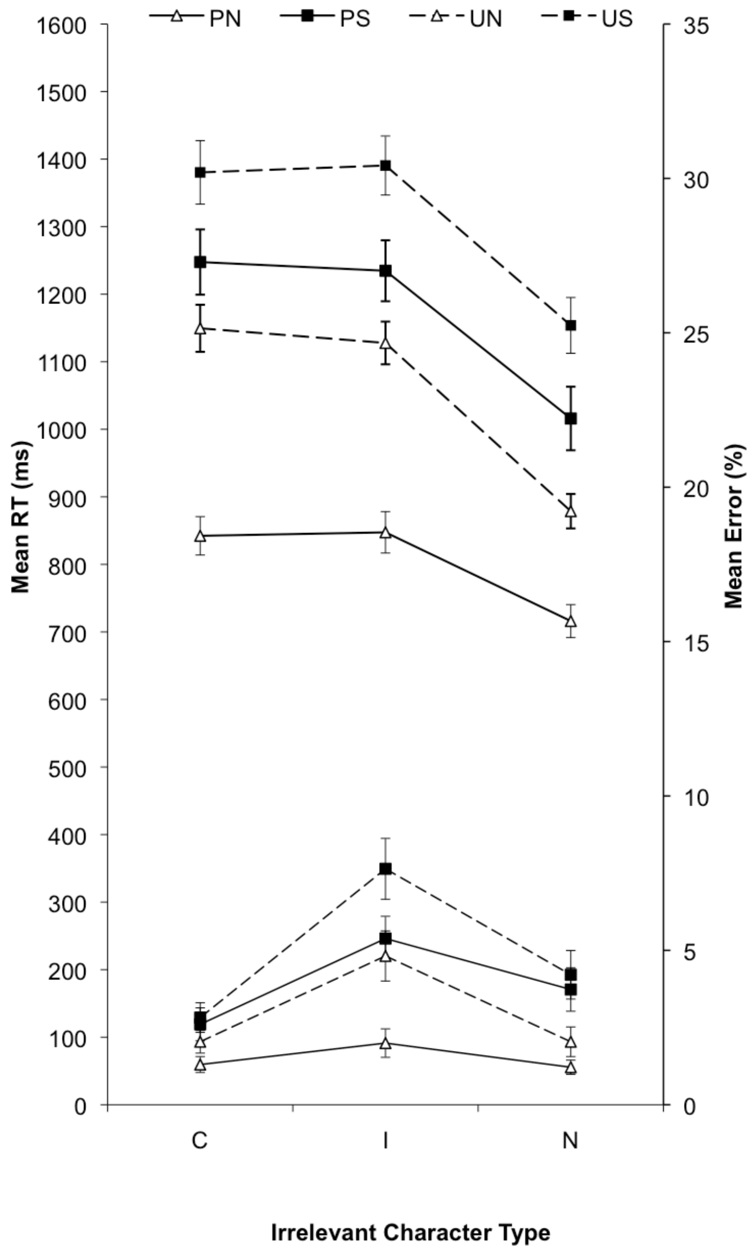


Figure 8: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 3. Means have been averaged over RSI. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials, C = Congruent, I = Incongruent, and N = Neutral.

2.4.2.2 Error rates

The main effects of trial transition [$F(1, 33) = 29.71$, $MS_e = .059$, $p < .01$], congruency [$F(2, 66) = 22.96$, $MS_e = .04$, $p < .001$], and predictability [$F(1, 33) = 9.82$, $MS_e = .061$, $p < .001$], were all statistically reliable. Similarly to the RT analyses, there were no statistically significant effects associated with RSI factor. Only the trial transition x stimulus type [$F(2, 66) = 5.56$, $MS_e = .028$, $p < .01$], was found to be statistically significant.

In order to examine this interaction in more detail simple main effects analyses were carried out. These revealed statistically significant crosstalk effects in both the data for the non-switch [$F(2, 66) = 6.16$, $MS_e = .04$, $p < .01$] and the switch trials [$F(2, 66) = 28.32$, $MS_e = .03$, $p < .001$]. However, the interaction reflected the relatively high number of errors committed on incongruent switch trials. As before, a congruency effect has been revealed in accuracy but not the RT data. Overall though, the data however do not reveal any systematic speed/error trade-offs.

2.4.3 Discussion

Perhaps the most salient aspect of the results is the very high degree of concordance with those reported in Experiment 1. In all major respects, the basic findings have been replicated. The same patterns of predictability effects and crosstalk effects were found as those in Experiment 1. Most interesting perhaps, is that the original three-way interaction between predictability, trial transition and stimulus type was reinstated.

As before, switching costs were additive with variations in stimulus type in the data for the unpredictable cases. In contrast, switching costs varied as a function of stimulus type for the data from the predictable condition. This is exactly the same pattern of performance as reported in Experiment 1 and provides further support for the idea that the crosstalk effects are modulated by task predictability. When the task is predictable and it is to be repeated participants find it relatively easy to filter out irrelevant stimulus information.

Although there are some correspondences with the findings reported by Sohn and Anderson (2001) – smaller switch costs for the unpredictable vs. predictable cases – the marginal failure to find effects of RSI underscored the failure to find their predicted higher order interaction between task predictability, RSI and task switching. As noted previously, Altman (2004b) has discussed that any effects of RSI are most likely to occur in cases where participants experience a range of delays within a given experiment. As RSI was manipulated across participants here, then it is perhaps not so surprising that such effects have not be found here.

2.5 EXPERIMENT 4

So far, the results provide clear indications of something that has been called character competition. An implication is that once the stimulus has been presented an immediate concern is to resolve which character to respond to. It has been assumed that fluctuations in this form of competition have been responsible for the changes in switching costs across the different testing conditions.

In order to examine further this idea Experiment 4 was carried out. Now on some trials a single (univalent) character was presented. On these trials, the task is unambiguous and there can be no competition from an irrelevant character. In this regard, performance on the univalent trials provides a useful baseline against which to compare performance on the other types of trials.

Moreover, there is an important sense in which performance on the univalent trials provides a window on performance when only endogenous factors are at play. In the current context, the influence of exogenous factors has been gauged relative to the various congruency effects that have been reported. Given that only one character is presented on univalent trials then it can be assumed that these trials should reveal most directly the operation of endogenous factors.

2.5.1 Method

2.5.1.1 Participants

Participants were 24 university students (19 females) with a mean age of 21.9 (5.8 SD) years old. They took part on this experiment for either course credit or payment. They all reported having normal or corrected to normal vision and hearing. Four were left-handed.

2.5.1.2 Design and stimuli

The design of Experiment 4 mirrored that of Experiment 3 very closely. Every aspect of the design of Experiment 4 was the same to the design of Experiment 3 except univalent trials were added (e.g., '3', 'A', 'G') alongside congruent, incongruent and neutral trials.

A further change was that, as it has been impossible to find any clear and systematic effects of RSI across the experiments, only one RSI (i.e., 250 ms) was tested. Consequently, the design reduced to a completely within-participants design.

The experimental trials were configured around four sequences; two sequences for the predictable condition and two for the unpredictable condition. Each sequence consisted of four blocks and each block comprised 48 trials. Within a block the balancing was such that there were equal numbers of switch and non-switch trials (24 each), equal numbers of congruent, incongruent, neutral and univalent trials (12 each), equal numbers of letter and digit trials (24 each), and finally equal numbers of left (consonant/even) and right (vowel/odd) key presses (24 each).

2.5.2 Results

Error responses, very fast responses (less than 100 ms) and responses that followed an error response were excluded from the analysis of the RT data. As a result, 9.5% of scores were excluded from the analyses.

To maintain coherence with the previous experiments RTs and transformed errors were analysed initially with ANOVAs in which predictability (predictable vs. unpredictable trials) and trial transition (switch vs. non-switch) and congruency (congruent, incongruent, and neutral stimuli – univalent stimuli were excluded) were entered as fixed factors. Supplementary analyses were then carried out with the data from univalent trials.

2.5.2.1 RTs

Analysis revealed statistically significant main effects for predictability [$F(1, 23) = 39.14$, $MS_e = 70407$, $p < .001$], trial transition [$F(1, 23) = 152.39$, $MS_e = 59877$], and stimulus type [$F(2, 46) = 147.67$, $MS_e = 16969$, $p < .001$]. In addition, the interactions between predictability x trial transition [$F(1, 23) = 34.91$, $MS_e = 13287$, $p < .001$], predictability x congruency [$F(2, 46) = 19.54$, $MS_e = 4550$, $p < .001$], trial transition x stimulus type [$F(2, 46) = 3.69$, $MS_e = 8838$, $p < .05$], and predictability x trial transition x stimulus type [$F(2, 46) = 5.04$, $MS_e = 6568$, $p < .05$] all yielded statistically significant results. In order to examine this three-way interaction in more detail the data for predictable and unpredictable cases were analysed separately.

A graphical summary of the RTs and error rates in all conditions is provided in Figure 9.

2.5.2.1.a Predictable trials

Analysis of the predictable trial data revealed statistically significant main effects of trial transition [$F(1, 23) = 188.91$, $MS_e = 36268$, $p < .001$], and stimulus type [$F(2, 46) = 110.05$, $MS_e = 7513$, $p < .001$]. Moreover, the trial transition x stimulus type interaction [$F(2, 46) = 25.95$, $MS_e = 4961$, $p < .01$], was also statistically reliable.

In order to specify the source of this interaction, the switch costs for the different cases (i.e., congruent, incongruent and neutral trials) were entered into a one-way ANOVA. The main effect of stimulus type was statistically reliable [$F(2, 70) = 8.30$, $MS_e = 9922$, $p < .01$].

An ensuing HSD test revealed that the resulting switch costs were equivalent on the congruent and incongruent trials ($p > .05$) but these costs were larger than the cost on neutral trials, ($p < .05$, both comparisons). As before, this pattern is essentially due to the relatively good performance on the congruent and incongruent non-switch trials in the predictable condition.

2.5.2.1.b Unpredictable trials

On unpredictable trials only the main effects of trial transition [$F(1, 23) = 74.18$, $MS_e = 36896$], and stimulus type [$F(2, 46) = 126.23$, $MS_e = 14006$], were statistically significant.

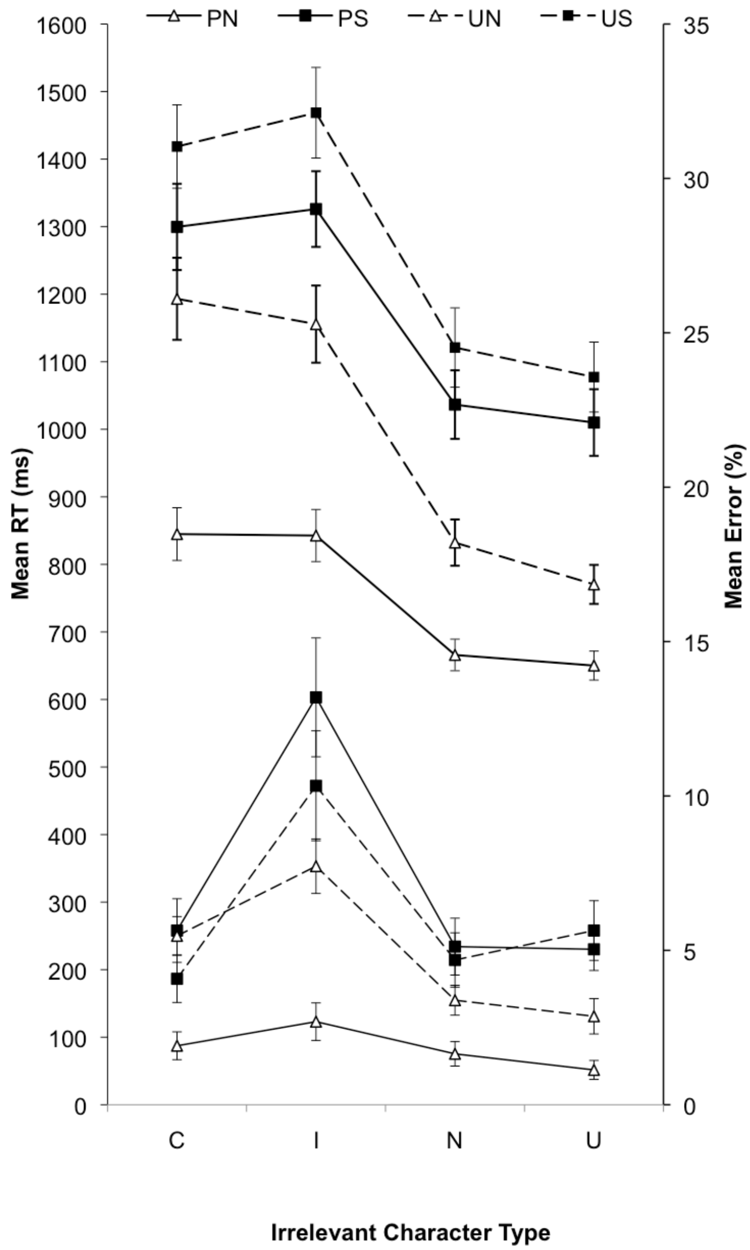


Figure 9: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 4. Means have been averaged over RSI. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials, C = Congruent, I = Incongruent, N = Neutral, and U = Univalent.

2.5.2.2 Error rates

Accuracy on non-switch trials was enhanced, relative to switch trials as revealed by a statistical main effect of trial transition [$F(1, 23) = 28.10$, $MS_e = .054$, $p < .001$]. The main effects of stimulus type [$F(2, 46) = 23.30$, $MS_e = .047$, $p < .001$] and predictability [$F(1, 23) = 12.43$, $MS_e = .037$, $p < .01$] were also statistically reliable. Several further interactions were also statistically significant [$F(1, 23) = 60.11$, $MS_e = .028$, $p < .001$] for the predictability x trial transition interaction, [$F(2, 46) = 8.87$, $MS_e = .024$, $p < .01$] for the trial transition x stimulus type interaction, and, [$F(2, 46) = 4.16$, $MS_e = .019$, $p < .05$] for the three-way interaction predictability x trial transition x stimulus type. Inspection of these data reveals relatively inaccurate responding on non-switch trials in the unpredictable condition. There is no obvious reason for this pattern, but there are also no signs of any systematic speed/error trade-offs in the data. However, in various cases (e.g., unpredictable incongruent trial-transition trials) a high percentage of excluded trials occurred (e.g., 16.9 %). In order to ensure that the current analysis is not affected by the high percentage of exclusion of trials an additional analysis was carried out. This analysis was performed without the exclusion of the outliers trials as described on the beginning of the results section. This analysis replicated the results described so far on this section without any marked deviations from the original findings.

2.5.3 Comparisons Involving the Univalent Stimuli

Analyses were carried out on the data from the neutral and univalent trials. Here, the repeated-measures ANOVA comprised the fixed factors stimulus type (neutral vs. univalent), predictability (as before) and trial transition (as before). Analysis of the RTs revealed that the main effects of trial transition [$F(1, 23) = 124.18$, $MS_e = 42{,}492$, $p < .001$], predictability [$F(1, 23) = 23.54$, $MS_e = 24497$, $p < .001$], and stimulus type [$F(1, 23) = 19.39$, $MS_e = 3385$, $p < .001$] were all statistically significant. In addition, the predictability x trial transition interaction [$F(1, 23) = 7.74$, $MS_e = 7028$, $p < .05$], was also found to be statistically significant. The predictability x stimulus type interaction just failed to reach statistical significant [$F(1, 23) = 3.56$, $MS_e = 3376$, $p = .07$]. As Figure 9 shows, the predictability x trial transition interaction reflects the fact that the switch costs were greater in the data for the predictable than the unpredictable condition. The trend towards significance in the predictability x stimulus type interaction reflects the fact that the slowing on neutral trials was numerically greater on unpredictable trials than it was on predictable trials.

This pattern is in line with the general slowing on unpredictable trials relative to predictable trials. Analysis of the errors revealed that the main effects of trial transition [$F(1, 23) = 52.06$, $MS_e = .027$, $p < .001$], and predictability [$F(1, 23) = 8.13$, $MS_e = .028$, $p < .01$], were statistically reliable as were the predictability x trial transition interaction [$F(1, 23) = 9.80$, $MS_e = .028$, $p < .01$], and the trial transition x stimulus type interaction [$F(1, 23) = 5.89$, $MS_e = .020$, $p < .05$]. The predictability x trial transition interaction reflects the fact that participants showed a larger difference in accuracy on predictable than unpredictable trials. The trial transition x stimulus type interaction reflects the fact that the difference in accuracy was greater on univalent trials than it was on neutral trials. Participants tended to be relatively inaccurate when switching into a univalent trial. Nevertheless, the data do not reveal any systematic speed/error trade-offs.

2.5.4 Discussion

Yet again, the three-way interaction between predictability, trial transition and congruency was found when the data from those trials that contained two character displays were analyzed. Switch costs were additive with stimulus type in the data for the unpredictable condition and switch costs varied as a function of stimulus type in the data for the predictable condition.

Previously this pattern of performance has been explained in terms of differential effects of character competition under predictable and unpredictable conditions. The strength of the competition has been gauged relative to cases in which two character displays were presented but only one of the characters was a task relevant character.

Additional evidence in favour of this view is now present in the data from this experiment. Although there was a cost associated on responses where two characters relative to when just a single character was presented, the size of this cost was minimal relative to the size of the competition effects. Participants were slower and less accurate to respond when confronted with displays containing two characters but further systematic costs obtained when two task relevant characters were present in the displays.

Finally, performance on the univalent trials is particularly revealing. Generally speaking, fastest RTs occurred on univalent trials and this suggests that whenever there were two characters presented on a trial there was a cost in performance relative to when only a single character was presented. Such an additional cost clearly reflects operations concerned with stimulus encoding and establishing which the task relevant character is.

Aside from such costs though, performance on the univalent trials clearly reveal the standard predictability and task switching effects. RTs were generally longer in the unpredictable than the predictable trials. Furthermore, RTs were longer on switch than on non-switch trials. Such observations were confirmed when the data from univalent trials were analyzed in a two-way within participants ANOVA in which the predictability and trial transition factors were defined as before. Now, both the main effects of predictability [$F(1, 23) = 17.06$, $MS_e = 12370$, $p < .001$], and trial transition [$F(1, 23) = 122.58$, $MS_e = 21764$, $p < .001$], were statistically reliable.

The predictability x trial transition interaction only revealed as a trend towards statistical reliability [$F(1, 23) = 3.18$, $MS_e = 5276$, $p =. 088$]. It has been assumed that performance on the univalent trials provides something of a window on endogenous processes uncontaminated by exogenous factors.

As a consequence, the data provide good grounds for arguing that, to large measure, the basic predictability effects and task switching costs reflect endogenous factors. This assumption will be examined further in the last experiment of the chapter where predictability will be manipulated on relatively different grounds relative to the previous experiments.

2.6 EXPERIMENT 5

So far, the experiments have been primarily focused on the interplay of task predictability (as an indicator of endogenous processes) and crosstalk (as an indicator of exogenous processes). Nevertheless, in the literature there are experiments that manipulate predictability also in other ways rather than comparing a predictable order to a completely random order of stimulus presentation.
It would be very interesting to examine whether or not these experiments address the effects discussed so far. An alternative way of addressing the notion of

predictability arises when considering Altmann's (2007) discussion of the explicit cuing paradigm. As has already been discussed it seems quite possible that it would be a mistake to consider performance in explicit cuing experiments as informative as performance under unpredictable conditions. The reason is that once the cue has been presented the participant knows with certainty what the next task will be. In this regard, it seems possible that the presentation of the cue materially affects task performance in ways different to what happens when participants operate in strictly unpredictable conditions. To pursue such ideas it is possible to examine whether explicit cuing results in generic preparation, switch preparation or both. In particular, it may be asked whether explicit cuing impacts on crosstalk in a similar fashion to that found here under predictable conditions (see Experiments 1 and 3 here).

One relevant study is that reported by Tornay and Milán (2001). They examined performance in both predictable and random conditions. In their first experiment, in the predictable conditions standard alternating runs sequences were used (e.g., AABBAA…). In the random conditions, the order of the tasks was randomized. In both predictable and random conditions prior to each trial, a character cue signaled the upcoming task. Two RSIs were compared and it was found that as the delay increased from 200 ms to 2100 ms switch costs decreased. The striking finding though was that the switch cost was abolished in the data for the random condition at the longer RSI. There was clear evidence of switch preparation in the random condition but no evidence of generic preparation in the predictable condition. However, it is a little difficult to be clear about what these data are revealing because the predictable/random difference is confounded by whether or not an explicit trial cue was presented.

In the final experiment of the chapter therefore, this confound was removed and performance was tested in two different random conditions. In the first no cue condition, the paradigm was the same used before in the unpredictable condition (see Experiment 3) - the color of the character pair indicated the task to be performed. In the second cued condition, the color of the fixation cross presented prior to the character pair indicated the task to be performed. The primary aim is to examine the sorts of preparatory processes that are invoked by the explicit cue. From the example of Tornay and Milán (2001), evidence of switch preparation in the cued conditions should be expected. Whether generic preparation takes place in the cued conditions remains to be seen.

2.6.1 Method

2.6.1.1 Participants

Participants were 36 university students (32 females) with a mean age of 20.2 (2.4 SD) years old. They took part for either course credit or payment. All reported having normal or corrected to normal vision and hearing and only one was left-handed.

2.6.1.2 Design and stimuli

The basic design of the experiment follows closely with that used in Experiment 3. In fact, the no precue (from now and onwards uncued condition) condition was simply a replication of the unpredictable condition tested in Experiment 3. The precued condition (from now and onwards cued condition) was again based closely on the unpredictable condition but the only difference was that the fixation cross that was presented during the RSI had the color of the upcoming task.Similarly to the previous experiments, the fixation cross appeared immediately after the participant's response and stayed until the onset of the following trial. A single RSI of 1200 ms was used in both conditions. The most salient differences in performance between the predictable and random cases discussed by Tornay and Milán (2001) were found at this RSI. The order of the conditions was balanced across the participants.

2.6.2 Results

Following data screening, a total of 14.2% of scores were eliminated prior to data analysis.

2.6.2.1 RTs

In the analysis, the trial transition and stimulus type factors were the same as before, however the predictability factor was replaced by a cuing factor (cued vs. uncued). The main effects of cuing [$F(1, 35) = 74.62$, $MS_e = 68831$, $p < .001$], trial transition [$F(1, 35) = 101.84$, $MS_e = 40927$, $p < .001$], and stimulus type [$F(2, 70) = 109.21$, $MS_e = 24052$, $p < .001$], were all statistically reliable. Moreover, the cuing x trial transition interaction [$F(1, 35) = 10.83$, $MS_e = 9429$, $p < .01$], the cuing x stimulus type interaction [$F(2, 70) = 14.04$, $MS_e = 6407$, $p < .001$], and the trial transition x stimulus type interaction [$F(2, 70) = 3.64$, $MS_e = 6312$, $p < .05$], were also found to be statistically significant. Notably, the cuing x trial transition x stimulus type interaction failed to reach statistical significance [$F(2, 70) = 2.80$, $MS_e = 6871$, $p > .05$].

The cuing x trial transition interaction revealed that the switch costs were on average larger in the uncued condition than the cued condition. In an attempt to analyze switch costs in the absence of crosstalk, only the data from neutral trials were considered further. As before, switch costs were computed on a participant-by-participant basis for the neutral trials separately from the cued and uncued conditions. These costs were then analyzed with a paired t-test. The results showed that the switch costs were statistically larger in the uncued (237 ms) than the cued condition (136 ms; $t(35) = 3.64$, $p = .001$, two-tailed test).

In order to examine the cuing x stimulus type interaction in more detail, crosstalk effects were computed as before for each participant, for the cued and uncued conditions, separately. These difference scores were then entered into a paired t-test. The test revealed that the size of crosstalk in the cued condition was statistically smaller (194 ms) than that in the uncued condition (273 ms, $t(35) = 5.25$, $p < .001$, two-tailed test). See Figure 10 for a graphical illustration of the RTs and error rates for the conditions of interest.

Finally, the trial transition x stimulus type interaction was decomposed using an HSD test. The only comparison to reach statistical significance was that between the means of the congruent and incongruent stimuli ($p <. 05$). The overall averaged switch costs were 178 ms, 225 ms and 186 ms in the data for the congruent, incongruent and neutral trials, respectively.

Further inspection of the data revealed that the interaction arose because of relatively short RTs on incongruent non-switch trials rather than corresponding long RTs on incongruent switch trials. There is no obvious reason for this particular pattern of responding.

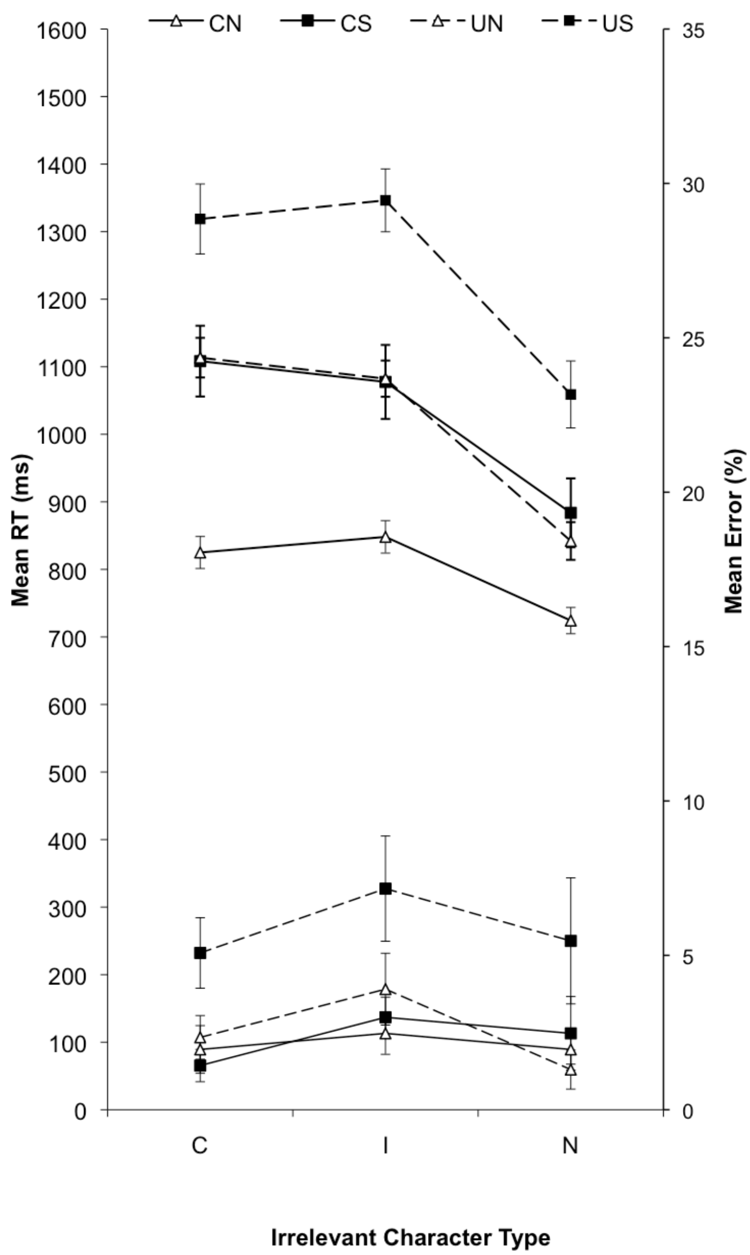


Figure 10. Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 5. Error bars represent the standard error of the mean (SE). CN = Cued Non-switch trials, CS = Cued Switch trials, UN = Uncued Non-switch trials, US = Uncued Switch trials, C = Congruent, I = Incongruent, and N = Neutral.

2.6.2.2 Error rates

Analysis of the error data revealed that the main effects of cuing [$F(1, 35) = 13.25$, $MS_e = .034$, $p < .01$], trial transition [$F(1, 35) = 35.15$, $MS_e = .06$, $p < .001$], and stimulus type [$F(2, 70) = 14.91$, $MS_e = .042$, $p < .001$], were all statistically reliable. Participants were generally, a) more accurate in the cued than the uncued cases, b) more inaccurate on switch than non-switch trials, and c) tended to make more errors on incongruent than congruent or neutral trials.

In addition to these main effects, the cuing x trial transition interaction [$F(1, 35) = 4.99$, $MS_e = .035$, $p < .05$] was statistically reliable. More errors were committed on switch trials in the uncued condition than in all other cases. Generally speaking, the data as a whole do not reveal any systematic speed/error trade-offs.

2.6.3 Discussion

There are two main results of interest. First, there is evidence of generic preparation in the data for the cued condition relative to the uncued condition. The data clearly show that participants are able to affect some preparatory processes on the basis of having identified the task precue. Responses were overall faster on cued vs. uncued trials and the benefits were equivalent for both switch and repeat responses. Second, the crosstalk effects were smaller in the cued than the uncued condition. The benefits were equivalent on both switch and non-switch trials. This pattern contrasts with the previous findings reported in Experiment 1 and 3 in which the reduction in crosstalk was more pronounced on non-switch than switch trials and will be discussed in more detail in the General Discussion.

Aside from these positive findings, the data failed to reveal any clear evidence of switch preparation: Switch costs were equivalent in the cued and uncued conditions. In the data reported by Tornay and Milán (2001) switch costs in the long RSI (1200 ms) case were abolished for their random (explicit cue) condition. In the present data, robust switch costs were present. The reasons for this difference are not clear but may reflect the fact that whereas participants experienced more than one RSI in the Tornay and Milán (2001) experiment in the present case participants experienced only one (cf. Altmann, 2004b). It is also useful to note here, that Monsell et al. (2003) failed to replicate Tornay and Milán (2001) and found equivalent switch costs under alternating runs and explicitly cued conditions.

In sum, the data clearly demonstrate that participants performed differently under the cued and uncued conditions. This in turn indicates that caution is warranted in comparing explicit cuing with predictable runs merely because one is random and one is predictable (Altmann, 2007; Monsell et al., 2003; Tornay & Milán, 2001).

2.7 GENERAL DISCUSSION

Across the five experiments reported here, a number of endogenous and exogenous factors that determine performance in simple task switching paradigms have been examined in some detail. A general issue has been with how task predictability affects performance and it seems that task foreknowledge has pervasive effects. Traditionally, these have been located at the level of executive mechanisms responsible for the control of the competing task-sets, but the present evidence suggests that even the early stimulus encoding stages of processing are sensitive to task foreknowledge.

2.7.1 Task predictability in Experiments 1 - 4

In the first four experiments, task predictability was examined by comparing alternating runs with random trials. Generally, participants performed better under predictable than unpredictable conditions. There was evidence of generic preparation: Participants were in general faster and more accurate in their responding under predictable than unpredictable conditions. However, despite the overall benefits in performance in the predictable conditions, switching costs were smaller in unpredictable than predictable conditions.

Critically, the variations in switching costs found here are generally attributable to performance on non-switch rather than switch trials. Participants were facilitated the most when responding in cases where task repetition was predicted. The data do not reflect any selective evidence of switch preparation in the predictable conditions. On the contrary, the data only reflect the presence of task priming. It is this priming that is responsible for the generally larger switch costs in the predictable than the unpredictable conditions. What this strongly suggests is that immediately prior to a predictable non-switch trial the previous task-set is maintained and is primed in WM (cf. Sohn & Anderson, 2001). The only uncertainty in this case is with respect to which particular stimulus-response set mapping will be needed. Other operations concerning the alternative task-set are not needed and indeed may be suppressed.

2.7.2 Crosstalk Effects in Experiments 1 - 4

Aligned to this general pattern are the particular findings regarding crosstalk. It was established in Experiment 1 that when the next task was predictable the size of the crosstalk effect was reduced relative to when the task was unpredictable. Again, this effect was carried on performance on non-switch trials. Even under these conditions however, crosstalk was not completely abolished.

One way of thinking about this, is whenever a task relevant character is presented it automatically invokes its associated task-set. Response slowing on bivalent as relative to univalent trials then directly reflects the sort of task-set interference that Monsell et al. (2003) discussed. However, the locus of such effects was not clear from Experiment 1 and in order to see whether they reflect early encoding or later stages of processing Experiment 2 was carried out. In Experiment 2 participants knew the lateral position of each task character, as this was kept constant across trials. Now crosstalk effects were generally reduced and from this it was concluded that the reduction in crosstalk seen in Experiment 1 reflected early encoding processes common to all trials. Further support for this claim is provided in the data from Experiment 3. Now the character pairs were always presented at fixation, but the position of the letter and the number varied at random over trials. As a consequence, the original three-way interaction between the predictability, trial transition and stimulus type was reinstated. Performance was facilitated the most on predictable non-switch trials.

What this overall pattern suggests is that the size of the crosstalk effects is primarily determined by how easy it is to recover the mapping between the task relevant character and its appropriate task-set. Fixing the position of the task relevant characters reduced crosstalk (in Experiment 2), but additional benefits have also been shown on predictable non-switch trials (in Experiments 1 and 3). Experiment 4 revealed that there were critical differences in performance between univalent and bivalent stimuli even if one of the attributes on the bivalent stimuli is not related to any task. When univalent trials were relative to bivalent neutral trials performance was found to be slower on the latter. Such a cost reflects clearly that additional operations take place when two characters are presented relative to when a single character is presented. These operations clearly reflect stimulus encoding processes that aim to establish which is the relevant (to a trial) character.

Critically, what the present experiments have revealed is that crosstalk effects are modulated by both exogenous visual encoding processes and endogenous preparatory processes. In this regard, it appears that task foreknowledge operates to enhance the activation of the appropriate task-set in WM. If the appropriate task relevant character is easy to identify and the participant knows that the task is to be repeated then crosstalk is minimised.

An issue now is whether such an enhancement in activation is due to boosting the activation of the appropriate task, suppressing the activation of the irrelevant task or some combination of excitation and suppression. The present data cannot settle this issue. It is interesting to note that the model espoused by Sohn and Anderson (2001) contains no inhibitory mechanisms, and this may be an oversight given other evidence for task suppression (see e.g., Karayandis, et al., 2009; and Monsell, Yeung, & Azima, 2000).

2.7.3 Task Preparation and Crosstalk in Experiment 5

In Experiment 5, task predictability was examined in a different way. Now performance was examined with uncued random trial sequences (as in Experiment 3) but in the predictable condition, a task precue preceded each trial while the order of trials was random. Relative to the uncued cases there was clear evidence of generic preparation with speeding on both switch and non-switch trials. There was also clear evidence that crosstalk was smaller in the cued than the uncued condition. However, the nature of the reduction in the crosstalk effects was unlike that shown in the predictable cases in Experiments 1 and 4. Whereas previously reduced crosstalk was shown only on non-switch trials, in Experiment 5 crosstalk was reduced on both switch and non-switch trials. What this suggests is that reduction in crosstalk reflected a selective and transitory increase in the priming of the cued task-set regardless of whether or not the task was repeated. Such task priming resulted in a reduction in interference from the competing task-set. This shows that an explicit task cue can produce selective and automatic effects of task priming and that these are quite different from the kind of task priming shown under the standard alternating runs cases.

2.7.4 Congruency Effects

It has been carefully pointed out that differences between crosstalk and congruency exist. Indeed, it is important to note that whereas crosstalk effects have been repeatedly found in the RT data in all the experiments, congruency effects have been most evident in the accuracy not RT data. Generally speaking, participants were least accurate on incongruent switch trials. On the basis of this evidence, it is tempting to locate crosstalk and congruency effects at different loci in the processing system. Here, a case has been built for locating the crosstalk effects at an early encoding stage of processing. Given that the congruency effects are primarily in the accuracy data then it seems appropriate to locate these at a later decisional/response stage of processing.

There are now several models of task switching that address congruency effects (Altmann & Gray, 2008; Brown, Reynolds, & Braver, 2007; Gilbert & Shallice, 2002; Meiran, 2000). A challenge presented by the current data is how best to model the very clear differences between crosstalk and congruency effects. The data strongly suggest that these effects can reflect different mechanisms concerning processes of encoding and more central decisional/response processes, respectively. It is therefore a mistake to attempt to model both kinds of effects with identical mechanisms.

It is, however, important to draw a distinction between the kind of bivalent stimuli used in the present experiments and others that have been used in related research. Here, each stimulus comprised a letter and a digit each of which unambiguously signal a different task. However, Monsell et al. (2003) used single digits as bivalent stimuli. Task A was an odd/even task – classify the digit as odd or even - and Task B was a high/low task – classify the digit as greater or less than 5. In using these kinds of single digit tasks Monsell et al. (2003) found systematic effects of task congruency that were generally larger for their unpredictable than their predictable cases. The effects in the unpredictable cases also dissipated if the same task was repeated over three successive trials. Without engaging with possible reasons for this pattern, it is important to realise that task congruency clearly produces different effects depending on the type of bivalent stimuli that are used.

What it was shown is that when stimuli such as A3 are used there are critical processes concerned with character encoding that can be modulated by task predictability. The ability to filter out the task irrelevant character is one such process. However, such filtering plays no such role with the single digit cases because the identical character invokes the two opposing task-sets and must be encoded. It is therefore not so surprising that congruency effects emerge most strongly when single digits are used.

2.8 CONCLUSIONS

The present experiments have provided some further important insights into task switching performance. Specifically, the findings have shown how higher-level knowledge about the upcoming task can affect processing once the task stimulus is presented. In this regard, it is perhaps a mistake to assume that exogenous and endogenous factors are completely insulated from one another at the level of cognitive mechanisms. The present data stand in contrast to accounts that posit such factors are functionally independent from one another (Sohn & Anderson, 2001; Sohn et al., 2000). What the current data strongly suggest is that task foreknowledge is useful insofar as it allows the participant to selectively enhance the activation of the appropriate task-set prior to the presentation of the imperative stimulus. This can then facilitate stimulus encoding processes.

Moreover, data from the final experiment have shown that caution is perhaps warranted in comparing alternating runs cases in which the trial order is predictable with explicit cuing cases in which the trial order is random. Task precues support particular automatic preparatory processes that are different from those witnessed in cases where the task type is given by the trial sequence alone.

3 TASK EXPECTATION AND TASK DIFFICULTY EFFECTS

3.1 GENERAL INTRODUCTION

In Chapter 2, the interplay of endogenous and exogenous control processes on task switching under various conditions has been explored. Broadly, endogenous control processes were defined as the top-down processes that are voluntary and goal directed. They require some effort and they are slower than exogenous control processes. The latter can be easily conceived as involuntary, automatic, stimulus driven bottom-up processes.

The critical issue in Chapter 3 is to understand further how this endogenous control manages through executive processes to overcome the interference caused by exogenous factors. In Chapter 2, exogenous interference was manipulated in two ways. Primarily, whether it was either present (crosstalk condition) or absent (no crosstalk condition). Secondly, when it was present (crosstalk condition) whether it was compatible (congruent trials) or incompatible (incongruent trials) in relation to the relevant task. Of the two manipulations, only the first (crosstalk) had an effect for the reasons discussed in Chapter 2. Therefore, exogenous control was initially studied in an 'on/off' state (on – crosstalk, off-no crosstalk). In the present chapter a more fine grained manipulation of the influence of exogenous control was sought. For that reason, the crosstalk and congruency manipulations were abandoned and a new variable (task ratio of presentation) was introduced. The details of this variable will be discussed further as the chapter progresses.

Many studies in the literature suggest that executive control is essential for activating the appropriate task-set (Luria & Meiran, 2005; Mayr & Kliegl, 2000; Rogers & Monsell, 1995). In general, it is assumed that during a task switching experiment both task-sets are maintained in WM. Support for this assumption comes from experiments that have shown that when a response is congruent between the current and the previous trial responses are facilitated than when this response is incongruent (cf. Rogers & Monsell, 1995). However, it has been argued that task-sets are not maintained in WM, but instead are directly activated by executive processes in LTM (Mayr & Kliegl, 2000, 2003). Within this framework, incongruent responses are slower than congruent responses because the irrelevant aspect of the stimulus triggers retrieval from LTM of the competing task-set. This causes greater competition and interference relative to congruent trials that need additional cognitive effort in order to be resolved (Allport, Styles, & Hsieh, 1994; Waszak, Hommel, & Allport, 2003).

In addition, it is assumed that executive control is also required in order to suppress the interfering activation of the irrelevant task-set. Support for this account comes from studies that have used Stroop stimuli and have demonstrated that it is more difficult to switch to the dominant task from the non-dominant task than the other way around (Allport, Styles, & Hsieh, 1994; Allport & Wylie, 1999; Wylie & Allport, 2000).

Specifically, bilingual participants were required to name numerals either in their first or second language in an unpredictable manner. Performance (RT) was impaired when they had to name numerals in their first language after naming numerals in their second language relative to when they had to do exactly the opposite (Meuter & Allport, 1999). This asymmetry effect has been explained in terms of the amount of inhibition that was exerted on a task-set on given trial. A dominant task-set, because it is naturally more activated than the non-dominant one, requires a greater amount of inhibition to be suppressed than when the less dominant task-set must be performed. This inhibition persists to the next trial (assuming it is a dominant task trial) and must be overcome in order to efficiently respond. In this case, a greater level of activation is needed to over come this *carry-over of inhibition* giving rise to a slowing of performance.

However, the asymmetry effect can be reversed. Some studies have revealed that the asymmetry effect can be reversed, so it becomes more difficult to switch from the dominant task to the non-dominant than the other way around. This result can be easily explained by Rogers and Monsell's (1995) TSR account. According to this point of view, reconfiguring of the dominant task-set is easier than reconfiguring to the non-dominant task-set simply because less effort is needed to load the task-set rules that govern responding.. This effect was clearly demonstrated in a study that used Stroop stimuli and the incongruent part of the stimulus was presented with a delay of 160 or 320 ms. In that way, the cue that signalled the irrelevant task was not presented. Suppression of the irrelevant task-set under these circumstances was not necessary and therefore the asymmetry effect was not observed (see Azuma & Monsell as reported by Monsell, Yeung, & Azuma, 2000).

At this point, it can broadly be concluded that task switching is heavily depended upon a top-down regulation of task activation and/or task inhibition from executive functions. The critical issue is to define which are the specific cognitive process/processes that make the dominant contribution to switch costs and under what circumstances.

One possible suggestion has to do with task-set priming. Priming can contribute to switch costs in many ways. There can either be a *repetition benefit* – priming that is produced simply by having just performed the same task (Ruthruff, Remington, & Johnston, 2001) or *task-set inertia* (TSI) – as task A is performed, priming builds up and when a switch back to task B is required performance is impaired. This impairment may arise for either or both of two reasons, a) task B is not primed, and, b) task A is heavily primed and causes interference (Allport, Styles, & Hsieh, 1994; Sohn & Anderson, 2001; Yeung & Monsell, 2003b). The main assumption is that the more task A is repeated the more priming it receives - *autogenous priming*, (Monsell, Sumner, & Waters, 2003).

Additionally it is important to consider something known as the *lag effect.* In this context the lag effect occurs when the more trials of task A are repeated the more difficult is to switch back to task B, has been reported by Ruthruff et. al. (2001) but not from other studies. Notably, a lag effect cannot be predicted if the main source of switch costs has to do only with executive control processes. Upon a task switch, executive control processing probably results in switch costs simply because it needs time to execute in order to perform the new task – TSR, (Rogers & Monsell, 1995). In that case, assuming that the priming of each task does not contribute to switch costs, TSR in order to perform task B will take the same time no matter how many trials of task A have elapsed.

Switch costs can also arise from carry-over effects of inhibition. In a study that employed 3 tasks (e.g., A, B, C) Mayr and Kelee (2000) found that performance on the last trial of an A-B-A sequence was slower relative to that of an A-B-C sequence. They attributed this effect to *backward inhibition*. Specifically, in an A-B-A sequence task A must be suppressed in a top-down manner in order to switch to Task B. However, this inhibition is carried over to the next trials and when task A must be activated again it must be overcome. In an A-B-C sequence, this carry-over of inhibition is not present and therefore it is not necessary to be overcome resulting in a better performance on the 3rd trial of an A-B-C relative to an A-B-A sequence.

On these grounds, it can be predicted that either no lag effect or a reverse lag effect would occur on a sequence of trials. If it is assumed that in order to perform task B, inhibition of task A is essential, then it can be expected that the more task B is repeated in succession then the easier it would be to switch back to task A. This can be explained either as a smaller effect of inhibition or due to less control biases against task A, (Monsell, et al., 2003). These control biases might become more relaxed as task B is repeated while task B becomes more dominant making it easier to switch back to task A even if task B is more primed. Whenever less control biases take place, either in the form of more activation of task B or less inhibition on task A, the prediction that can be made is the same: no lag effect can be expected.

This assumption, among others, was examined in a series of experiments conducted by Sumner and Ahmed (2006). The lag effect was examined mainly by varying the type of stimuli that were used between the experiments. Central to their study was the examination of the lag effect on blocks of trials in which either univalent or/and bivalent stimuli were presented. Participants had to perform two tasks with a speeded response by pressing a key. One of the two tasks required responding to a letter ‘I, S, O, X’ and the other required a response to a colour ‘red, green, blue, yellow’. The same keys were assigned for both tasks (e.g., for some of participants the ‘I, S, red, green’ responses were assigned to one key whereas ‘O, X, blue, yellow’ responses were assigned to the other key). For the letter task, stimuli were presented in a square box while for the colour task stimuli were presented in circle. In the univalent blocks of trials, the letter stimuli were presented in black font while the colour task was a plus sign ‘+’ that changed colours between trials.

In the bivalent blocks of trials, coloured letters were presented. Participants were informed prior to the experiment that the norm was to expect 8 consecutive trials of the same task until a task switch was required. However, they were also instructed that rare unexpected switches might occur prior to the completion of the expected eight non-switch trials of each task. A protruding ‘clock hand’ was presented emerging from behind the cue shape indicating the current position in a run of each trial. The hand rotated 45° clockwise on each trial and after 8 rotations jumped to 12 o’clock signalling a task switch. Of direct interest to the present study is their experiment 3. The main issue that was investigated was whether as performance improves in one task (as a result of several non-switch trials) it becomes harder to switch to the other task. The design was the same as in their experiment 1 except that switch trials and non-switch trials were equally possible to occur. What they have found is that on blocks of bivalent trials, after several succeeding trials of task A, it becomes easier to repeat task A and easier to switch back to the competing task B if circumstances arise.

The indirect hypothesis here, suggests that performance on a switch trial directly depends on the relative task-set activation state (e.g., carryover of autogenous priming). It becomes harder to switch away from a task if that task has been highly primed after several non-switch trials. However, control biases affect how soon performance will reach asymptote. In the case of a strong application of control biases (e.g., on predictable blocks of trials), performance reaches an asymptote on the second trial of a task (Monsell, et al., 2003). Under predictable conditions therefore, it can be expected that the relative task-set activation remains the same for all non-switch trials, no matter their position in a run. Switching tasks after any number of non-switch trials of a given task would be equally difficult.

However, this assumption cannot explain why as it becomes easier to perform one task it becomes easier to switch away from it. Sumner and Ahmed (2006), suggest that the factors that determine performance on the current task cannot simply affect a single 'relative task-set activation' level that can also determine the difficulty to switch to another task. They propose mainly two explanations that can account for their experiment 3 findings. First, control states are carried over and affect performance on a switch trial. For instance, inhibition that was applied on task A in order to perform task B might be carried on and be present when task A must be performed again. This carry-over of inhibition might be stronger after shorter task lags relative to longer task lags. Second, switch costs can be influenced by control factors through expectancy. As a run of non-switch trials is getting lengthier, participants may increasingly expect a task-switch even if they have been informed that a task switch is equally probable at all times – 'gamblers fallacy' (Kahneman & Tversky, 1972). According to the authors, the mere conclusion of their study regarding bivalent data is that as autogenous priming builds up and makes the current task more dominant less control bias in its favour is needed in the form of inhibition of the competing task. Therefore, switching to the competing task B becomes easier as a sequence of consecutive trial of task A becomes lengthier. They conclude that the carry-over of control bias, probably in the form of inhibition, must contribute directly to switch performance rather than indirectly in the form of previous effects on task-activation levels.

The general model of task switching that they propose can be summarised as follows: As a task is repeated performance improves and reaches an asymptote through autogenous priming – repetition benefit. The number of trials that is needed in order to reach an asymptote is modulated by the current level of control bias. Upon a task switch, performance is poor both due to the fact the task is not primed – no repetition benefit, and because priming for the previous task is carried over and causes interference – a TSI component. In cases that the stimuli are very similar or bivalent, that is they are associated with task-sets other than the relevant one, then the wrong task-set might be activated through exogenous priming.

Performance on bivalent trials is expected to be worse relative to performance on univalent trials due to that reason. Under these circumstances, control biases can take the form of inhibition applied to the competing tasks. Its main role is to reduce interference in response selection whenever necessary. Control biases' strength directly depends on the level of interference present. Control biases can also be modulated according to expectancy and can now take the form of activation separate from the form of inhibition discussed previously. In that case, control biases can directly affect performance on non-switch trials and determine the length of time needed to reach asymptote. Residual control biases make it difficult to switch back to a task-set not favoured by such bias. Even in the case that switches are fully expected and prepared, a switch cost arises (Sumner & Ahmed, 2006).

Finally, it's worth mentioning that the following experiments constitute a good reason that justifies the use of alternating runs paradigm as a predictable condition vs. explicit cuing paradigm as an unpredictable condition. Altmann (2007) suggested that alternating runs paradigm has a confounding relating to the position in a run of non-switch and switch trials that differentiates switch costs from that observed in an explicit cuing paradigm run of trials. Specifically, switch trials are always in the position 1 while non-switch trials are always in the position 2 in an alternating runs paradigm (ABBABBA…) block of trials. This is not true for a random (AAABABA…) block of trials. Comparisons therefore among the two switch costs seem to be problematic. Although the first claim is acceptable, the second is arguable.

As proposed earlier, it is this attribute of alternating runs trials that elicits strong control biases probably in the form of inhibition. Altman (2007) considered that to be a selective advantage to the subsequent non-switch trials after a task switch in alternating runs paradigm trials and thus a confounding. This is because this pattern of control biases is not present in explicit cuing or random trials. Nevertheless, it can be argued that this pattern of control biases allows the study of executive control under two clearly different circumstances (stronger endogenous control vs. weaker endogenous control). Predictable non-switch trials in an alternating runs paradigm can be used as an effective baseline simply because it seems that they do not involve cognitive processes (e.g., loading task in WM) found in other kind of trials (unpredictable trials). Thus, the architecture of the cognitive system can be studied from a multidimensional perspective allowing for an efficient mapping of the cognitive processes that control task switching.

In the following series of experiments, the previously-mentioned assumptions were tested in circumstances were exogenous control was manipulated by presenting two tasks of unequal difficulty in either equal or different ratios of presentation and under predictable and unpredictable conditions on various RSIs. They idea behind these manipulations is that exogenous control can be studied under a variety of magnitudes of influence. Specifically, the cognitive system will be examined under predictable and unpredictable conditions where a strong interfering easy task will be presented on block of trials including a difficult task. In order to study further the extent of the effects that will arise on both tasks two more experiments will be discussed. In the first of these experiments, the easy task will be presented more often than the difficult task while in the second the opposite pattern will take place. Finally, an attempt to uncover any RSI effects on switch costs will be carried in the last experiment of the chapter (Experiment 9).

3.2 EXPERIMENT 6

The aim of the first of this series of experiments was to examine the assumptions regarding the relation of endogenous and exogenous factors in conditions where switching from a dominant to a non-dominant task and vice-versa was required. As before, participants were tested in a variation of the standard alternating runs paradigm that included both predictable and unpredictable conditions. In both cases, they had to switch between two digit classification tasks namely, the magnitude (dominant - easy) and the parity (non-dominant - difficult) task. The design of this experiment allows for the study of the asymmetry effect under conditions where strong intentional control is exerted (i.e., in predictable conditions) versus conditions where this control is more relaxed (i.e., in unpredictable condition). Specifically, under predictable non-switch trials, strong inhibition of the irrelevant task is expected since it is known in advance that a task switch will not take place on the upcoming trial. Due to this strong inhibition, it is expected that switching back to that task will be very demanding because this strong inhibition must be overcome.

On the other hand, under unpredictable conditions, a task switch is equally probable to occur on any given trial. In that case, strong inhibition of the irrelevant task is not adaptive because circumstances may arise where activation of this task is going to be essential. For that reason, any priming of tasks is not strongly inhibited during the RSI. Inhibition of the irrelevant task will occur following the onset of the stimulus. Therefore, the relative priming of both tasks will directly determine performance. Switch costs are expected to be smaller relative to that observed on predictable conditions.

This assumption can be expected to be true if either an asymmetry effect or a reversed asymmetry effect is revealed. In the first case, it is assumed that the dominant (easy) task will require strong inhibition in order for the non-dominant (difficult) task to be activated resulting in larger switch costs in the first relative to the second task. This inhibition will be even stronger under predictable conditions for the reasons described above. In the latter case, it is assumed that switching to the dominant (easy) task is going to be easier simply because it needs less activation in order to reach the response threshold relative to the non-dominant (difficult) task. For that reason, switch costs should be larger for the non-dominant (difficult) task relative to the dominant (easy) task – a reversed asymmetry effect.

Moreover, if it is assumed that the dominant (easy) task is more primed relative to the non-dominant (difficult) task then it can be expected that it will also require stronger inhibition when a switch from it is required. Based on that assumption, it can be expected that on predictable cases switching to the non-dominant (difficult) task is going to be more difficult relative to switching back to the dominant (easy) task. This difference is expected to be less marked on unpredictable cases than on predictable cases due to less inhibition on both tasks. It can be expected therefore that under predictable conditions switching tasks will be more difficult relative to unpredictable conditions giving rise to larger switch costs.

3.2.1 Method

3.2.1.1 Participants

Participants were 24 university students (14 females) with a mean age of 24.3 (7.4 SD) years old that took part on this experiment for either course credit or payment. They all reported having normal or corrected to normal vision and hearing while three were left-handed.

3.2.1.2 Design and stimuli

The digit classification task was chosen for this series of experiments due to its unique nature. Digits, as stimuli, comprise two simple and yet distinct classification tasks that vary in difficulty, namely the magnitude and parity tasks. The magnitude task has been found to be more automatic and thus easier when relative to the parity task (Monsell, et al., 2003; Otten, Sudevan, Logan, & Coles, 1996).

In the parity (odd/even) classification task participants had to decide whether the target digit was an odd or even number. In the magnitude (high/low) classification task the participants had to decide whether the target digit was a high (above five) or low (below five) number. The 1, 2, 3, 4, 6, 7, 8, 9 digits were used as stimuli. On each trial, a digit was presented and participants had to make a speeded key press. There was a left and a right response key and the ‘odd’ and ‘high’ responses were assigned to the right key and the ‘even’ and ‘low’ responses to the left key.

Prior to the experimental trials, participants underwent training blocks of trials where on each trial a single digit was presented centrally on the screen. Blocks of trials were generated for the separate classification tasks. Each block of trials contained 24 cases and digits were equally represented in each of their blocks (3 times each). The training session comprised 16 blocks (8 parity (odd/even) blocks and 8 magnitude (high/low) blocks). The session was initiated by a parity classification block followed by a magnitude classification block and the presentation continued accordingly until the end.

In the experimental trials, there were two main conditions – a predictable condition and an unpredictable one. In the predictable condition the sequence of trials started with a parity trial, thereafter the sequence was a parity trial, magnitude trial, magnitude trial, parity trial and so on (i.e., PPMMP…). Therefore, every 3rd and 5th trial was a switch trial and every 2nd and 4th trial in the sequence was a non-switch trial. In a given block of trials, there were 48 instances. Across the 48 trials there were equal numbers of switch and non-switch trials, equal numbers of congruent and incongruent trials, equal numbers of parity and magnitude trials, and finally there were equal numbers of left (even/low) and right (odd/high) key presses. In addition, a character that appeared in trial *n* never appeared on the immediate subsequent trial *n+1*. In addition, conditions were tested in which the RSI varied. For one group of participants the RSI was set at 250 ms RSI, for another at 600 ms RSI whereas for a different group the RSI was set at 1200 ms.

Across the experimental trials, a mixed design was used containing five factors: RSI (250, 600 and 1200 ms) constituted the between-groups factor, and pair type (congruent or incongruent), trial transition (switch or non-switch), predictability (predictable or unpredictable), and difficulty (easy task-magnitude or difficult task-parity), were the within-participants factors. At the start of each trial, a central fixation plus sign (0.4° x 0.4° of visual angle) was presented. In the pre-experimental training task, the fixation plus sign was followed by a centrally presented digit. Digits were presented as black, bold, courier new, size 18 font (0.5° x 0.5° of visual angle).

On the experimental trials, the fixation plus sign was followed by the display of the digit in either red or green font. Participant's task was to classify the digit's parity (odd/even) when the digit appeared in red font and the digit's magnitude (high/low) when the digit appeared in green font.

3.2.1.3 Apparatus

The software and hardware that was used in this series of experiments was identical to that used in the previous chapter.

3.2.1.4 Procedure

The procedure for the training and experimental trials was identical to that used in the experiments described up to this point. The only difference was that participants were trained in the parity and magnitude tasks during the training session while in the experimental trials they were presented with single digits instead of character pairs.

3.2.2 Results - Training Trials

Error responses and very fast responses (less than 100 ms) were excluded from the analysis of the RT data. As a result, an exclusion of 6.5% of scores has occurred prior to data analysis. Separate analyses were carried out for mean correct RTs and percentage errors. For both data sets a split plot analysis of variance (ANOVA) was carried out in which the between participants grouping factor was the RSI (250 ms, 600 ms and 1200 ms) and the within participants factors was difficulty (easy vs. difficult task).

3.2.2.1 RTs

The analysis revealed statistically a significant main effect of difficulty [$F(1, 21) = 16.502$, $MS_e = 34346$, $p < .01$], revealing that participants were significantly slower when performing the parity task relative to the magnitude task. The main effect of RSI failed to reach statistical significance.

3.2.2.2 Error rates

Error rates were analysed in the same way as the RTs. The associated ANOVA revealed that main effect of difficulty [$F(1, 21) = 7.725$, $MS_e = 1.289$, $p < .05$], was statistically reliable showing that participants were more error prone when performing the parity task than when comparing the magnitude task. No effect of RSI was evident in the analysis of error rates.

For a graphical illustration of the RTs and error rates for the conditions of interest in Experiment 6 see Figure 11.

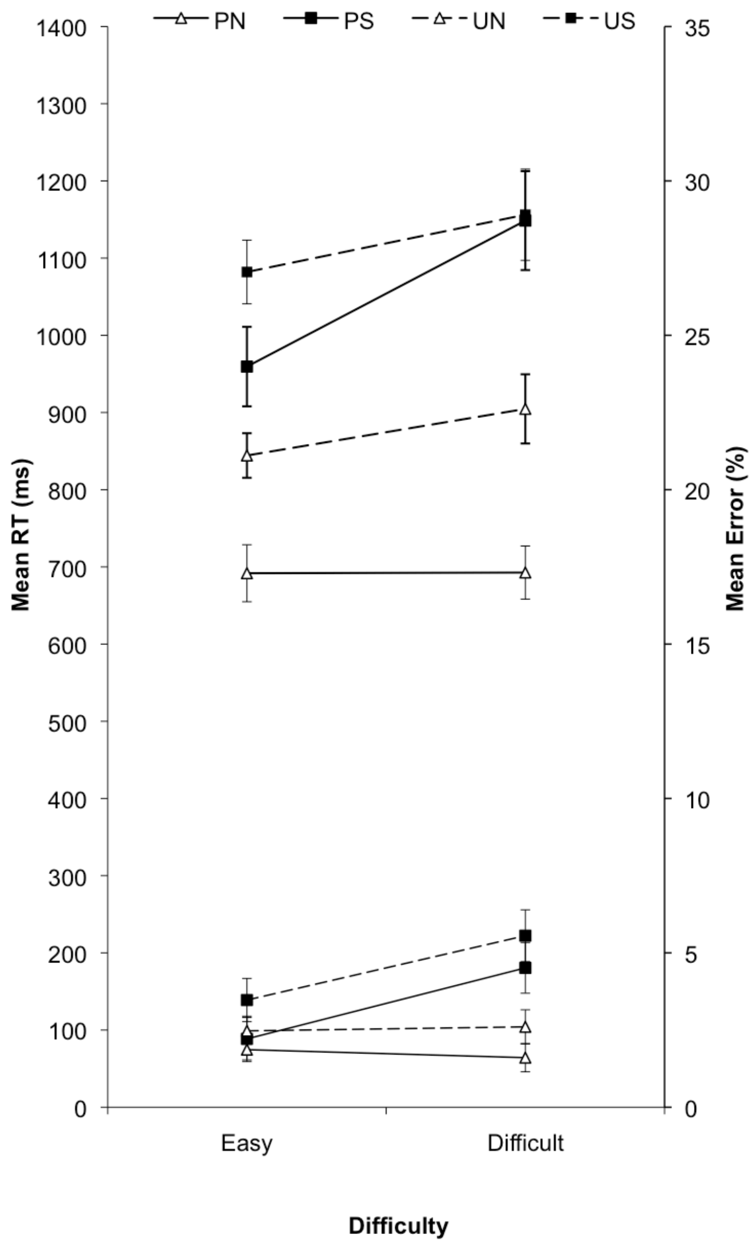


Figure 11: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 6. Means have been averaged over RSI. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials, Easy = Magnitude Task, Difficult = Parity Task.

3.2.3 Results - Experimental Trials

The analysis of the experimental trials resembled closely that of the training trials. Error responses, very fast responses (less than 100 ms) and in this case responses that followed an error response were excluded from the analysis of the RT data. As a result, an exclusion of 6.7% of scores has occurred prior to data analysis. For both data sets (RTs and percentage errors) a split plot analysis of variance (ANOVA) was carried out in which the between participants grouping factor was the RSI (250 ms, 600 ms and 1200 ms) and the within participants factors were predictability (predictable vs. unpredictable trials), trial transition (switch vs. non-switch trials) and difficulty (easy vs. difficult task).

3.2.3.1 RTs

The analysis revealed statistically significant main effects of trial transition [$F(1, 21) = 156.609$, $MS_e = 28179$, $p < .001$], difficulty [$F(1, 21) = 13.395$, $MS_e = 23596$, $p < .01$], and predictability [$F(1, 21) = 17.080$, $MS_e = 42977$, $p < .001$]. The main effect of RSI failed to reach statistical significance. In general terms, responses were slower on switch than non-switch trials, they were slower overall on unpredictable than predictable case and finally, they were slower overall on difficult than on easy trials. Nevertheless, these general patterns were modulated by several significant interactions. A number of statistically significant interactions was revealed namely, the predictability x trial transition interaction [$F(1, 21) = 16.649$, $MS_e = 9896$, $p < .01$], difficulty x trial transition [$F(1, 21) = 7.387$, $MS_e = 16574$, $p < .05$], and predictability x difficulty x trial transition [$F(1, 21) = 30.671$, $MS_e = 2976$. $p < .001$]. In order to examine these interactions in more detail the data for predictable and unpredictable cases were analysed separately.

3.2.3.1.a Predictable trials

Data were entered into a two-way within participants ANOVA in which trial transition and difficulty were entered as fixed factors. Both the main effect of trial transition [$F(1, 23) = 137.166$, $MS_e = 22904$, $p < .001$], and difficulty [$F(1, 23) = 21.936$, $MS_e = 9877$, $p < .001$], were statistically significant. The trial transition x difficulty interaction [$F(1, 23) = 20.512$, $MS_e = 10363$, $p < .001$], was also found to be statistically reliable. A Tukey's HSD test indicated that RT was reliably larger on difficult switch trials relative to easy switch, easy and difficult non-switch trials. Furthermore, RT on easy switch trials was reliably faster from easy and difficult non-switch trials while no statistically significant differences on RTs were revealed for the latter ($p < .05$, all comparisons). It is evident therefore, that performance on difficult switch trials is substantially slower relative to the other trials and drives the reported interaction.

3.2.3.1.b Unpredictable trials

For the data from the unpredictable trials the main effects of trial transition [$F(1, 23) = 104.650$, $MS_e = 13724$, $p < .001$] and difficulty [$F(1, 23) = 5.964$, $MS_e = 18213$, $p < .05$] were statistically significant.

3.2.3.2 Error rates

Error rates were analysed in the same way as the RTs. The associated ANOVA revealed that the main effects of trial transition [$F(1, 21) = 25.392$, $MS_e = .016$, $p < .001$], difficulty [$F(1, 21) = 4.688$, $MS_e = .013$, $p < .05$], and predictability [$F(1, 21) = 7.510$, $MS_e = .024$, $p < .05$], were all statistically reliable. In addition, one interaction, namely the trial transition x difficulty interaction [$F(1, 21) = 9.722$, $MS_e = .029$, $p < .01$], was also found to be statistically significant.

A Tukey's HSD test revealed that errors were reliably larger on difficult switch trials relative to easy switch, easy and difficult non-switch trials ($p < .05$, no other comparisons reached statistical significance). Inspection of the data across the RT and accuracy analyses revealed that there was no evidence of any systematic speed/error trade-offs in performance.

3.2.4 Discussion

All the basic effects reported in Chapter 2 were replicated by the present data. Specifically, switching tasks was more difficult than repeating tasks, while in the predictable condition RTs were overall faster relative to the unpredictable condition. Errors were in general less on non-switch than on switch trials and larger on unpredictable than on predictable cases. Similarly to Chapter 2, there were no statistically reliable effects of RSI.

Central to this experiment was the task difficulty factor. Data analysis showed that, in general, RTs were slower when performing the difficult task relative to performing the easy task. Responses were also less accurate on difficult than on easy trials. These results clearly indicate that an asymmetry effect is not evident here. The easy task was overall easier to perform and switching to it was easier relative to the difficult task and not the other way around – a reverse asymmetry effect.

Interestingly, the magnitude of the difficulty effect varied as a function of predictability. On predictable cases, switching to the difficult task was more demanding relative to switching to the easy task resulting in larger switch costs. That was not true for the unpredictable cases where no differences in switch costs between the easy and difficult trials were observed.

As stated in the discussion of Experiment 1, the differences between predictable and unpredictable cases are manifest in an overall performance cost seen in the predictable cases. It has been accepted that such benefits arise from the fact that participants are in a higher state of readiness for the upcoming trials on predictable cases than on unpredictable cases due to the certainty of the upcoming task on the first case. These overall benefits have been referred in Chapter 2 as *predictability effects* and it is assumed here that they reflect endogenous factors that relate to executive control.

In order to have a better understanding of the predictability effects the predictable and unpredictable cases must be examined separately. It must be kept in mind that switch costs can arise, a) because of benefits that accrue on non-switch trials, b) because of costs that accrue on switch trials or, c) because of a combination of these factors. In addition, the present data suggest that it is performance on non-switch trials that is the main determinant of switch costs on predictable cases.

On predictable cases, the difficulty effect was more robust on switch trials relative to non-switch trials. In fact, there was not any difficulty effect on non-switch trials. This finding suggests that when participants anticipate performing the task that they have just performed they maintain the already loaded task-relevant information in a state of readiness. The task-irrelevant information is kept suppressed in order for the task-relevant information to be easily accessible on the upcoming trial. This idea is in accord with Rogers and Monsell's (2003) findings. In their experiment 2, they demonstrated that after a task switch on predictable cases only one non-switch trial is enough for performance to recover completely to an asymptote level.

Interestingly, on predictable switch trials, RTs were larger when participants had to switch to the difficult task relative to when they had to switch to the easy task. This larger switch costs on difficult trials may have arisen either from the fact that, a) interference from the easy task is very difficult to overcome relative to non-switch trials, b) that the difficult task is more difficult to be reloaded in WM than the easy task or, c) a combination of both. A digit can always be classified in terms of parity and magnitude giving rise to priming to both tasks, however the magnitude (easy) task is more readily available and thus interference occurs when a parity (difficult) task must be performed. This interference must be overcome in order for an adequate response to be given when a parity classification task is presented (Otten, et al., 1996).

On unpredictable trials, RTs were facilitated on non-switch trials than on switch trials and faster overall on easy trials than on difficult trials. Switch costs were additive as a function of difficulty. The observed patterns in RTs arise mainly because, a) a decision about the correct task to be performed on a given trial is being made upon the presentation of the stimulus - in that case interference from the competing task must be overcome after the onset of the trial, b) the magnitude (easy) task is 'naturally' primed and, c) performance on a given trial directly depends on whether or not the task has just been performed and thus primed on the previous trial.

Finally, it seems that a determinant of switch costs in the predictable, but not in the unpredictable condition, is strong inhibition. It has been shown in Chapter 2, that performance on predictable non-switch trials varied substantially from predictable switch and unpredictable trials. This finding was attributed to the strong inhibitory processes that probably take place when a task repetition is expected on the upcoming trial. It is reasonable to assume that this is the case here as well and that the interaction between task difficulty and trial transition reflect at least partial task-set inhibition. This issue, along with the others raised here, will be examined further in the following experiment.

3.3 EXPERIMENT 7

In the previous experiment, it has been shown that switch costs are modulated as a function of difficulty and predictability. It seems that under predictable conditions strong control of the competing tasks sets is exerted, while in unpredictable condition that is not the case. The main determinant of switch costs therefore under the two conditions is assumed to be a strong endogenous modulation of the activation/inhibition of the relevant and/or the irrelevant task under the predictable condition because the upcoming task is expected with absolute certainty.

A more relaxed modulation of this activation/inhibition under the unpredictable condition occurs because there is no certainty regarding which of the two tasks will be presented on the upcoming trial. As a result, a different pattern of switch costs for the two tasks was observed under predictable but not under unpredictable conditions.

In order to examine the assumption that the different patterns in switch costs arise from a differential modulation of task-set activation/inhibition as a function of predictability the following experiment was conducted. In this experiment, one of the tasks namely the magnitude (easy) task is presented more often than the parity (difficulty) task. It is assumed that this differential presentation ratio will benefit the task that is presented more often due to priming and/or expectancy. For instance, on predictable cases the upcoming task is expected with absolute certainty like in the previous experiment. In that case, it can be expect that if that results in strong endogenous control and in the form of inhibition, then predictable switch costs will resemble that of Experiment 6.

Specifically, even if priming builds up for the task that is presented more often (magnitude task) this advantage will be lost upon switching to the competing task (parity task) due to strong inhibition on that task (magnitude task). Thus, when a switch back to the magnitude task is required activation/retrieval of that task will occur from zero. It is expected that it will be more difficult to switch to the difficult task rather than the easy task on predictable trials. Upon successful activation/retrieval of the task-set in WM the task-set will remain there as long as it is necessary. Therefore, it can be assumed that no effect of difficulty will be observed on predictable non-switch trials.

On the other hand, on unpredictable trials a more relaxed control is applied. Task-sets are probably partially inhibited because it is highly possible that they will be needed again. In that case, whatever priming/control biases result from the uneven task presentation will not be lost and therefore a different pattern of performance (in favour of the most presented task) will be observed. In addition, as has already been discussed, uncertainty regarding the upcoming task occurs on unpredictable trials.

However, because the easy task is expected to occur more often than the difficult task on unpredictable cases participants may adopt a strategy in which they will activate/bias the easy task more than the difficult task in advance. Overall, the unpredictable easy task is expected to have a double benefit, namely priming due to, a) a more frequent ratio of presentation and, b) a kind of advance preparation where participants will activate/bias the easy task more often than the difficult task before the onset of the trial due to expectation.

3.3.1 Method

3.3.1.1 Participants

Participants were 24 university students (16 females) with a mean age of 21.7 (2.0 SD) years old. They took part on this experiment for either course credit or payment. They all reported having normal or corrected to normal vision and hearing while one was left-handed.

3.3.1.2 Design and stimuli

The design of Experiment 7 was very close to that of Experiment 6. Every aspect of Experiment 7 resembled that of Experiment 6 except from the fact that the easy task (magnitude task) was presented in a ratio of 2:1 in relation to the difficult task (parity task).

There were both predictable and unpredictable blocks of trials. In that regard, a predictable block of trials was initiated with the presentation of two consecutive trials of the parity task followed by 4 consecutive trials of the magnitude task (e.g., AABBBBA…) while in an unpredictable block of trials the presentation of tasks was completely random except from the first trial that was always a parity classification trial.

The first trial of each block could not be regarded either as a switch or as a non-switch trial, therefore for balancing reasons an extra trial that served as a parity switch trial was added. In that sense, in a given block, 49 trials of which 17 were parity classification trials and 32 were magnitude classification trials existed. For the parity classification task, 1 trial was excluded from the analysis, 8 were non-switch trials and 8 were switch trials. For the magnitude task, 24 were non-switch trials and 8 trials were switch trials.

3.3.2 Results – Training Trials

The analysis of the training trials is identical to the one used in the previous experiment. An exclusion of 4.7% of scores has occurred prior to data analysis after excluding error responses and very fast responses.

1.1.1.1 RTs

As in the previous experiment, the analysis revealed statistically a significant main effect of difficulty, [$F(1, 21) = 5.746$, $MS_e = 34435$, $p < .05$] revealing that participants were significantly slower when performing the parity task relative to the magnitude task. The main effect of RSI [$F(1, 21) = 4.041$, $MS_e = 28030$, $p < .05$] was also statistical significant.

3.3.2.1 Error rates

Error rates were analysed in the same way as the RTs. The associated ANOVA revealed that neither the main effect of difficulty nor the effect of RSI was evident in the analysis of error rates.

3.3.3 Results - Experimental Trials

In the experimental trials, 7.9% of scores were excluded from analysis after excluding error responses, very fast responses and responses that followed an error response. In this experiment, only the RTs of the second trial (first non-switch trial) of a run of four consecutive trials of the task that was presented more often in the present experiment (magnitude task) were taken into account in the present analysis.

Consequently, an equal number of predictable switch and non-switch trials were entered into the analysis for both tasks. That was not feasible for the unpredictable condition because switching occurs randomly and thus the runs of consecutive trials vary for both tasks.

In that case, every trial was taken into account in the present analysis. Despite of the above changes every other aspect of the analysis was the same with that of the previous experiment.

3.3.3.1 RTs

The analysis revealed statistically significant main effects of trial transition [$F(1, 21) = 155.178$, $MS_e = 31306$, $p < .001$], difficulty [$F(1, 21) = 28.643$, $MS_e = 20250$, $p < .001$], and predictability [$F(1, 21) = 13.483$, $MS_e = 23384$, $p < .001$]. The main effect of RSI failed to reach statistical significance.

In general terms, responses were slower on switch than non-switch trials, they were slower overall on unpredictable than predictable case and finally, they were slower overall on difficult than on easy trials. Nevertheless, these general patterns were modulated by several significant interactions.

A number of statistically significant interactions was revealed; namely, the predictability x difficulty interaction [$F(1, 21) = 13.841$, $MS_e = 2917$, $p < .01$], difficulty x trial transition[$F(1, 21) = 22.499$, $MS_e = 15051$, $p < .001$], and difficulty x RSI, [$F(2, 21) = 4.441$, $MS_e = 20250$, $p < .05$].

In regard to the predictability x difficulty interaction, a Tukey's HSD test revealed that RTs were reliably larger on unpredictable difficult trials relative to predictable easy, predictable difficult and unpredictable easy trials. Moreover, RTs on predictable difficult trials were reliably larger relative to predictable easy trials but not from unpredictable easy trials.

Finally, RTs were reliably larger on unpredictable easy trials relative to predictable easy trials. Similar analysis for the difficulty x trial transition showed that RTs were reliably larger on difficult switch trials relative to easy switch, easy and difficult non-switch trials. Easy switch trials RTs were also reliable larger when relative to easy and difficult non-switch trials. No significant differences were found among easy and difficult non-switch trials ($p < .05$, all comparisons).

For the final interaction, namely the difficulty x group type interaction, simple main effects analyses revealed that the difficulty effect was evident in both the 600 ms [F (1, 21) = 12.71, MS_e = 257387, $p < .01$], and the 1200 ms RSI [F (1, 21) = 24.20, MS_e = 489997, $p < .001$] but not in the 250 ms RSI ($p > .05$).

3.3.3.2 Error rates

Error rates were analysed in the same way as the RTs. The associated ANOVA revealed that only the main effect of trial transition was statistically reliable [F(1, 21) = 4.487, MS_e = 0.022, $p < .05$]. In addition, two interactions, namely the trial transition x difficulty [F(1, 21) = 62.532, MS_e = .026, $p < .001$], predictability x difficulty [F(1, 21) = 15.059, MS_e = .014, $p < .001$].

The trial transition x difficulty interaction emerged because whereas participants were more accurate on non-switch than switch trials in the parity task, this pattern was reversed in the data for the magnitude task ($p < .05$, Tukey's HSD test, both effects). This suggests that participants did tend to trade speed for accuracy on the non-switch trials in the magnitude task.

An HSD test revealed that the predictability x difficulty interaction arose because participants committed the most errors on the unpredictable switch trials in the parity task ($p < .05$, all comparisons; no other comparisons reached statistical significance).

The predictability x trial transition [F(1, 21) = 4.070, MS_e = .020, p = .057], and the predictability x difficulty x group [F(2, 21) = 3.035, MS_e = .014, p = .07], marginally failed to reach statistical significance.

Figure 12 provides a graphical illustration of summary RTs and error rates averaged over the RSI factor.

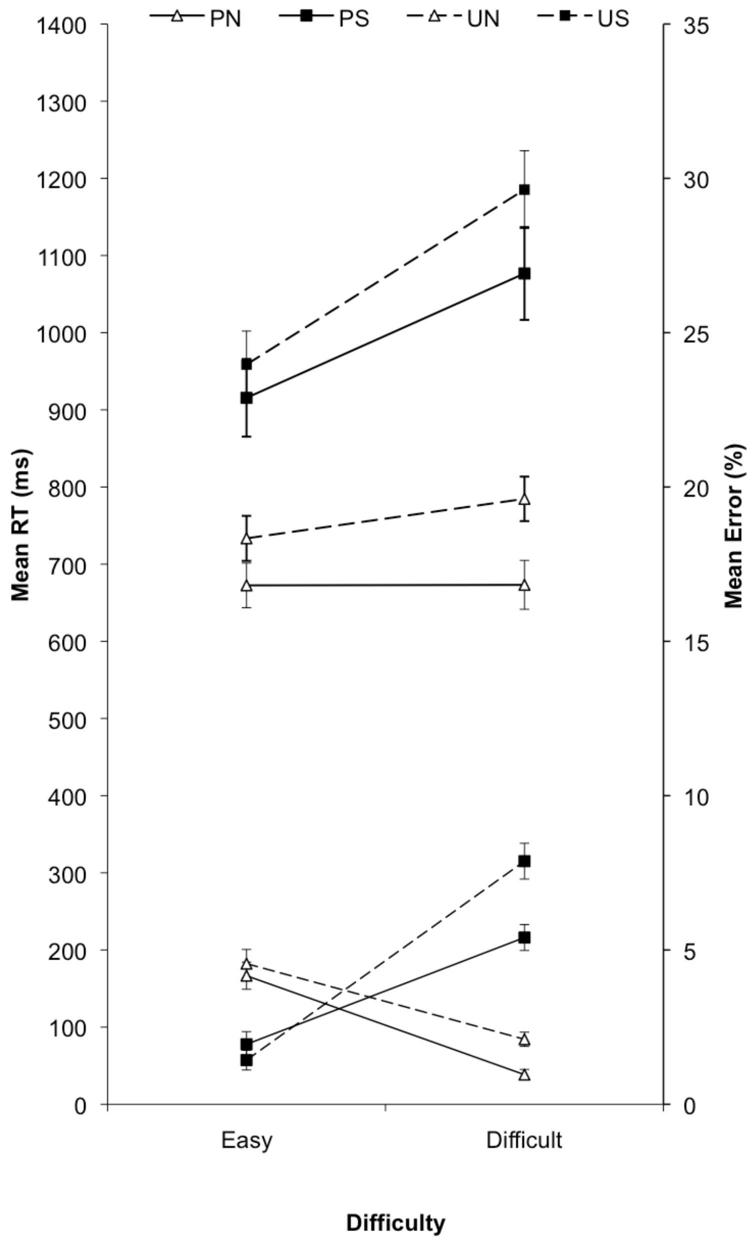


Figure 12: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 7. Means have been averaged over RSI. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials, Easy = Magnitude Task, Difficult = Parity Task.

These marginally insignificant interactions came out because there was a constant pattern of error rates across both predictable and unpredictable conditions and on every RSI. Specifically, error rates on the difficult task were higher on switch trials when relative to non-switch trials. However, the opposite was true for the easy task where error rates were higher on non-switch trials relative to switch trials.

This pattern cannot simply indicate a speed/error trade-off because RTs on easy non-switch trials do not exhibit any unusual reduction relative to the other trials. As a matter of fact, there were cases in which RTs on easy non-switch were larger relative to other trials. For instance, RTs on easy non-switch were larger relative to the difficult non-switch trials for the 250 ms group (801 ms as opposed to 745 ms) and 600 ms group (594 ms as opposed to 591 ms). The corresponding error rates were (4.3% as opposed to 1.8%) for the 250 ms and (4.5% as opposed to 0.8%) for the 600 ms group respectively. Figure 13 provides a graphical illustration of mean error rate difference (switch -non-switch trials) of the conditions of interest across the RSI factor.

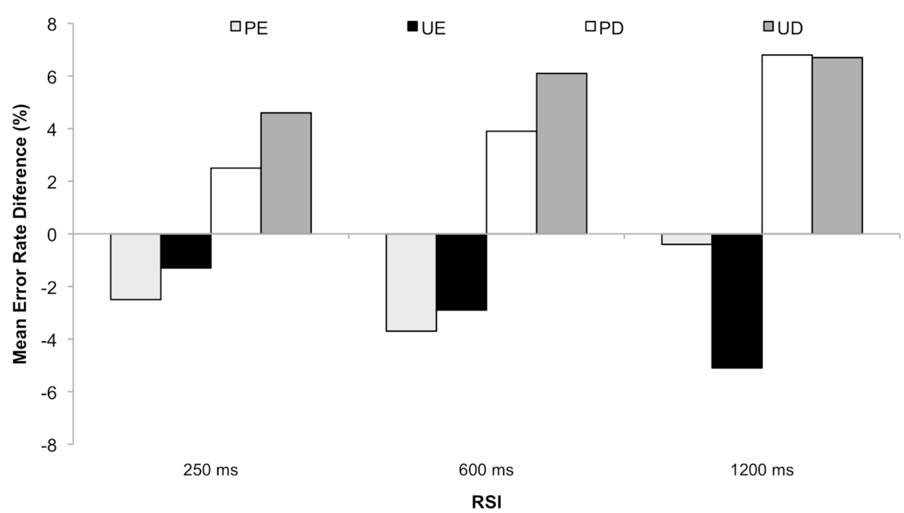


Figure 13: Graphical illustration of the mean error rate difference (switch – non-switch trials) for the conditions of interest in Experiment 7 and across RSI. PE = Predictable Easy trials, UE = Unpredictable Easy trials, PD = Predictable Difficult trials, UD = Unpredictable Difficult trials, Easy = Magnitude Task, Difficult = Parity Task. RSI = Response - Stimulus Interval.

The possible reasons behind this pattern of results will be discussed further in the discussion section. Further inspection of the overall data across the RT and accuracy analyses and despite this complex pattern of interactions, revealed that there was no evidence of any systematic speed/error trade-offs in the overall performance.

3.3.4 Discussion

The results obtained from this experiment fit comfortably with the initial expectations. The pattern of predictable switch costs was intriguingly similar to that of experiment 6. On the other hand, the pattern of unpredictable switch costs was different from that of the previous experiment. In the present case, switch costs on unpredictable trials were larger on difficult trials relative to easy trials. It is clear that performance on the most presented task (easy task) was enhanced as a result of the task ratio manipulation on unpredictable trials. It seems that, although priming of the magnitude (easy) task occurs in both conditions, its effects are evident only under the unpredictable condition. As mentioned earlier, the reason behind this finding is that strong endogenous control is exerted on predictable trials due to a certainty regarding the upcoming task. This control includes probably strong inhibition of the activation of the irrelevant to the trial task cancelling out whatever activation benefit that had occurred from previous priming.

That is not the case under the unpredictable condition were such control is assumed to be weaker. The most frequent task (magnitude task) seems to have received additional priming because it was presented more often and/or because participants probably actively biased the easy task prior to the onset of the trial due to expectations of the upcoming task. The result is that switch costs for the unpredictable cases resembled that of the predictable trials. Switch costs were additive in both cases and appeared to be smaller for the easy trials. Due to that reason, the three-way interaction observed in the previous experiment was not found to be statistically reliable in this experiment indicating the expected benefit that the unpredictable easy trials received.

It is also worth mentioning that an interesting pattern was observed in the error rates. Specifically, the error rate on easy non-switch trials was higher when relative to easy switch trials and that was true for both the predictable and unpredictable cases. Moreover, this pattern was observed on 250 ms and 600 ms but not on the 1200 ms RSIs. This is not the first time that such a pattern emerges (see Yeung and Monsell 2003a, experiments 1 and 3) however the present data appear to be very consistent across the various conditions. A probable explanation may have to do with the relatively low demands that arise on easy non-switch trials. In the specific experiment, the easy task is primed and therefore the low task demands become lower as the general view of RTs indicate. These demands may become even lower when the task is repeated on non-switch trials. If that is true then this low demanding situation may result in a more relaxed top-down control on the related task-set leading to a more careless response. The net result under these circumstances is a higher error rate.

In the present experiment, repetition priming and expectation had an effect and it is evident on performance. A very important question concerns the magnitude of these effects. What will happen if the difficult task is primed? Can the difficult task appear to be the easy one in terms of performance?

3.4 EXPERIMENT 8

In this experiment, the assumptions and findings of the previous experiments were considered further. In this experiment, the parity (difficult) task was presented more often than the magnitude (easy) task. The predictions are clear-cut - no differences in the pattern of predictable switch cost are expected on the predictable condition. In contrast, a different pattern of unpredictable performance, relative to that of the previous experiments, in favour of the difficult task should be the case. On predictable trials due to strong endogenous control, resulting from the absolute certainty regarding the upcoming task, no difference on the pattern of results relative to the previous two experiments should be evident. Nevertheless, on unpredictable cases the difficult task is expected to occur more often relative to the easy one. Task priming and expectation are expected to modulate activation and inhibition related processes in such a way as to benefit the difficult task. This effect should be evident on the performance of the difficult task and most likely at an expense on the easy task’s performance.

3.4.1 Method

3.4.1.1 Participants

Participants were 24 university students (17 females) with a mean age of 22.1 (5.1 SD) years old that took part on this experiment for either course credit or payment. They all reported having normal or corrected to normal vision and hearing while five were left-handed.

3.4.1.2 Design and stimuli

The design of Experiment 8 was identical to that of Experiment 7. Every aspect of Experiment 8 resembled that of Experiment 7 except from the fact that the difficult task (parity task) was presented in a ratio of 2:1 in relation to the easy task (magnitude task). There were both predictable and unpredictable blocks of trials. In that regard, a predictable block of trials was initiated with the presentation of two consecutive trials of the magnitude task followed by 4 consecutive trials of the parity task (e.g., BBAAAA…) while in an unpredictable block of trials the presentation of tasks was completely random except from the first trial that was always a magnitude classification trial.

Similarly to the previous experiment, the first trial of each block was not regarded either as a switch or as a non-switch trial, therefore for balancing reasons an extra trial that served as a magnitude switch trial was added. In that sense, in a given block, 49 trials of which 17 were magnitude classification trials and 32 were parity classification trials existed. For the magnitude classification task, 1 trial was excluded from the analysis, 8 were non-switch trials and 8 were switch trials. For the parity task, 24 were non-switch trials and 8 trials were switch trials.

3.4.2 Results – Training Trials

The analysis of the training trials was identical to the one used in the previous experiments. An exclusion of 3.2% of scores has occurred prior to data analysis after excluding error responses and very fast responses.

3.4.2.1 RTs

The analysis revealed a statistically significant main effect of difficulty [$F(1, 21) = 5.369$, $MS_e = 41769$, $p < .05$], revealing once more that participants were significantly slower when performing the parity task relative to the magnitude task. The main effect of RSI failed to reach statistical significance.

3.4.2.2 Error rates

Error rates were analysed in the same way as the RTs. The associated ANOVA revealed that the main effect of difficulty [$F(1, 21) = 3.642$, $MS_e = .106$, $p = .07$], failed marginally to reach statistical significance. The effect of RSI once again failed to reach statistical significance.

3.4.3 Results - Experimental Trials

In the experimental trials, 7.5% of scores were excluded from analysis after excluding error responses, very fast responses and responses that followed an error response. Similarly to the previous experiment only the RTs of the second trial (first non-switch trial) of a run of four consecutive trials of the task that was presented more often in the present experiment (parity task) were taken into account in the present analysis. Figure 14 provides a graphical illustration of summary RT and error rate averaged over the RSI factor.

3.4.3.1 RTs

The analysis revealed statistically significant main effects of trial transition [$F(1, 21) = 122.293$, $MS_e = 19058$, $p < .001$], and predictability [$F(1, 21) = 60.652$, $MS_e = 14801$, $p < .001$]. The main effect of difficulty and RSI failed to reach statistical significance.

In general terms, responses were slower on switch than non-switch trials and they were slower overall on unpredictable than predictable case. Nevertheless, these general patterns were modulated by several significant interactions.

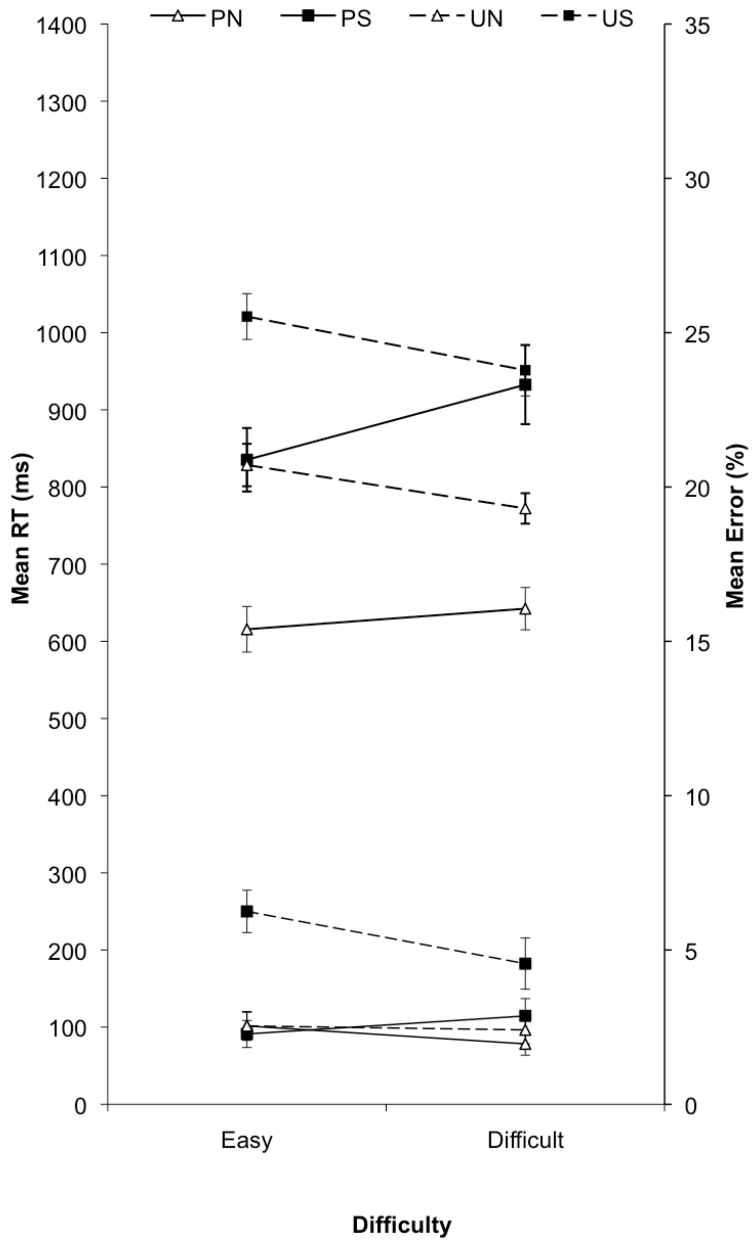


Figure 14: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 8. Means have been averaged over RSI. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials, Easy = Magnitude Task, Difficult = Parity Task.

These interactions included the predictability x difficulty interaction [$F(1, 21) = 84.630$, $MS_e = 2214$, $p < .001$], predictability x trial transition [$F(1, 21) = 7.949$, $MS_e = 7229$, $p < .05$], and predictability x difficulty x trial transition [$F(1, 21) = 15.841$, $MS_e = 1337$, $p < .01$]. In order to examine these interactions in more detail the data for predictable and unpredictable cases were analysed separately.

3.4.3.1.a Predictable trials

Data were entered into a two-way within participants ANOVA in which trial transition and difficulty were entered as fixed factors. Both the main effect of trial transition [$F(1, 23) = 80.134$, $MS_e = 19468$, $p < .001$], and difficulty [$F(1, 23) = 11.715$, $MS_e = 7885$, $p < .01$], were statistically significant. The trial transition x difficulty interaction [$F(1, 23) = 5.575$, $MS_e = 5362$, $p < .05$], was also found to be statistically reliable. A Tukey's HSD test indicated that RT was reliably larger on difficult switch trials relative to easy switch, easy and difficult non-switch trials. Furthermore, RT on easy switch trials was reliably larger from easy and difficult non-switch trials while no statistically significant differences on RTs were revealed for the latter ($p < .05$, all comparisons).

3.4.3.1.b Unpredictable trials

For the data from the unpredictable trials, only the main effects of trial transition [$F(1, 23) = 109.847$, $MS_e = 7539$, $p < .001$ and difficulty [$F(1, 23) = 18.414$, $MS_e = 5161$, $p < .001$ were statistically significant. Switch costs were additive similarly to the unpredictable cases in Experiment 6. It is noteworthy that that the difficulty effect on the unpredictable condition has been reversed. That is RTs on the easy trials was larger than on difficult trials.

3.4.4 Error Rates

Error rates were analysed in the same way as the RTs. The associated ANOVA revealed that the main effects of trial transition [$F(1, 21) = 8.074$, $MS_e = .027$, $p < .05$], and predictability [$F(1, 21) = 19.722$, $MS_e = .011$, $p < .001$], were all statistically reliable.

In addition, two interactions, namely the predictability x trial transition interaction [$F(1, 21) = 19.882$, $MS_e = .009$, $p < .001$], and the predictability x difficulty x trial transition [$F(1, 21) = 6.399$, $MS_e = .019$, $p < .05$], was also found to be statistically significant. The data for predictable and unpredictable cases were analysed separately in order to be examined in more detail.

3.4.4.1 Predictable trials

Data were entered into a two-way within participants ANOVA in which trial transition and difficulty were entered as fixed factors. Neither the trial transition nor the difficulty effects were found to be statistically significant.

3.4.4.2 Unpredictable trials

For the data from the unpredictable trials, only the main effect of trial transition [$F(1, 23) = 23.379$, $MS_e = .017$, $p < .001$], was statistically significant. The trial transition x difficulty interaction [$F(1, 23) = 5.693$, $MS_e = .022$, $p < .05$], was also found to be statistically reliable. A Tukey's HSD test indicated that error rate was reliably larger on easy switch trials relative to easy and difficult non-switch trials ($p < .05$, both comparisons; no other comparisons reached statistical significance). Inspection of the data across the RT and accuracy analyses revealed that there was no evidence of any systematic speed/error trade-offs in performance.

3.4.5 Discussion

The results of Experiment 8 replicate and take one step further the results of the previous experiments. The pattern of predictable switch costs is almost identical with that of the previous two experiments verifying the stated assumptions and predictions. Noteworthy are the results of the unpredictable trials. Unpredictable switch costs resemble that of Experiment 6, however the difficulty effect was reversed. Specifically, performance on the parity (difficult) task was overall better relative to that of the magnitude (easy) task. It seems therefore that priming and expectation induced by the differential ratio of presentation of tasks is strong enough to reverse performance between two different in difficulty tasks.

In addition, switch costs for the unpredictable cases were additive in nature. It seems that either the additional ratio of presentation did not make the difficult task more primed than how much the easy task already is or that despite of the expectations that participants had for the trial *n+1* task, they failed to prepare the difficult task adequately in advance. The result is overall faster RTs for the difficult task but no difference in switch costs between the two tasks. Whatever the case might be, this large in magnitude effect is completely cancelled out under conditions were strong endogenous control is exerted (predictable cases).

3.5 MODELING TASK SWITCHING

In order to test the current theoretical ideas further, a model consisting of a set of simple equations was developed in order to simulate the current results. RTs in the various conditions are modeled by varying various numerical estimates of component cognitive processing as defined by these equations in an Excel spreadsheet. In this attempt, the focus of the presented equations is to represent the idea that a modulation of activation of the two tasks occurs in a top-down manner according to expectation/carry-over of task-set bias. Based on the interpretation of the current results the core components of the model include the theoretical assumptions that:

a) Endogenous control is feasible but more relaxed on unpredictable than on predictable conditions - task-sets are biased according to the probability that a given task is to occur on the upcoming trial. Specifically, in the predictable condition the upcoming task is expected with full certainty and a strong endogenous control is applied in order to prepare it while in contrast, in the unpredictable condition the upcoming task is expected in a relative state of uncertainty and thus it is prepared accordingly.

b) On predictable non-switch trials the task is maintained in WM - based on the fact that minimum crosstalk and no difficulty effect was evident on predictable non-switch trials it can be assumed when a task repetition is expected on the upcoming trial the current task is maintained in WM and it is somehow insulated from any exogenous influences.

c) The carry-over of inhibition and its relative influence on performance depends on the relative discrepancy of the difficulty of the two tasks. Taking into account that, in contrast to some findings in the literature, a reversed asymmetry effect in the current data was evident, it is hypothesised that a possible explanation for these contrasting effects is that the discrepancy in difficulty between two tasks can lead either to an asymmetry or to a reverse asymmetry effect.

d) Endogenous control modulates the activation of the relevant/irrelevant task-set by either biasing or suppressing their activation states - the modulation of task-sets' activation states is possible via an activation/inhibition related process and the model attempts to provide the specific mechanism of this process.

e) Repetition priming affects only performance on unpredictable non-switch trials – that is because any effect of priming is cancelled out on predictable trials due to the presence of strong endogenous control. In contrast on an unpredictable switch trial *n* there is no repetition of the task that was presented previously on the *n-1* trial.

f) An advance preparation and task-set decay component affects only predictable trials - on predictable trials the task is expected with absolute certainty on the upcoming trial. In cases where a task repetition is expected, then the task-set is maintained on WM and it is subject to decay as the RSI increases whereas, when a task switch is expected a full advance preparation of that task is attempted.

Central to the present model is the idea of a task strength that is defined as simply the product of the task expectancy (TE) and the natural task difficulty (TD). The role of this component will be clarified later as the section progresses.

This central component of the model is reflected in Equation 1:-

$$TS = TE \times TD \qquad (1)$$

In attempting to capture the data of the three experiments described so far in the chapter, various task parameters have been estimated and the stages of information processing have been encapsulated at a fairly abstract level in terms of the equations that specify commonly accepted component processes. As stated in the beginning of this section, the aim has been to try to capture the data in arbitrary time units that roughly correspond with the mean condition RTs shown in Figures 11, 12 and 14.

The general form of the model is given in Equation 2:-

$$RT = CP + TM - AP + TSR \times rb \qquad (2)$$

According to above equation, the RT on a given trial is the sum of a set of component processes. CP stands for assorted processes that are common to all kinds of trials, for example, encoding the stimulus, generating an actual response etc. TM stands for task maintenance and only takes place on predictable non-switch trials. As stated before, the assumption is that when a task repetition is expected on trial *n* an attempt is made to maintain the current task-set in WM during the RSI in order for the task to be readily available on trial *n+1*. Task maintenance carries a cost additional to the assorted processes.

Therefore, on predictable non-switch trials performance reflects only task maintenance in addition to the assorted common processes. It is possible that the task components maintained in WM are subject to decay as time elapses leading to a gradual increase in the value of TM. The AP, TSR and rb components do not play a role on predictable non-switch trials therefore they take a value of 0.

The RT on a predictable non-switch trials is given by Equation 3:-

$$RT_{\text{Pred-NSw}} = CP + TM \qquad (3)$$

On predictable switch trials however, the participant has to attempt to activate the alternative task-set to that just executed.

The general form of the equation reduces to Equation 4:-

$$RT_{\text{Pred-Sw}} = CP - AP + TSR \qquad (4)$$

AP stands of advance preparation. There is no cost associated with task maintenance (i.e., TM = 0) and the component AP is subtracted from the cumulative total of the other processes. In addition to advance preparation, performance on predictable switch trials concerns TSR or task-set reconfiguration. In the general form of the equation, TSR is multiplied by the rb factor. The rb factor is discussed in more detail below, but on predictable switch trials it is set to 1.

The TSR term is defined according to Equation 5:-

$$TSR = COI + RTP + ITS \qquad (5)$$

In the model, TSR is defined as the sum of three terms namely, COI or carry-over of inhibition, relevant task priming (RTP) and irrelevant task suppression (ITS). COI specifies the counteraction of the carried-over inhibition of the relevant task-set that was carried from the previous trial.

COI is defined via Equation 6:-

$$COI = \frac{K}{TS_{(r)}} \tag{6}$$

K is an arbitrary constant and TS is the inherent difficulty of the relevant task (r). This equation encapsulates the idea that more effort is needed to overcome the carryover of inhibition of an easy than a difficult task. RTP refers to those processes concerning the activation of the relevant task in the model. This is expressed as the product of the task strength TS by a mental effort term ME. ME is a free parameter that is varied according to condition and may reflect cognitive process such as refractoriness on task-set processing.

RTP is defined via Equation 7:-

$$RTP = TS_{(r)} \times ME \tag{7}$$

ITS refers to the amount of suppression that is applied to the irrelevant task-set on a given trial. It is simply set at the task strength of the irrelevant task-set (i).

ITS is defined via Equation 8:-

$$ITS = TS_{(\mathrm{i})} \tag{8}$$

The corresponding case for unpredictable switch trials is given Equation 9:-

$$RT_{\mathrm{Unpred\text{-}Sw}} = CP + TSR \tag{9}$$

Given that the next trial is unknown there can be no advance preparation, similar to that of predictable switch trials, of a particular task-set. Rather, an effort is being made in order to partially prime both tasks in WM according to task expectancy and thus determine their availability for the upcoming trial.

Finally for the unpredictable non-switch trials the formalism is given in Equation 10:-

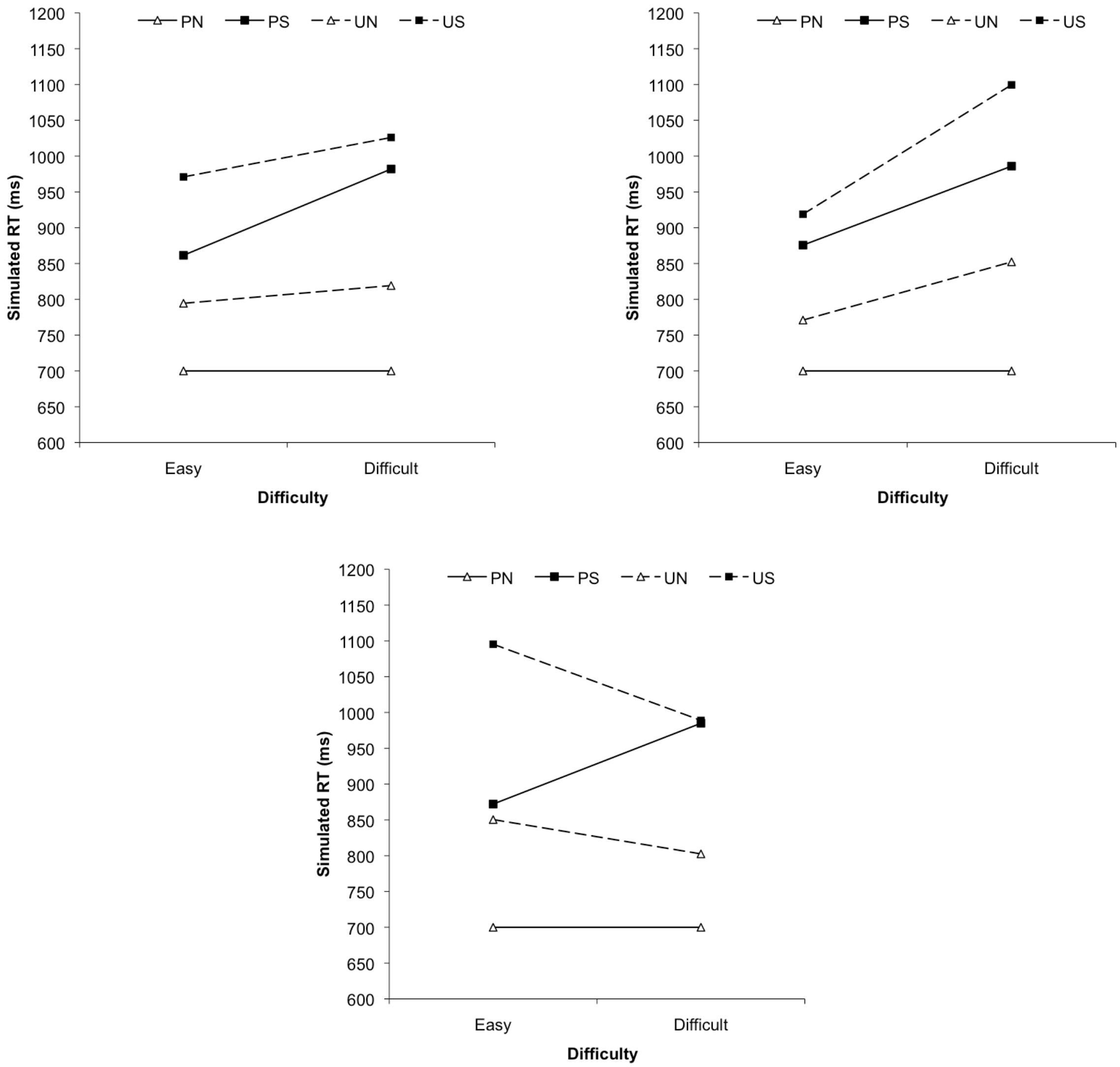
$$RT_{\text{Unpred-NSw}} = CP + TSR \times rb \qquad (10)$$

In this case, the TSR term is modulated by the rb factor. rb is a proportional factor that is set to 1 in all other cases, but on the unpredictable non-switch trials it is reduced to less than one. The effect of the rb factor is to reduce the impact of task-set reconfiguration on non-switch trials and it reflects a process similar to repetition priming. On trial *n+1* it is less effortful to activate the relevant task and suppress the irrelevant task if the task is repeated from trial *n*. In order to 'simulate' the previous findings a model fitting was carried by manually tuning numerical values in the various components of the model in a spreadsheet. Specifically, within the model there are four variables – CP, TM, AP, K and rb - that have been given arbitrary but fixed across experiments values that were used in 'simulating' all three data sets. The TE (task expectancy) and TD (task difficulty) variables were taken from the experiments. The parity task was the most difficult task in all cases and this value was fixed at 100 with the task difficulty of the magnitude task being expressed as a proportionate value computed from the training RTs in the corresponding experiment. The ME variable is a free parameters that have been varied in an almost arbitrary fashion across the experiments aiming to reflect variability under different conditions. Figure 15 provides a list of the key parameters and their values used to simulate the experimental data. Figure 16 provides graphical illustrations of the 'simulated' mean RTs for the various conditions of interest in Experiments 6 to 8.

In conclusion, as can be seen from Figure 16 the 'simulation' captures the basic patterns of performance across experiments 11, 12 and 14. Specifically, it is evident that the outcome of this 'simulation' resembles closely central experimental effects such as the predictability and the trial transition effect. In addition, the difficulty effect is similar across the three 'simulations' on predictable conditions. However, the difficulty effect is modulated according to task expectancy only on unpredictable trials. This pattern of results resembles closely the experimental findings.

Variable		Experiment 1 MGN = PRT	Experiment 2 MGN > PRT	Experiment 3 MGN < PRT
		Objective variables		
TE MGN P/U		1/0.5	1/0.67	1/0.33
TE PRT P/U		1/0.5	1/0.33	1/0.67
TD MGN		92	96	95
TD PRT		100	100	100
		Subjective variables – Fixed		
CP		650	650	650
TM		50	50	50
AP		300	300	300
K		4000	4000	4000
rb		0.45	0.45	0.45
		Subjective variables – Not Fixed		
ME				
PN	MGN	0	0	0
	PRT	0	0	0
PS	MGN	4	4	4
	PRT	5	5	5
UN	MGN	4	3	8
	PRT	5	8	3.7
US	MGN	4	3	8
	PRT	5	8	3.7

Figure 15: Key parameters and values of the ‘simulation’ of the experimental data. MGN = Magnitude Task, PRT = Parity Task, TE = Task Expectancy, TD = Task Difficulty, TM = Task Maintenance, CP = Common Processes, ME = Mental Effort, K = K constant, rb = Repetition Bias, AP = Advance Preparation, P = Predictable, U = Unpredictable, PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Non-switch trials.



<u>Figure 16</u>: Graphical illustration of the model's RTs for the conditions of interest 'simulating' the results of experiments 6 - upper left figure, 7 – upper right figure and, 8 - bottom figure. PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials. Easy = Magnitude Task, Difficult = Parity Task.

3.5.1 Comparison with Earlier Models

Although the current model shares many common components with the task switching models discussed in Chapter 2 it has also several important modifications. Specifically, all models include an initial activation level for a task upon the onset of a trial. This initial level determines how difficult or easy a task is naturally. Repetition priming modulates the initial activation so that non-switch trials are always faster than switch trials. In contrast to the other models, the current model suggests that repetition priming has an effect only on unpredictable cases where endogenous control is more relaxed relative to predictable cases.

In that case, responses on predictable non-switch trials are facilitated not because of repetition priming but because the task is maintained in WM (subject to decay). Thus, the current model proposes that when a task is expected to be repeated on the upcoming trial then there is no task retrieval mechanism involved (e.g like the one proposed by Sohn & Anderson (2001)). Therefore, the current task is not subject to exogenous influences that affect the task selection process.

This account can explain adequately why there are minimum crosstalk/difficulty effects only on predictable non-switch trials. If task selection occurred and priming was the main determinant of performance on predictable non-switch trials then it should be expected that similar effects on predictable and unpredictable non-switch trials would occur. Results so far indicate that this not the case. There is a clear difference in the pattern of results between the two cases that is very difficult to be explained by earlier models.

An endogenous component is included in all models. The novelty in the current model is that it assumes that this component modulates tasks' activation levels in both predictable and unpredictable cases. In the latter nevertheless, it does so in a more relaxed manner depending on the probability of each task to occur on the upcoming trial. In that case, the current model includes a more flexible probabilistic component that can account for a wide array of results (e.g., 100%, 75%, 50%, …10% probability of a task to occur on the upcoming trial).

In contrast, Sohn and Anderson's (2001) model assumes that task preparation is not possible in unpredictable cases. In their account, performance in unpredictable cases is being determined strictly exogenously. Although results so far cannot clarify the relative contribution of exogenous (priming) and endogenous (expectancy) control on task switching performance it will be shown later in the thesis that it is endogenous control (expectancy) that plays a more central role relative to exogenous control (priming) on task switching performance.

A similar component to Sohn and Anderson's (2001) exogenous component that can account for congruency/crosstalk effects, is utilized in Yeung and Monsell's (2003b) (conflict resolution) and Gilbert and Shallice's (2002) (inhibitory component) models. In the current model, similarly to the latter model an activatory and inhibitory mechanism is used to describe the process by which the relevant task is activated and the irrelevant to the trial task is inhibited in order for a response to be produced.

The mechanism integrates task expectancy (level of foreknowledge), recency (repetition priming), difficulty (initial level of activation) and the processing time available prior to the onset of the trial (RSI) and the overcome of the carry-over of inhibition (TSI) of a task on a trial *n* from the trial *n-1*. The last component takes task switching models one step further with the capability to explain the asymmetry and reverse asymmetry effects found in the thesis and in the literature.

In conclusion, it is necessary to investigate how RSI effects can be uncovered and how these can be explained based on the assumptions stated so far in the thesis. For that reason, the following experiment where the RSI effect is central has been conducted.

3.6 EXPERIMENT 9

The interest in the last experiment of the chapter is focused on the conditions necessary for uncovering the effect of RSI. It has been evident up to this point that manipulating RSI between participants results in no significant effects on performance.

Following Altman's (2004b) suggestion that the effects of RSI are more probable to be evident under conditions where the RSI in manipulated within participants rather than between participants an experiment where the RSI is manipulated within participants was carried out. It was assumed that this manipulation would be enough in order to reveal a decrement of switch costs when enough time for preparation was allowed.

3.6.1 Method

3.6.1.1 Participants

Participants were 12 university students (9 females) with a mean age of 22.6 (1.9 SD) years old that took part on this experiment for either course credit or payment. They all reported having normal or corrected to normal vision and hearing while one was left-handed.

3.6.1.2 Procedure

The procedure resembled closely that of Experiment 6 where the two task were presented equally often under predictable and unpredictable conditions. The difference is the way that RSI was manipulated. Participants had to perform two predictable and two unpredictable blocks of trials on two different RSIs. Specifically, a predictable and an unpredictable block of trials was administered with an RSI of 250 ms while similarly, another predictable and unpredictable block of trials was administered with a 1200 ms RSI. The focus of the experiment is, as already mentioned, the effect of RSI on switch costs. For that reason, emphasis on the analysis of the training trials was not deemed necessary and only experimental trials are analyzed and discussed.

3.6.2 Results

Error responses, very fast responses (less than 100 ms) and in this case responses that followed an error response were excluded from the analysis of the RT data. As a result, an exclusion of 8.8% of scores has occurred prior to data analysis. For both data sets (RTs and percentage errors) a within participants analysis of variance (ANOVA) was carried out in which the within participants factors were RSI (250 ms vs 1200 ms) predictability (predictable vs. unpredictable trials), trial transition (switch vs. non-switch trials) and difficulty (easy vs. difficult task).

3.6.2.1 RTs

The analysis revealed statistically significant main effects of trial transition [$F(1, 11) = 44.800$, $MS_e = 95027$, $p < .001$], difficulty [$F(1, 11) = 13.605$, $MS_e = 39925$, $p < .01$], and predictability [$F(1, 11) = 8.035$, $MS_e = 64201$, $p < .05$]. The main effect of RSI failed to reach statistical significance. In general terms, results replicated that of Experiment 6. Responses were slower on switch than non-switch trials, they were slower overall on unpredictable than predictable case and finally, they were slower overall on difficult than on easy trials.

A number of statistically significant interactions was revealed; namely, the RSI x trial transition interaction [$F(1, 11) = 50.908$, $MS_e = 2959$ $p < .001$], predictability x trial transition interaction [$F(1, 11) = 5.845$, $MS_e = 6332$, $p < .05$], difficulty x trial transition [$F(1, 11) = 6.033$, $MS_e = 13920$, $p < .05$], and predictability x difficulty x trial transition [$F(1, 11) = 13.858$, $MS_e = 3990$, $p < .01$]. In order to examine these interactions in more detail the data for predictable and unpredictable cases were analysed separately.

3.6.2.1.a Predictable trials

Data were entered into a three-way within participants ANOVA in which RSI, trial transition and difficulty were entered as fixed factors. Only the main effect of trial transition [$F(1, 11) = 51.957$, $MS_e = 48963$ $p < .001$], and difficulty [$F(1, 11) = 23.232$, $MS_e = 15310$, $p < .01$], were statistically significant. The RSI x trial transition interaction [$F(1, 11) = 4.437$, $MS_e = 10295$, $p = .059$], failed marginally to reach statistical significance. Finally, the trial transition x difficulty interaction [$F(1, 11) = 10.732$, $MS_e = 12839$, $p < .01$], was also found to be statistically reliable.

A Tukey's HSD test indicated that RT was reliably larger on difficult switch trials relative to easy switch, easy and difficult non-switch trials. Furthermore, RT on easy switch trials was reliably larger from easy and difficult non-switch trials ($p < .05$, all comparisons; no other comparisons reached statistical significance). It is evident therefore that, performance on difficult switch trials was substantially slower relative to the rest trials and drives the reported interaction.

Figure 17 provides a graphical illustration of summary RT and error rate averaged over the difficulty factor.

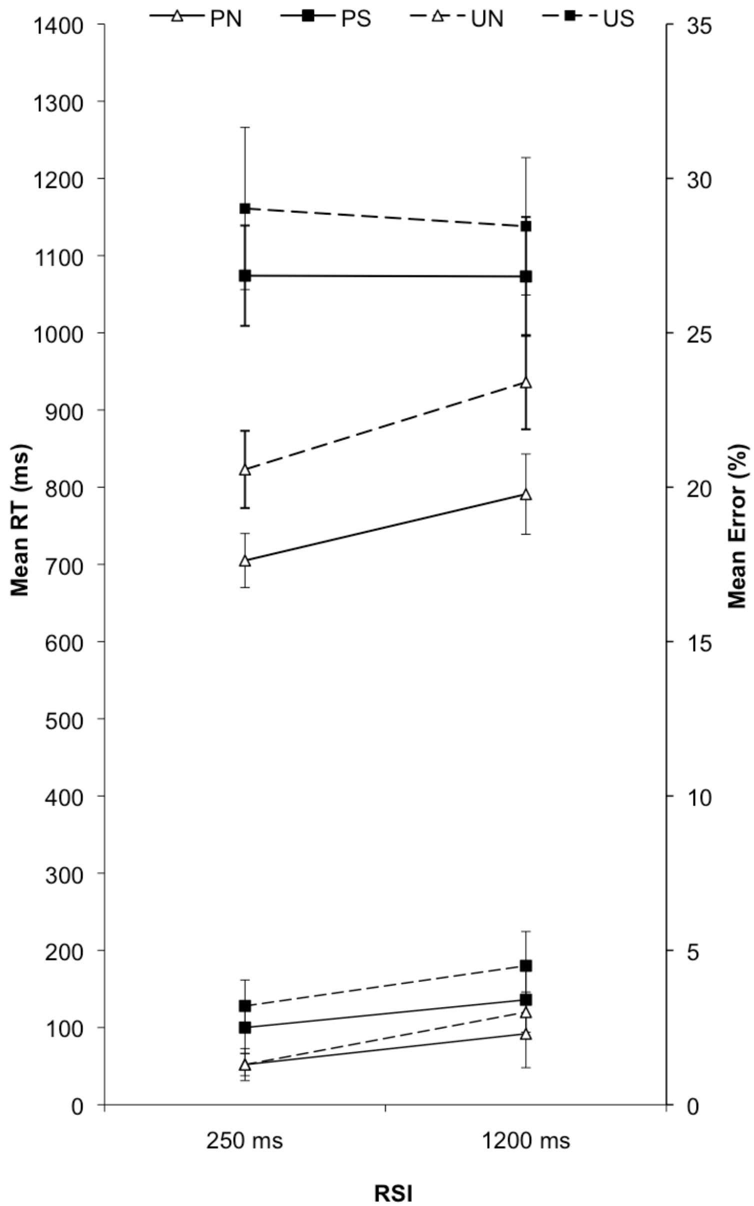


Figure 17: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 9. Means have been averaged over the difficulty factor. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials. RSI = Response Stimulus Interval.

3.6.2.1.b Unpredictable trials

For the data from the unpredictable trials the main effects of trial transition [$F(1, 11) = 33.404$, $MS_e = 52394$, $p < .001$], and difficulty [$F(1, 23) = 4.996$, $MS_e = 28663$, $p < .05$], were statistically significant. Switch costs were additive with trial type. The RSI x trial transition interaction [$F(1, 11) = 12.849$, $MS_e = 8741$, $p < .01$], was also found to be statistically reliable.

A Tukey's HSD test indicated that the average RT for the 250 ms RSI switch trials were larger from that of the 250 and 1200 ms RSI non-switch trials. Similarly, the average RT for the 1200 ms RSI switch trials were larger from that of the 250 and 1200 ms RSI non-switch trials. Finally, the average RT for the 1200 ms RSI non-switch trials were larger from that of the 250 ms RSI non-switch trials ($p < .05$, all comparisons; no other comparisons reached statistical significance). It is evident therefore that the reduction of switch costs on the 1200 ms RSI relative to that of the 250 ms RSI is driven mainly by an increase of the RTs on non-switch trials.

3.6.2.2 Error rates

Error rates were analysed in the same way as the RTs. The associated ANOVA revealed that the main effects of trial transition [$F(1, 11) = 6.293$, $MS_e = .043$, $p < .05$], and predictability [$F(1, 11) = 11.810$, $MS_e = .026$, $p < .01$], were all statistically reliable. In addition, two interaction, namely the predictability x trial transition interaction [$F(1, 11) = 10.482$, $MS_e = .014$, $p < .01$], and the RSI x trial transition interaction [$F(1, 11) = 5.155$, $MS_e = .012$, $p < .05$], were also found to be statistically significant.

For the predictability x trial transition interaction, a Tukey's HSD test revealed that errors were reliably larger on unpredictable switch trials relative to unpredictable non-switch trials ($p < .05$, no other comparisons reached statistical significance). Finally, a Tukey's HSD test for the RSI x trial transition interaction revealed that both the 250 ms and the 1200 ms RSI switch trials were less accurate from the 250 ms non-switch trials ($p < .05$, both comparisons; no other comparisons reached statistical significance). Inspection of the data across the RT and accuracy analyses revealed that there was no evidence of any systematic speed/error trade-offs in performance.

3.6.3 Discussion

All the basic effects reported in Experiment 6 were replicated in the present experiment. Moreover, an RSI effect was found on switch costs as indicated by the RSI x trial transition interaction. It seems that this interaction is mainly driven by a slowing on RTs on unpredictable non-switch trials on the 1200 ms. A similar indication is evident on predictable trials.

In detail, the switch trials had similar RTs for both the 250 ms and 1200 ms RSIs (1074 ms and 1073 ms respectively). On predictable non-switch trials however, an increase on RTs was evident on the 1200 ms relative to the 250 ms RSI (705 ms and 791 ms respectively). Nevertheless, the RSI x trial transition in predictable cases marginally failed to reach statistically significance. It seems therefore that Altman's (2004b) suggestion holds true - it is more probable to observe RSI effects when RSI is manipulated within participants rather than between participants. What has to be noted here is that the RSI effect has a striking effect on the RTs on non-switch trials while there seemed to be no effect on switch trials.

It seems therefore that under certain conditions, like the ones described here, a long RSI can result in smaller switch costs but not necessarily due to an improvement on switch trials but rather due to a slowing on RTs on non-switch trials. This can be probably attributed to task decay in cases where the task is been held in WM for later use (predictable non-switch trials) or to the fact that the repetition priming effect has vanished (unpredictable trials).

3.7 GENERAL DISCUSSION

In this series of experiments, the way by which predictability can affect performance on simple task switching experiments has been examined under specific conditions. In general, performance was found to be better on predictable trials relative to unpredictable trials. Moreover, performance on switch trials was found to be worse relative to that on non-switch trials. These findings are in accordance with the results of Chapter 2.

The specific aim of this series of experiments was to investigate how endogenous control modulates activation between different task-sets that varied in difficulty. It was evident from the findings that task difficulty plays a role probably prior to loading the task-set or some of its components in WM. When the task-set is loaded and maintained in WM, as in predictable non-switch trials, task difficulty has no effect.

In addition, the difficulty effect becomes apparent in circumstances where loading of the appropriate task-set or some of its components in WM is required (e.g., as in predictable switch trials). Loading/retrieval of the task-set for the difficult task or some of its components is more demanding resulting in slower performance relative to easy trials.

Performance on predictable trials is not affected when one of the tasks is presented more often in a given block of trials. Up to this point, these data seem to challenge some of the assumptions of the Sumner and Ahmed (2006) proposed model. One basic assumption they make is that as a task is repeated autogenous priming for that task builds up. It is suggested that upon a task switch autogenous priming may negatively affect task switching both because the relevant task is not primed and because priming from the previous trial is carried over and causes interference that must be resolved before a response is given.

Specifically, performance with bivalent stimuli, like the ones used in the present study, is expected to be worse relative to performance with univalent stimuli. Control biases in that case can take the form of inhibition and modulate the activation of competing tasks.

In addition, control biases can affect performance through expectancy by taking the form activation. In that case, they affect performance on non-switch trials and determine if the asymptote level will be reached earlier or later in time. Residual control biases make it difficult to switch back to a task that is not favoured by them. If the above assumptions hold true then a modulation in the pattern of predictable switch costs across the three experiments should be expected.

Despite the fact that expectancy is the same across the three experiments on predictable trials (participants have complete foreknowledge regarding the upcoming trial) performance should be affected by the differential ratio of presentation of the two tasks. For instance, in the last experiment where the difficult task was presented more often than the easy task it should be expected that switch cost for the easy task should equal or exceed the switch cost of the difficult task on predictable trials. The reason is that there should be control biases in favour of the difficult task and against the easy task. The results clearly show that this is not the case.

Moreover, the carry-over of inhibition account cannot also adequately explain the predictable switch costs described here for the reasons described above. If a carry-over of inhibition occurred then it should be expected, for instance, that in Experiment 7 where the easy task is presented more often than the difficult task that the easy task will require greater inhibition in order to perform the difficult task. That is because the already easy task due to repetition will be more primed and thus more automatic/easy. This inhibition should be overcome when the easy task had to be performed again giving rise to greater switch costs. This pattern was not observed.

In predictable cases, it can be assumed that the additional activation/inhibition/control bias that the tasks acquire is modulated by strong endogenous control because the upcoming task is expected with absolute certainty. In that case, a form of TSR occurs where in simple terms, the irrelevant task components are either discarded or strongly inhibited from/in WM whereas relevant task components are loaded in WM. Under these circumstances, switch costs are heavily influenced by this mechanism and the influence of any autogenous priming, carry-over of inhibition/control biases is undermined.

The situation is somewhat different under unpredictable conditions. Due to the lack of the certainty that occurs on predictable cases it is not adaptive to discard all or part of the task's components from WM for the task that has just been performed simply because the task might be needed on the upcoming trial. In that case, it can be speculated that both tasks are maintained in WM in a relative state of readiness.

If that is true, then whatever autogenous priming, carry-over of inhibition/control biases of each task is present should be preserved. Moreover, if a participant expects that a task is to be presented on the upcoming trial then it should prove possible to prepare for this task at least partially before the onset of the trial.

Endogenous control under these conditions is present but more relaxed relative to predictable trials and can occur either, a) before or/and, b) after the onset of the stimulus. In the first case, it modulates partially the relative activation/inhibition of the two tasks in WM achieving equilibrium of availability between the two tasks or biasing the task that is more expected. In the latter case, endogenous control is elicited after the onset of the stimulus in order to resolve the resulting interference between the two tasks.

This interference is the result of any autogenous priming, (i.e., carry-over of inhibition/control biases). Thus, exogenous control in the form of TSI is a determinant under unpredictable conditions while strong indications of some form of TSR seem to exist. Exogenous control is mainly driven by the bivalent's stimulus conflicting attributes and because the two tasks are at least partially available in WM. This availability seems to be modulated in terms of the ratio of presentation of the two tasks.

Specifically, in the last experiment performance on the difficult task was better relative to performance on the easy task under unpredictable conditions. This result seems to be in accordance with the proposal of Sumner and Ahmed (2006). However, their assumptions seem to be restricted only unpredictable cases. Under these cases, due to lack of strong endogenous control and the fact that probably the two tasks are at least partially maintained in WM a clear effect of priming/inhibition/control bias on task performance is evident.

Finally, this study reveals a reversal of the asymmetry effect. It has to be noted however, that the present data do not rule out the explanation (carry-over of inhibition) given in studies that reported an asymmetry effect. Instead, a very possible explanation is that the relative discrepancy in difficulty between the two tasks is not adequate in order to produce an asymmetry effect.

For instance, performing the difficult task in the present study might not require such a strong inhibition of the easy task such as to produce a substantial delay when the easy task must be performed again. Even when the easy task was primed, and thus became stronger, an asymmetry effect was not observed.

The reversal in task difficulty in overall performance (not a reversal in switch costs) was evident when the difficult task was primed and when weak endogenous control was applied (unpredictable condition). It is more plausible to assume therefore, that this reversal is more a result of priming/bias of the most presented task than of inhibition.

The present data suggest, either a complete absence, small differences or an equal carry-over of inhibition for the two tasks with one of the two last cases being more possible. While the literature provides several studies reporting asymmetrical switch costs between two tasks of different difficulty, this study aligns with studies that report a reversal of this asymmetry.

The present results impose one more restriction on the conditions needed to produce such an asymmetry. Further experimentation involving the manipulation of the discrepancy of the difficulty between tasks may shed light on the previously mentioned assumption.

3.8 CONCLUSION

Two conditions have been examined where presence and absence of strong endogenous control resulted in different patterns of switch costs. It seems that the main determinant of behaviour under predictable conditions happens in a top-down manner through the application of strong endogenous control. Under unpredictable conditions, a more relaxed supervision by the cognitive system in the selection of task-sets occurs.

However, evidence for some short of TSR seems to be present in unpredictable cases. Participants, according to their expectations, seem to have prepared accordingly the two competing tasks. The net outcome is a more flexible management of the available task-sets under unpredictable conditions relative to the rigid selection that takes place under predictable conditions.

4 TASK SIMILARITY EFFECTS

4.1 GENERAL INTRODUCTION

In the previous chapters the main focus was, a) on examining the relative influence of endogenous and exogenous control processes on task switching under various conditions and, b) in investigating further how this endogenous control manages through executive processes to efficiently manage the interference caused by exogenous control.

In general, up to this point it has been established that a different pattern of cognitive control occurs under predictable and unpredictable cases. Specifically, on predictable conditions strong endogenous control was evident. It was assumed that this control takes the form of inhibition of the irrelevant task when a task is repeated. The result is a nearly complete absence of any sign of exogenous influence in the form of interference on predictable non-switch trials.

In Chapter 2, this was manifested as a reduction of crosstalk effect while in Chapter 3 this was evident as an absence of the difficulty effect when a task was known in advance that would be repeated on trial *n+1*. On predictable switch trials, where the previously irrelevant task is now the relevant one, both crosstalk and difficulty effects were observed giving rise to several interactions. What was found is that even when a task (easy vs. difficult) was presented more or equally often to the competing task no changes in the pattern of switch costs were observed across the various manipulations (see Experiments 6, 7 and 8).

This was primarily attributed to a strong endogenous control that probably takes the form of inhibition of the irrelevant task on non-switch trials *n*. On a switch trial *n+1,* the previously irrelevant task now needs all or most of its components to be engaged in order for a correct response to be generated. Therefore, difficulty effects arise according to the specifications of each task.

On unpredictable trials, switch costs were predominantly found to be additive in nature (that was not the case for Experiment 7). In addition, the crosstalk and difficulty effects were found to have an effect on both unpredictable non-switch and switch trials. Moreover, in Chapter 3 the ratio of task presentation resulted in a modulation of the pattern of performance on unpredictable cases across Experiments 6 to 8. This was assumed to be a result of a weaker application of endogenous control on unpredictable conditions relative to the control applied under predictable conditions.

It was speculated that, the specific nature of endogenous control on unpredictable cases is primarily to either, a) with the modulation of the activatory/inhibitory biases of the two tasks according to the probability of their appearance on the upcoming trial, b) the carryover of these activatory/inhibitory biases onto the next trial due to lack of strong inhibitory processes or, c) a combination of both a and b.

A question that has arisen from these findings is what irrelevant task components this endogenous control inhibits. If two tasks have similar components then upon a switch trial less inhibition may be required because fewer components may need to be inhibited. The opposite can also be true if sharing many components leads to an increased task-set interference that also needs to be inhibited. A consequent step therefore in the thesis is to examine how tasks are related to each other – how tasks can be regarded as similar and if/how this similarity can affect somehow performance.

In general, studies that attempted to examine whether or not task switching involves switching between one or more components of the task-sets involved have not provided clear evidence that this variable clearly affects task switching performance. In particular, early studies indicated that there is actually no effect (Allport, Styles, & Hsieh, 1994). More recent work however, has provided evidence that under some conditions switch costs may increase when two task components, as opposed to one component, need to be switched prior to response on a switch trial (Hübner, Steinhauser, & Futterer, 2001).

In the first experiment of their study, participants had to classify numerals in terms of parity and magnitude by giving speeded response by pressing a button. The stimuli were large digits shaped by smaller digits. For instance, one of the stimuli in the study was a large ‘2’ that was formed by smaller ‘6’ digits. Before each trial, a cue appeared centrally on the screen and varied in terms of shape and size. The shape of the cue signalled which task was to be performed on the upcoming trial. An eclipse signalled the parity task while a square signalled the magnitude task. The size of the cue indicated the target level. A large cue informed participants that they should classify the global stimulus shape while a small cue that they should classify the local elements of the stimulus. For instance, if a large ‘2’ shaped by smaller ‘6’ digits was the stimulus then a small eclipse indicated that the number ‘6’ was to be classified in terms of parity.

Overall, in the experiment five different switching conditions were tested, a) both task and target level remained the same, b) the tasks changed randomly but the target level remained fixed, c) the task remained fixed but the target level changed randomly, d) both tasks and target levels changed randomly and, e) two blocks were presented where task and levels varied together (e.g., the parity task was presented always at the local level while the magnitude task was presented always at the global level).

Participants therefore, were tested in conditions where no task switching was required (cond. a), when switching between one task component (similar tasks) was required (conds. b and c), when switching between two task components (dissimilar tasks) was essential (cond. d) and finally, when switching between two linked components was necessary (cond. e). Analysis of the results revealed that the larger switch costs were observed when both task and levels varied independently (cond. d). It was assumed that when a selection of two independent task components is required during task execution, then more attentional control is necessary in order to adequately switch tasks. This requirement of more attentional control increases residual switch costs.

Finally, according to the authors, these results indicate that residual switch costs are not only a result of passive processes such as interference but rather their major portion can be attributed to attentional control that is required during task execution in order for a successful response to be given (Hübner, et al., 2001). This conclusion seems to be in line with the assumption stated in Chapter 2 - exogenous and endogenous control are not insulated from one another but rather there is an interplay between the two that determines performance.

It is essential at this point to define what components a task-set includes. A task-set predominantly contains three major kinds of components and that is, a) perception or encoding of the stimulus, b) manipulations or judgements about the stimulus, and c) response selection, programming and execution (Arrington, Altmann, & Carr, 2003).

In their study, similarly to the previously described findings, task similarity was found to facilitate task switching. Reduced switch costs were observed when participants had to switch between similar than dissimilar tasks. Specifically, two experiments were carried out.

In the first experiment, there were four classification tasks involving a rectangular target namely a height, width, hue, and brightness task. The first two involve processing of the spatial properties of the cue while the latter two involve processing of its surface properties. It is clear that, similarly to the previous study, the tasks could share an attentional selection component or not. The target was presented below a cue (the words ‘WIDTH’, ‘HEIGHT’, ‘HUE’, ‘BRIGHT’) with a delay of 500 ms on each trial. Participants had to give speeded responses using the keys of a standard keyboard. Trials were sorted in 16 conditions based on which of the four tasks was presented the on trial *n* and trial *n-1*.

The results revealed a similarity effect as described previously. Performance was impaired when participants had to switch between tasks that did not share an attentional component than when they switched between task that shared an attentional component. In addition, the fact that this similarity effect was not found to interact with task indicates that the improvement of performance cannot be attributed to the specific switch demands of each task (task difficulty).

In their second experiment, the researchers manipulated task similarity in terms of the response output modality component rather than attentional selection component. In particular, participants had to classify the height of a rectangle as tall or short by using a response set that varied according to the cue. Two of the response sets involved manual responses while the other two involved vocal responses. Trials therefore could include a switch or repetition of response modality from a trial *n* to a trial *n+1*.

The manual response sets required, in one case, that the participants had either to use their first finger of their left and right hands in order to respond and, in the second case, their second fingers of the left and right hands respectively. The vocal response set, required the verbalization of the numbers ‘1’ and ‘2’ in one case, and the verbalization of the letters ‘A’ and ‘B’ in the other case. Instructions were given that specified how the above described response sets mapped onto the ‘tall’ or ‘short’ rectangle response. The methodology resembled closely that of experiment 1 and the cues this time consisted of the words ‘FIRST’, ‘SECOND’, ‘NUMBER’ and ‘LETTER’.

The results of the second experiment were similar to that of the first experiment. Performance was impaired when participants had to switch between trials that required a shift in response modality relative to trials when this shift was not required (Arrington, et al., 2003).

Concluding, results in studies that have compared switch performance between similar tasks (tasks that shared a component) against dissimilar tasks (tasks that did not share components) demonstrated that switch performance is impaired when a switch to a dissimilar task is required. Task similarity was defined as to whether or not two or more tasks share a component that belongs to one of the three following categories of components namely, perception or encoding of the stimulus, manipulations or judgements about the stimulus, and response selection, programming and execution (Arrington, et al., 2003).

Despite the fact that the results are clear-cut and provide strong evidence for a similarity effect on task switching, it seems that the previously mentioned studies have examined the phenomenon by manipulating task similarity in terms of tasks that do or do not share an attentional/response component. What remains to be studied is how switch performance is affected when two tasks do or do not share components that belong to the ‘manipulations or judgements about the stimulus category’.

In their study Arrington et.al. (2003), indicate that there can be several boundaries to the similarity effect. Specifically, they note that as the tasks get increasingly dissimilar the switch costs will not continue to decrease. For instance, it is established (see Chapter 2) that when stimuli are univalent switch costs are greatly reduced relative to switch costs in conditions involving bivalent stimuli. In terms of task similarity however, univalent stimuli have unique components and appear to be less similar relative to bivalent stimuli with overlapping components.

Moreover, it is not certain that increasing similarity will definitely result in a decrement in performance. In the second experiment by Arrington et al. it was shown that when participants switched between manual responses made with different fingers RTs were faster relative to when switching between a vocal and a manual responses.

Based on this finding, the authors point out that one might extrapolate to a situation that involves even more similar response sets (like the one used in the thesis’ previous experiments where participants had to use the same set of finger responses to classify two different tasks) and predict even more rapid responses between these tasks due to an increase of similarity of the responses relative to the responses in their study. However, as they also clarify, the opposite of the outcome predicted by the similarity effect can be true. Bivalent responses (two tasks share the same response set) can lead to greater switch costs than univalent responses (two tasks have different response sets) due to response set conflict (Meiran, 2000).

Similarly, results in a study that presented two stimuli on different SOAs revealed that crosstalk occurs when the same task (e.g a parity task) has to be performed on both the first and the second stimulus relative to cases where a parity task is followed by the same task (Logan & Schulkind, 2000). Concluding, Arrington et al. proposed that when sequential switching from one task to another is required (as in univalent trials) then similarity between the two tasks facilitates performance. In contrast, when two similar tasks are activated/required concurrently (as in bivalent trials) interference may occur. This interference between the two tasks must be resolved prior to the response resulting in a slowing of performance.

In the present study, the previously discussed findings and assumptions will be examined further under conditions where bivalent alphanumerical stimuli will be used (e.g., G4) mapped onto the same response sets (e.g., even/consonant response mapped onto a key pressed by the left index finger) and under predictable and unpredictable conditions. Given that in both similar and dissimilar conditions stimuli will be bivalent and that response sets will overlap it is assumed that task similarity is manipulated only onto a conceptual level.

Specifically, in the current study task similarity will not be examined at a response or attentional/perceptual level like in the studies described previously. Task similarity will be defined in regard to which semantic set a stimulus invokes upon presentation. In that case, the parity task is regarded as similar to the magnitude task because they both involve the interpretation and understanding of the semantic properties of numbers. In contrast, the parity/magnitude tasks are regarded as dissimilar to the consonant/vowel categorization task because the latter involves a different semantic set – the interpretation and understanding of the semantic properties of letters.

Based on the literature, it is expected therefore that performance will be better when participants will have to switch between two conceptually similar tasks (parity vs. magnitude task) rather than when they have to switch between conceptually dissimilar tasks (letter classification vs. parity task). In the first case, the two tasks share similar components that are not needed to be changed on switch trials leading to improved performance (due to less number of components that is needed to be switched prior to a successful response). In contrast, the opposite should be true in the latter case where switching between dissimilar tasks is required.

4.2 EXPERIMENT 10

Central to this experiment are two numerical and one alphabetical task. For the reasons described earlier, it is expected that when participants have to make responses on blocks of trials where dissimilar tasks are presented (numerical vs. alphabetical classification task) switch costs will be larger relative to blocks of trials where similar tasks are presented (numerical vs. numerical classification task).

4.2.1 Method

4.2.1.1 Participants

Participants were 24 university students (18 females) with a mean age of 22.8 (4.9 SD) years old. They all took part on this experiment for either course credit or payment. They all reported having normal or corrected to normal vision and hearing while four were left-handed.

4.2.1.2 Design and stimuli

Central to the experiment were three classification tasks. The same magnitude and parity tasks were used as before. A letter classification task was also used - on each trial participants had to decide whether the letter was consonant or vowel. The 1, 2, 3, 4, 6, 7, 8, 9 digits and the A, E, U, B, R, G, T, O letters were used as stimuli. On each trial, a pair of characters was presented and participants had to make a speeded key press. Letters and digits appeared randomly either as first (left) or second (right) character in the pair. There was a left and a right response key and the ‘consonant’, ‘even’ and ‘high’ responses were assigned to the left key and the ‘vowel’, ‘odd’ and ‘low’ responses to the right key.

Prior to the experimental trials, participants underwent training blocks of trials where on each trial a single character was presented centrally on the screen. Blocks of trials were generated for each classification task. Each block of trials contained 24 cases and individual letters and digits were equally represented in each of their blocks (3 times each). The training session comprised 18 blocks - 6 parity (odd/even classification) blocks, 6 magnitude (high/low classification) blocks and 6 letter (consonant/vowel classification) blocks of trials. The session was initiated by a letter classification block followed by a parity classification block, followed by a magnitude classification block and the presentation continued accordingly until the end.

During the experiment, participants were presented with 3 sequences each consisting of 8 blocks of trials. in each sequence, only two of the previously mentioned tasks were presented. Therefore, in one sequence participants had to make parity and letter classifications, in another they had to make parity and magnitude classifications, while in the other they had to make magnitude and letter classifications.

On each sequence, blocks of trials were divided equally according to two main conditions – a predictable and an unpredictable one. In the predictable condition (e.g., in the parity and magnitude classification sequence), the sequence of trials was configured according to alternating runs paradigm (e.g., PPMMP...).

The blocks of trials were configured similarly to the ones described so far. In a given block of trials, there were 48 instances. Across the 48 trials there were equal numbers of switch and non-switch trials, equal numbers of congruent, incongruent and neutral trials, equal numbers of each of the two competing task trials, and finally there were equal numbers of left (consonant/even/low) and right (vowel/odd/high) key presses.

The RSI was fixed throughout the experiment at 1200 ms. Across the experimental trials, a within participants design was used containing four factors, pair type (congruent, incongruent or neutral), trial transition (switch or non-switch), predictability (predictable or unpredictable), and task (magnitude, parity or letter).

On the experimental trials, the fixation plus sign was followed by the display of the character pair in red, green or blue font. Participant’s task was to classify the letter type (consonant/vowel) when the character pair appeared in red font, the digit’s parity (odd/even) when the character pair appeared in green font and finally the digit's magnitude (high/low) when the character pair appeared in blue font.

4.2.1.3 Apparatus

The software and hardware that was used in this series of experiments was identical to that used in the previous chapters.

4.2.1.4 Procedure

The procedure for the training and experimental trials was very similar to that used in the experiments described up to this point. The difference here was that during the training session eight of the blocks consisted of pairs with the task being parity classification, another eight consisted of pairs with the task being magnitude classification, while on the other blocks the task was letter classification.

The main experiment required participants to go through three sequences of eight blocks each. In each sequence only two of the three previously discussed tasks were presented. For each sequence, four blocks of trials were predictable blocks while the remaining four were unpredictable blocks of trials. Each block consisted of 48 trials. The presentation of sequences was counterbalanced across participants.

4.2.2 Results

4.2.2.1 Training trials

Error responses and very fast responses (less than 100 ms) were excluded from the analysis of the RT data. As a result, an exclusion of 3.2% of scores has occurred prior to data analysis. Separate analyses were carried out for mean correct RTs and percentage errors.

For both data sets a one-way analysis of variance (ANOVA) was carried out in which the within participants factor was task with three levels (consonant/vowel, high/low, and odd/even tasks).

4.2.2.1.a RTs

The analysis revealed a statistically significant main effect of task [$F(2, 46) = 3.895$, $MS_e = 2922$, $p < .05$]. A Tukey's HSD test revealed that the odd/even task (651 ms) was significantly slower than the high/low task (609 ms) while the consonant/vowel task RTs (627 ms) did not differ from either of the two previously mentioned tasks ($p < .05$).

4.2.2.1.b Error rates

Error rates were analyzed the same way as RTs .The ensuing ANOVA revealed a main effect of task [$F(2, 46) = 46.054$, $MS_e = .019$, $p < .001$]. The ensuing Tukey's HSD test revealed that there was no statistically significant difference in accuracy between the odd/even and the consonant/vowel task whereas performance was significantly less accurate on both when relative to the high/low task ($p < .05$).

4.2.2.2 Switch costs analysis

Following Arrington et. al. (2003), the main concern is with switch costs. Specifically, of main interest in this experiment is the direct comparison of the two numerical tasks and the modulation of their switch costs when each is paired with either a similar (numerical) or a dissimilar (alphabetical) task. The alphabetical task's switch costs will be tested individually as it is paired with a dissimilar (numerical) task in all cases. The corresponding switch costs for the two numerical tasks (switch – non-switch trials RTs) were entered into a three-way within participants analysis of variance (ANOVA). The within participants factors were the task (odd/even vs. high/low task), predictability (predictable vs. unpredictable trials) and similarity (similar vs. dissimilar task). Excluded scores for the relevant data are reported in detail in Appendices 51 to 53. The results revealed a statistically significant main effect of task [$F(1, 23) = 8.409$, $MS_e = 39022$, $p < .01$], indicating that switching to the odd/even task was harder relative to switching to the high/low task. The predictability effect is exactly the same as before [$F(1, 23) = 10.660$, $MS_e = 40342$, $p < .01$]. In particular, predictable switch costs were found to be larger relative to unpredictable switch costs. Furthermore, two interactions namely the task x predictability [$F(1, 23)$

= 4.625, MS_e = 16074, $p < .05$], and the task x similarity [$F(1, 23) = 7.811$, MS_e = 11284, $p < .05$], were found to be statistically significant. For the task x predictability interaction further analysis with a Tukey's HSD test revealed that the odd/even task's predictable switch costs (387 ms) were significantly larger when relative to both the corresponding unpredictable switch costs (253 ms) and the high/low predictable (265 ms) and unpredictable (210 ms) switch costs. No other comparison revealed statistically significant differences ($p < .05$, both comparisons).

A Tukey's HSD test was run for the task x similarity interaction. Results revealed that switch costs for the odd/even task, when that was paired either with the similar (high/low - 312 ms) or dissimilar task (consonant/vowel - 328 ms), were larger relative to the high/low task's switch costs, when the latter was paired with either the similar (odd/even - 272 ms) or the dissimilar task (consonant/vowel - 202 ms). Finally, switch costs for the high/low task were found to be smaller when that was paired with the dissimilar task relative to when it was paired with the similar task. A graphical illustration for the switch costs for the two numerical tasks when these were paired with a similar or dissimilar task is presented in Figure 18.

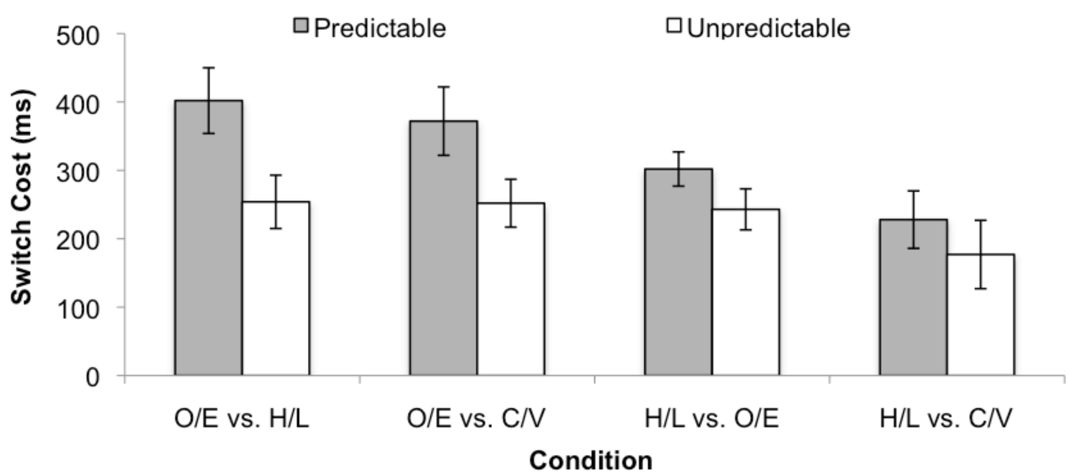


Figure 18: Graphical illustration of switch costs for the two numerical tasks (O/E and H/L) when paired with the numerical (O/E or H/L) and the alphabetical (C/V) tasks respectively in Experiment 10. Error bars represent the standard error of the mean (SE). Switch Cost = (switch trial RT – non-switch trial RT), Predictable = Predictable trial transition, Unpredictable = Random trial transition, H/L = high/low classification task, C/V = consonant/vowel classification task, O/E = odd/even classification task.

The consonant/vowel switch cost analysis revealed only a main effect of predictability [$F(1, 23) = 15.072$, $MS_e = 11193$, $p < .01$]. Predictable switch costs were larger relative to unpredictable switch costs. As expected, a task similarity effect was not uncovered because the consonant/vowel task was performed in both conditions with a dissimilar (numerical) task. A graphical illustration for the switch costs for the consonant/vowel task is presented in Figure 19.

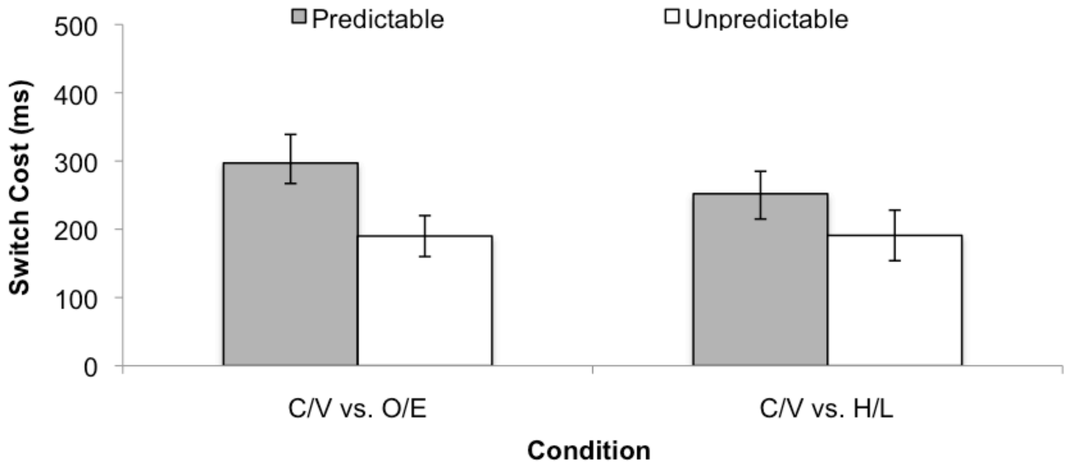


Figure 19: Graphical illustration of switch costs for the alphabetical task (C/V) when paired with the numerical (O/E or H/L) tasks in Experiment 10. Error bars represent the standard error of the mean (SE). Switch Cost = (switch trial RT – non-switch trial RT), Predictable = Predictable trial transition, Unpredictable = Random trial transition, H/L = high/low classification task, C/V = consonant/vowel classification task, O/E = odd/even classification task.

The key finding from this analysis is, in contrast to Arrington et. al. (2003) results, that there was a case where switch costs reduced when a task (high/low) was paired with a dissimilar task relative to when it was paired with a similar task (odd/even). This reduction in switch costs was relatively uniform between predictable and unpredictable cases implying at first sight that common components are responsible for it are across the two cases (as defined by the task switching model discussed in the previous chapter). The fact that there was no other effect on switch costs when a task was paired with either a similar (high/low) or dissimilar task suggests that the similarity effect, as described by Arrington et. al. (2003), can only be uncovered under specific conditions. As the current results show, not only are there cases in which there is no similarity effect when comparing similar task's to dissimilar task's switch costs but the opposite to what Arrington et al. (2003) suggests can be true – switch costs can decrease when switching between dissimilar tasks relative to when switching between similar tasks. Therefore, while it is true that when two tasks share components switching between them can be easier relative to when they do not share components, the opposite can also occur. The reason behind these contradicting findings probably has to do with the nature of the shared components.

In the previous studies, including Arrington et. al. (2003) study, task similarity was manipulated at a perceptual/attentional or response level. In the present study, task similarity was manipulated at what was defined as a conceptual level. In Arrington's et. al. (2003) study, it is suggested that when components are common between tasks then less components need to be switched when switching between similar tasks relative to when switching to dissimilar tasks resulting in smaller switch costs in the first. This result however, seems to have a generalizability limit. It seems that when tasks share perceptual/attentional or response components it is easier to switch between them relative to when tasks share conceptual components. This difference in the pattern of switch costs across the two conditions may result from task-set interference occurring between conceptually similar tasks. Sharing conceptual components may result in an unintentional activation of the irrelevant task resulting in an increase in switch costs. This idea will be discussed further in the Discussion section.

In sum central aim of this experiment was to investigate the similarity effect on task switching performance. Task similarity was defined as to whether or not different tasks share components at an attentional/perceptual, response level, or conceptual level. It is primarily suggested that switching between two tasks that share a component (similar tasks) is easier relative to switching between tasks that do not share such a component (dissimilar tasks). While this has been empirically established for tasks that share components at an attentional/perceptual or response level, conditions seem to apply where the opposite is true – switch costs can increase when switching between two conceptually similar tasks relative to when switching between conceptually dissimilar tasks.

The present experiment, in which tasks were regarded as similar when they shared a component at a conceptual level (numerical task vs. numerical task) demonstrated a condition that contradicts Arrington et. al. (2003) findings - a reverse similarity effect occurred. Specifically, it has been shown that switch costs for a numerical task (high/low) decreased when switching was required from/to an alphabetical task (consonant/vowel) relative to when switching was required from/to a numerical task (odd/even). Further analyses of the data will be used in order to discuss further the model advanced in Chapter 3.

4.2.2.3 RTs and error rates analysis

Primary aim of this analysis is to enhance coherence in the thesis by verifying the general assumptions stated so far. In addition, it is important to examine with further data the task switching model's central ideas proposed in the previous chapter. Emphasis will be given on summarizing RT data in this section since conclusions of the current and previous studies are based mostly on these. Error data will be reported here only in the case of a speed-error trade off. Effects will be reported as significant at the $\alpha = 0.05$ level. The detailed RTs and error analysis for the relevant conditions is included in Appendices 51 to 53. Overall, the results from the RTs and error rates analysis are in accord with the previous findings in the thesis. Specifically, in all conditions, a trial transition main effect was found - switch trials were overall slower and less accurate relative to non-switch trials. That was also true for predictable cases - a predictability main effect was revealed indicating that performance was facilitated when advance foreknowledge for the upcoming trial was provided relative to when no foreknowledge was available.

A predictability x trial transition interaction was found in all cases indicating that switch costs were also larger on predictable relative to unpredictable cases. In addition to the findings described earlier, when the high/low task was paired with the consonant/vowel an additional interaction, namely the predictability x task interaction was found to be statistically significant. The interaction is driven by the fact that the difference between the predictable and unpredictable RTs for the high/low task is larger relative to that of the consonant/vowel task. Figure 20 provides a graphical illustration of the summary RT and error rate data for the condition of interest.

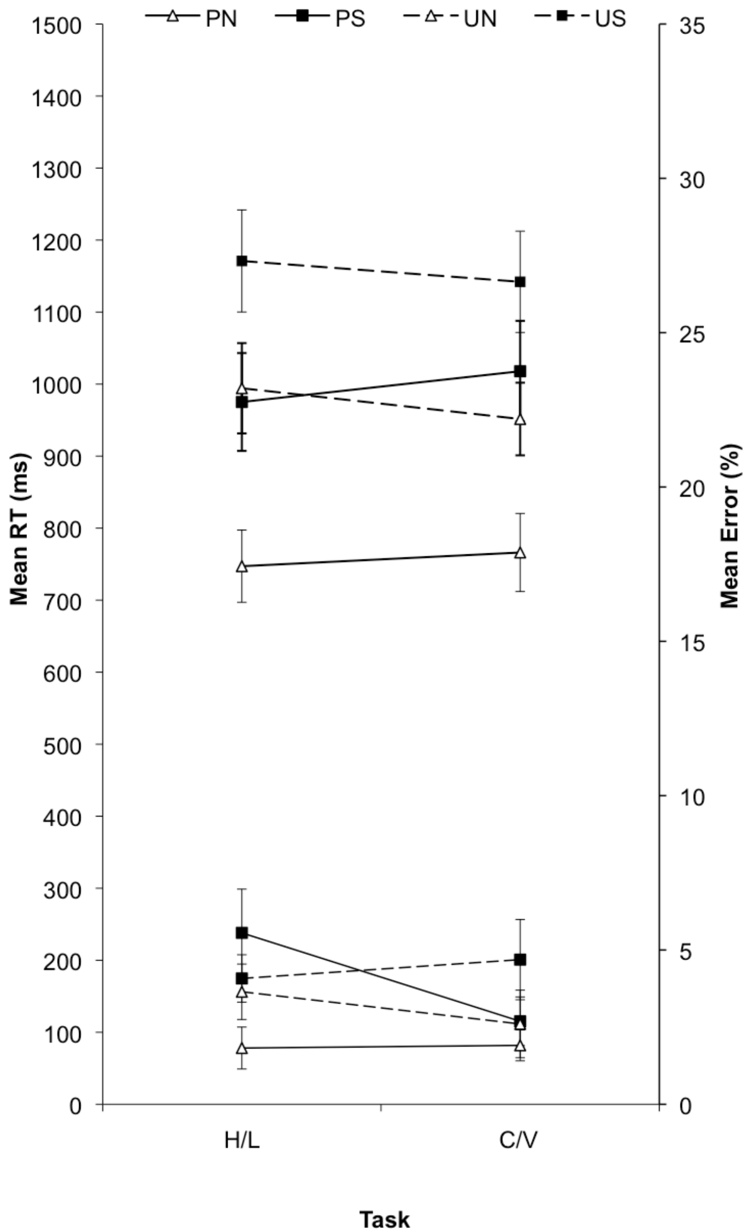


Figure 20: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 10. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials, H/L = high/low classification task, C/V = consonant/vowel classification task.

When the consonant/vowel task was paired with the odd/even task, in contrast to the previous condition, an additional main effect of task was revealed. Performance on the odd/even task was slower relative to consonant/vowel task.

In addition to the central findings described in the beginning of the section, two interactions, namely the predictability x task and task x trial transition interactions were found to be statistically significant. For the predictability x task interaction, data revealed that RTs in unpredictable cases were slower for the odd/even task relative to the consonant/vowel task. That was not true for predictable RTs that were very similar for both tasks.

Finally, for the task x trial transition interaction, data revealed that overall switch costs were larger for the odd/even task relative to the consonant/vowel task. A graphical illustration of the summary RTs and error rates for the condition of interest is presented on Figure 21.

Similarly to the previous condition, a task effect was revealed when the odd/even task was paired with the high/low task. RTs on the odd/even task were slower relative to the high/low task. A graphical illustration of the summary RTs and error rates is for this condition is presented on Figure 22.

A central finding of the present analysis is that a task difficulty effect similar to that described on the previous chapter was also found here whenever two different in difficulty tasks (as defined in the training analysis) were performed in a given block of trials. It has to be noted here, that the odd/even task was not defined as a more difficult task relative to the consonant/vowel task in the training trials. On experimental trials however, when the two tasks were performed on the same block of trials the average RT for the odd/even task was significantly slower relative to that of the consonant/vowel task. This deviation of task difficulty between the training and experimental trials supports some central ideas of the task switching model proposed in the previous chapter.

Specifically, it provides evidence that, a) the discrepancy in difficulty between two tasks is a key determinant to performance and, b) that there is an interplay between task components when switching between two tasks is required (e.g., experimental trials) meaning that performance of a given task is in part determined by properties of the competing task. A graphical illustration of the RTs for the two tasks in the conditions of interest is presented in Figure 23.

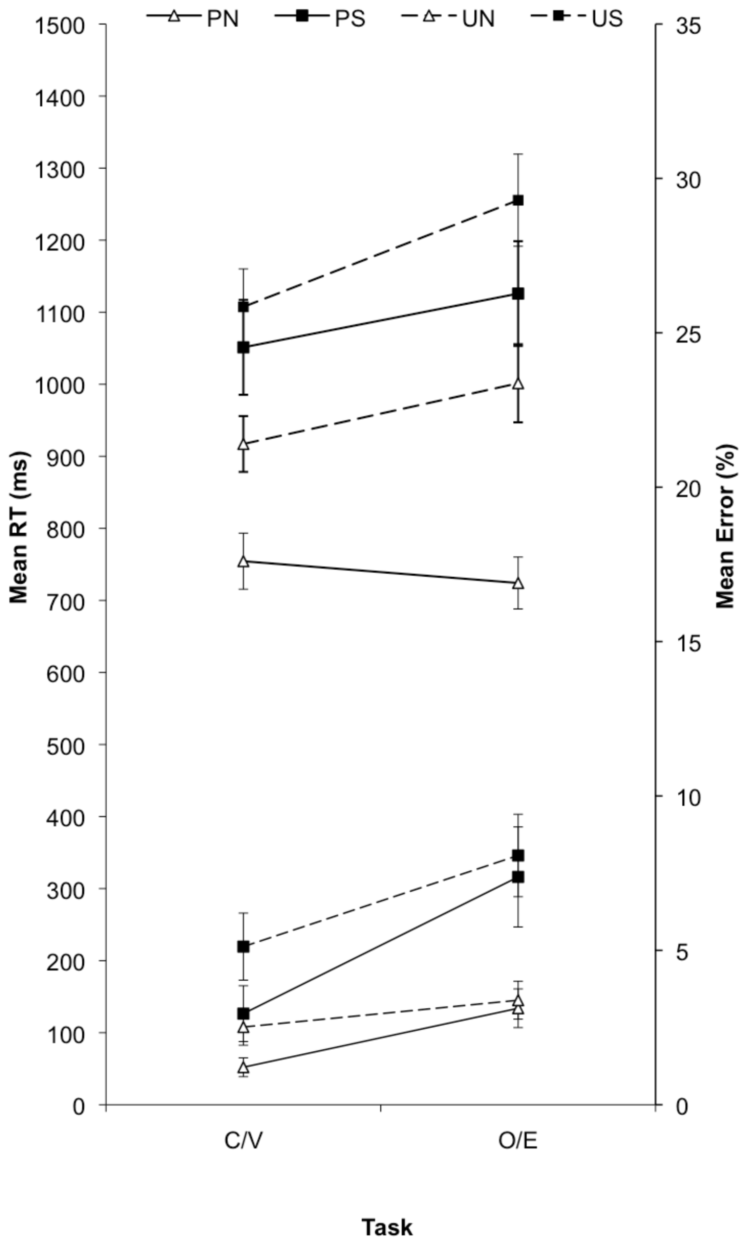


Figure 21: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 10. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch trials, PS = Predictable switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials, O/E = odd/even classification task, C/V = consonant/vowel classification task.

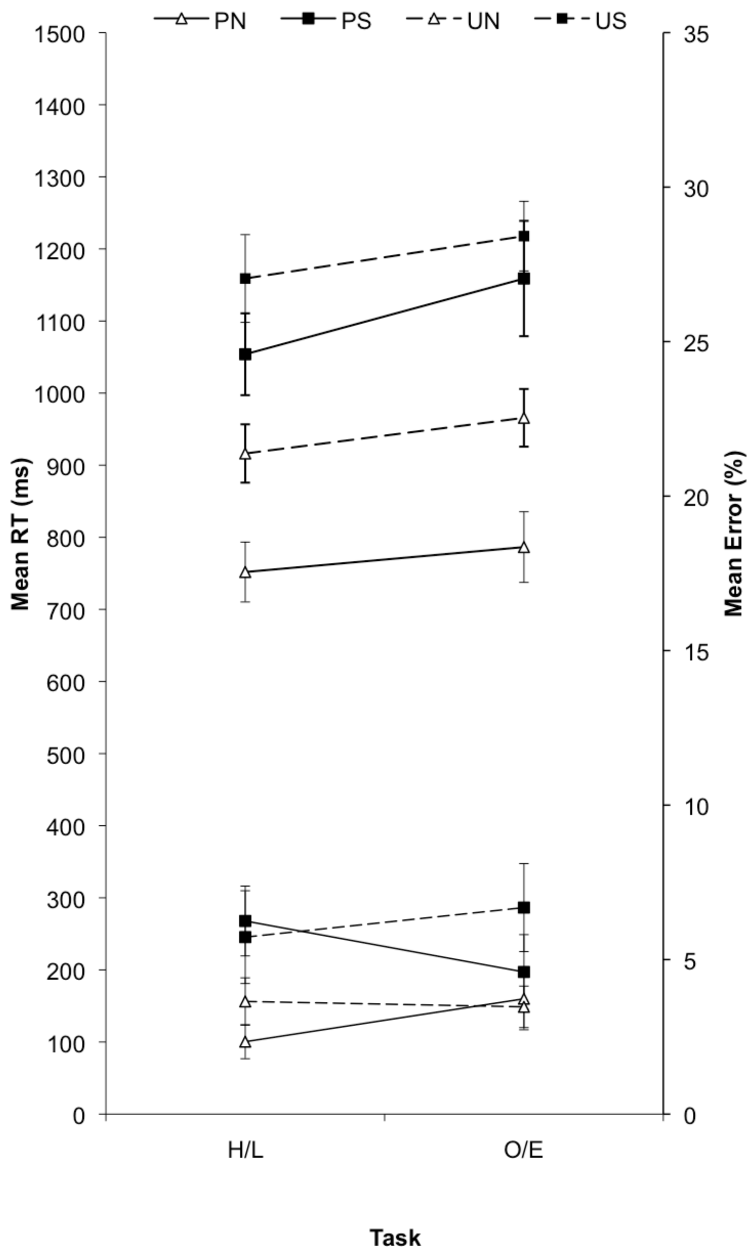


Figure 22: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 10. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials, H/L = high/low classification task, O/E = odd/even classification task.

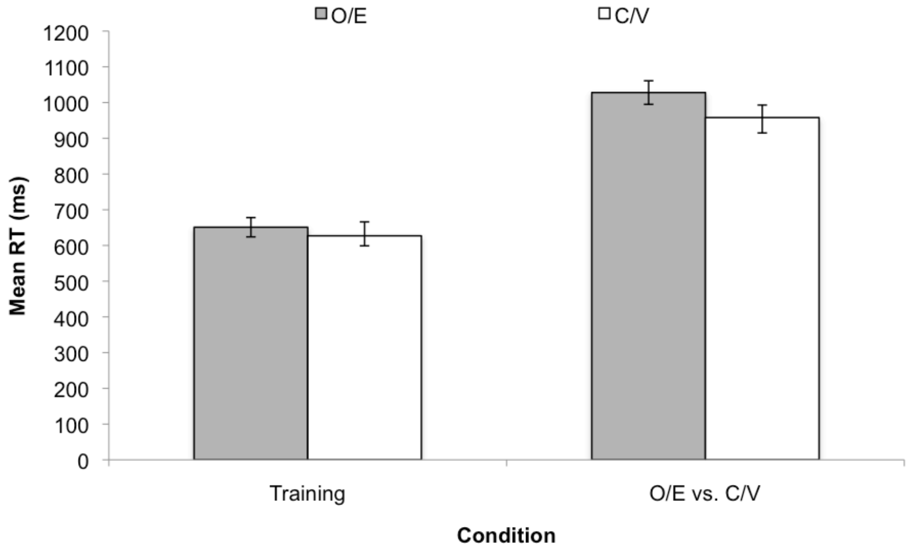


Figure 23: Graphical illustration of the RTs for the C/V and O/E tasks across the training and experimental trials in Experiment 10. Error bars represent the standard error of the mean (SE). C/V= consonant/vowel classification task, O/E = odd/even classification task.

Finally, a task difficulty effect was absent in predictable non-switch trials in all conditions (paired t-test, $p > .05$). This result replicates the previous findings and strengthens the assumption that when a non-switch trial is expected then the current task is maintained in WM in order to be readily available on the next trial. A more extensive discussion of the results is provided on the following section.

4.2.3 Discussion

As stated before, the main effects of predictability and trial transition discussed so far in the thesis were also replicated by this experiment in every condition. In addition, switch costs were found once again to be larger on predictable relative to unpredictable cases. The focus of the present experiment was to examine the effect of task similarity on switch costs. Tasks were defined as similar when they shared a component at a conceptual level (numerical task vs. numerical task). The results revealed a condition that contradicts Arrington et. al. (2003) findings, no similarity effect was found and in one case a reverse similarity effect occurred on switch costs. Specifically, it has been shown that switch costs for a numerical task (high/low) decreased when switching was required from/to an alphabetical task (consonant/vowel) relative to when switching was required from/to a numerical task (odd/even). It is of primary interest for the thesis to examine further this reduction in switch costs and uncover any difference in the pattern of reduction across predictable and unpredictable cases. An attempt to explain the results will be made, in terms of the task switching model discussed on the previous chapter, later on this section. At first sight, the decrease of predictable and unpredictable switch costs seems to occur in a similar manner across predictable and unpredictable conditions. However, further analysis of the RT data for the high/low task where the within participants factors were predictability (predictable vs. unpredictable trials), trial transition (switch vs. non-switch trials) and similarity (similar vs. dissimilar task) revealed a predictability x trial transition interaction, [$F(1, 23) = 5.680$, $MS_e = 10340$, $p < .05$]. The main effect of predictability, [$F(1, 23) = 24.855$, $MS_e = 61258$, $p < .001$] and trial transition, [$F(1, 23) = 64.092$, $MS_e = 42201$, $p < .001$] were also found to be statistically significant. A graphical representation of the RTs for the high/low task across conditions is presented on Figure 24.

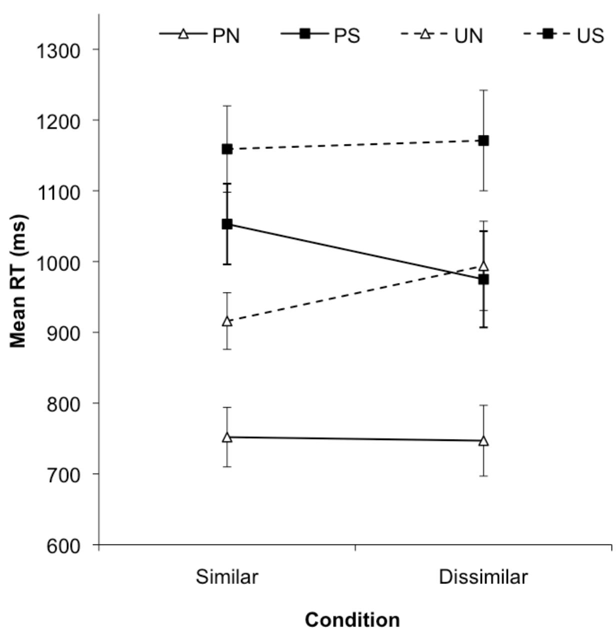


Figure 24: Graphical illustration of the RTs for the high/low task across conditions in Experiment 10. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials, Similar = odd/even classification task, Dissimilar = consonant/vowel classification task.

Closer observation of the interaction revealed that the reduction in predictable switch costs is primarily attributed to a decrease in RTs on predictable switch trials when the high/low task was paired with the consonant/vowel task (975 ms) relative to when it was paired with the odd/even task (1054 ms). The predictable non-switch trials remained relatively unaffected across conditions (747 ms and 752 ms for the first and latter condition respectively). On unpredictable trials, the opposite pattern of RTs was observed. A decrease on switch costs was primarily a result of an increase in RTs on non-switch trials when the high/low task was paired with the consonant/vowel task (994 ms) relative to when it was paired with the odd/even task (916 ms). Unpredictable switch trials RTs remained relatively unaffected across conditions (1171 ms and 1159 ms for the first and latter condition respectively).

At first sight, it appeared that the reduction in switch costs (when the high/low is paired with the dissimilar task) was similar between predictable and unpredictable cases. Closer inspection of the results nevertheless, revealed that the source of this reduction is different between the two cases. On predictable trials, there is a marked decrease of RTs on switch trials whereas on unpredictable cases there is a marked increase on RTs on non-switch trials when the high/low task is paired with the dissimilar task relative to when it is paired with the similar task. Predictable non-switch and unpredictable switch trials RTs remain unaffected across conditions.

It is of interest to examine how the task switching model discussed earlier in the thesis accounts for this pattern of results. It seems reasonable that RTs on predictable non-switch trials remain unaffected across conditions since the model assumes that once the task is loaded in WM and as long as a task repeat is expected then the task is maintained in WM for further use on the upcoming trial. In the model there is no component of the irrelevant task-set that affects the RTs for these trials therefore RTs should remain unaffected regardless of the nature of the competing task. Essentially, the common processes (*CP*) and task maintenance (*TM*) components determine RTs when a task repetition is expected.

The RT on a predictable non-switch trials is given by Equation 3 of the model:-

$$RT_{\text{Pred-NSw}} = CP + TM$$

Unpredictable switch trials' RTs remain also unaffected across conditions. It was equally difficult to switch to the high/low task from trials that involved the odd/even or consonant/vowel task. A central assumption of the model is that on unpredictable cases an effort is being made in order to have both task-sets partially active in WM aiming to keep both of them readily available for the upcoming trial. Unpredictable switch RTs for the high/low task were very similar regardless of the similarity of the competing task. However, these similar results may be the result of different processes.

The corresponding equation for unpredictable switch trials is given in Equation 9 of the model:-

$$RT_{\text{Unpred-Sw}} = CP + TSR$$

Where TSR is given by equation 5:-

$$TSR = COI + RTP + ITS$$

Specifically, it should be expected that when switching from a similar task (odd/even) to the high/low task faster RTs should be observed in the latter relative to when switching from a dissimilar task (consonant/vowel). That is, because similar tasks share components that are held in WM. These components do not need to be changed upon an unpredictable switch trial as in the case of switching between dissimilar tasks.

However, the fact that tasks share components has a drawback – it may lead to an extra bias towards the unintentional activation of the more recently performed task. This extra bias, not present when tasks do not share components, needs to be overcome in order to respond increasing RTs in unpredictable switch trials involving similar tasks.

In sum, on unpredictable switch trials involving dissimilar tasks more task components need to be changed when switching tasks relative to trials involving similar tasks. On the latter cases, fewer components need to be changed when switching tasks however an extra bias to activate the irrelevant task occurs relative to cases involving dissimilar tasks. The result is an additional, but different between cases, process in both similar and dissimilar conditions resulting in similar RTs between the two.

If the above assumption is true, then components such as relevant task priming (*RTP*) or irrelevant task suppression (*ITS*) should have equal values in both similar and dissimilar task switching conditions reflecting nevertheless different processes.

RTP is defined via Equation 7:-

$$RTP = TS_{(r)} \times ME$$

While ITS is defined via Equation 8 of the model:-

$$ITS = TS_{(\mathrm{i})}$$

The idea that an extra bias occurs towards the activation of the more recently performed task on unpredictable blocks of trials involving similar tasks is further supported by the unpredictable non-switch trials' RTs. Specifically, on unpredictable non-switch trials an increase on RTs is observed when the high/low task is paired with the consonant/vowel task relative to when it is paired with the odd/even task. The model assumes that on unpredictable non-switch trials performance is better relative to unpredictable switch trials because it is easier to activate the relevant and suppress the irrelevant to the trial task. This process is reflected on the repetition bias (*rb*) component.

RT for the unpredictable non-switch trials is given in Equation 10:-

$$RT_{\text{Unpred-NSw}} = CP + TSR \times rb$$

Given that in the model all of the components except the repetition bias (*rb*) are common between unpredictable switch and non-switch trials it should be assumed that task similarity has an effect on the cognitive process that is reflected by this component (*rb*). Repetition bias is more effective on blocks of trials where similar tasks are presented because common conceptual components are held active constantly in WM leading to an extra bias (relative to when switching between dissimilar tasks) towards the activation of the more recently performed task (as discussed previously).

While this process may lead to a slowing of performance on unpredictable switch trials it leads to a speeding of performance on unpredictable non-switch trials involving similar tasks relative to trials involving dissimilar tasks. The speeding in RTs on unpredictable non-switch trials involving similar tasks relative to dissimilar tasks is reflected in smaller *rb* values on the first relative to the second case.

Finally, RTs on predictable switch trials were found to be facilitated when the high/low task was paired with the dissimilar consonant/vowel task relative to when it was paired with the similar odd/even task. This finding is probably a result of increased task-set interference in the latter case.

RT for the predictable switch trials is given in Equation 4 of the model:-

$$RT_{\text{Pred-Sw}} = CP - AP + TSR$$

On blocks of trials where similar tasks were presented an unintentional activation of the irrelevant task may have occurred more often relative to cases where dissimilar tasks were presented. Specifically in the current experiment, when two numerical tasks were presented they shared, between other components, the same aspect of the stimulus (digit). That was not the case in conditions where a numerical and an alphabetical task were presented. In that case, tasks utilized a different aspect of the stimulus (digit or letter).

Therefore, it is probable that when similar tasks were presented, the common aspect of the stimuli triggered the irrelevant task more often relative to when dissimilar tasks were presented. This resulted in an increase of RTs in the first case relative to the second case. The model seems able to account for this pattern of results due to a component that mirrors suppression of the irrelevant task. Based on the results, the irrelevant task suppression component (*ITS*) of the equation should take higher values (resembling more effort – increased RTs) when two tasks are similar relative to when two tasks are dissimilar in order for the model to simulate adequately the data. The previously described pattern of RTs nevertheless was not evident for the odd/even task. Switch costs remained unaffected regardless of which task was the switched-from task. The fact that the odd/even task remained unaffected regardless of the task that it was paired with may have to do with task difficulty. Analysis of the training trials, in accordance with previous findings in the thesis, revealed that the odd/even task was more difficult to perform relative to the high/low task. The odd/even task's difficulty may in part arise from the fact that whenever a digit is presented an unintentional activation of the high/low task occurs causing interference. If that is the case, then it should be expected that performance on the odd/even task would remain relatively unaffected even in cases where the high/low task is not included in an experiment. Finally, it is noteworthy that while in the training session the consonant/vowel did not differ in difficulty from the odd/even task, a task effect emerged on experimental trials when switching between the two was required. In that case, the odd/even task was found to be more difficult relative to the consonant/vowel task. These findings along with the previously discussed assumptions will be examined further in the following experiment.

4.3 EXPERIMENT 11

In the second and final experiment of this chapter, two alphabetical and one numerical task were presented in an attempt to extend the findings of the previous experiment. Based on the previously discussed effects, it is expected now that when participants have to make responses in blocks of trials where dissimilar tasks are presented (numerical vs. alphabetical classification task) switch costs will decrease (or remain unaffected but not in any case increase) relative to blocks of trials where similar tasks are presented (alphabetical vs. alphabetical classification task). Moreover, it is of interest to examine the pattern of results in the present experiment in an identical condition of the previous experiment (consonant/vowel vs. odd/even task). The pattern of performance in the specific condition should be similar across the two experiments. Any deviation should be examined and discussed on the basis of the third task involved, as this is the central difference across the two experiments.

4.3.1 Method

4.3.1.1 Participants

Participants were 24 university students (16 females) with a mean age of 20.8 (2.0 SD) years old that took part on this experiment for either course credit or payment. They all reported having normal or corrected to normal vision and hearing while one was left-handed.

4.3.1.2 Design and stimuli

The design of the present experiment resembles closely that of the previous experiment. The critical difference here is that the numerical magnitude task was replaced by an alphabetical classification task namely the 'half task' (Schneider & Logan, 2007).

In that case, participants when cued they had to classify whether a letter belonged to the first or the second part of the alphabet. Characters belonging to the first part of the alphabet were considered the A, E, B, G letters while the R, O, T, U letters were considered to belong to the second part of the alphabet. Every other aspect of the experiment was the same as that of the previous one.

4.3.2 Results

4.3.2.1 Training trials

Error responses and very fast responses (less than 100 ms) were excluded from the analysis of the RT data. As a result, an exclusion of 9.1% of scores has occurred prior to data analysis. Separate analyses were carried out for mean correct RTs and percentage errors. For both data sets a one-way analysis of variance (ANOVA) was carried out in which the within participants factor was task with three levels (consonant/vowel, first/second, and odd/even tasks).

4.3.2.1.a RTs

The analysis revealed a statistically significant main effect of task [$F(2, 46) = 4.517$, $MS_e = 5595$, $p < .05$]. A Tukey's HSD test revealed that the first/second task (739 ms) was significantly slower ($p < .05$) than the odd/even task (671 ms) while the consonant/vowel task RTs (709 ms) did not differ from either of the two previously mentioned tasks ($p > .05$).

4.3.2.1.b Error rates

Error rates were analysed in the same way as the RTs. No statistically significant differences in accuracy were found between the three tasks. The following analysis resembles closely the analysis of the previous experiment.

4.3.2.2 Switch costs analysis

The main interest in this experiment was the direct comparison of the two alphabetical tasks and the modulation of their switch costs when each is paired with either a similar (alphabetical) or dissimilar (numerical) task. Moreover, a cross-experimental switch cost comparison of the consonant/vowel vs. odd/even task was sought in order to compare the pattern of performance between two identical conditions across the two experiments. Aim of the latter comparison is to detect if there are any indirect effects of the third task of the experiment (first/second) on switch costs. Excluded scores for the conditions of interest are reported in Appendices 54 to 56.

The results revealed only a statistically significant main effect of predictability [$F(1, 23) = 15.374$, $MS_e = 26097$, $p < .01$]. In particular, predictable switch costs were found to be larger relative to unpredictable switch costs. In contrast to the previous experiment, no modulation of switch costs was observed for any of the two tasks. An attempt to explain the reasons behind this finding will be made later on this chapter. Figure 25 provides a graphical illustration of the switch costs for the consonant/vowel and first/second task.

The odd/even task's switch cost analysis revealed only a main effect of predictability [$F(1, 23) = 21.553$, $MS_e = 21588$, $p < .001$]. The odd/even task was paired both times with a dissimilar task (in accord with the previous experiment) and thus no task similarity effect was anticipated. Predictable switch costs were larger relative to unpredictable switch costs. Figure 26 provides a graphical illustration of the switch costs for the odd/even task.

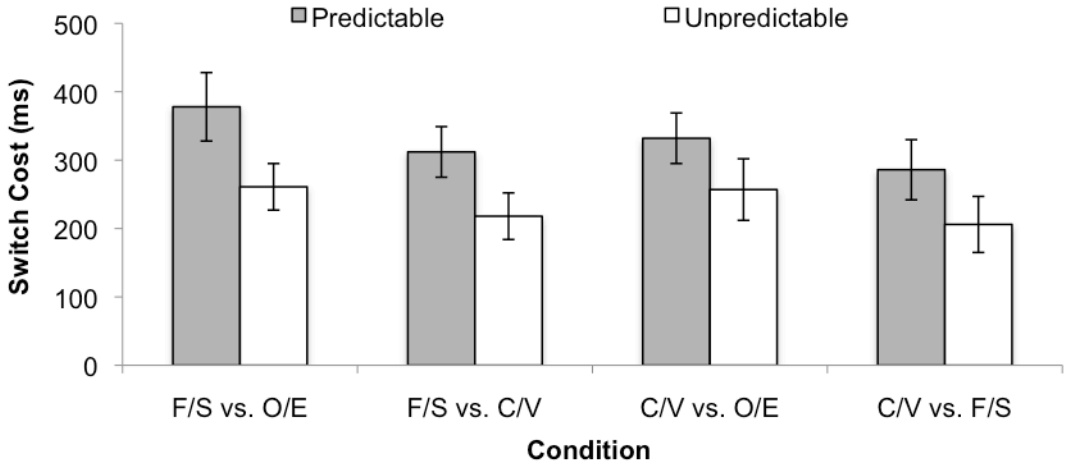


Figure 25: Graphical illustration of switch costs for the two alphabetical tasks (F/S and C/V) when paired with the alphabetical (F/S or C/V) and the numerical (O/E) tasks respectively in Experiment 11. Error bars represent the standard error of the mean (SE). Switch Cost = (switch trial RT – non-switch trial RT), Predictable = Predictable trial transition, Unpredictable = Random trial transition, H/L = high/low classification task, C/V = consonant/vowel classification task, O/E = odd/even classification task.

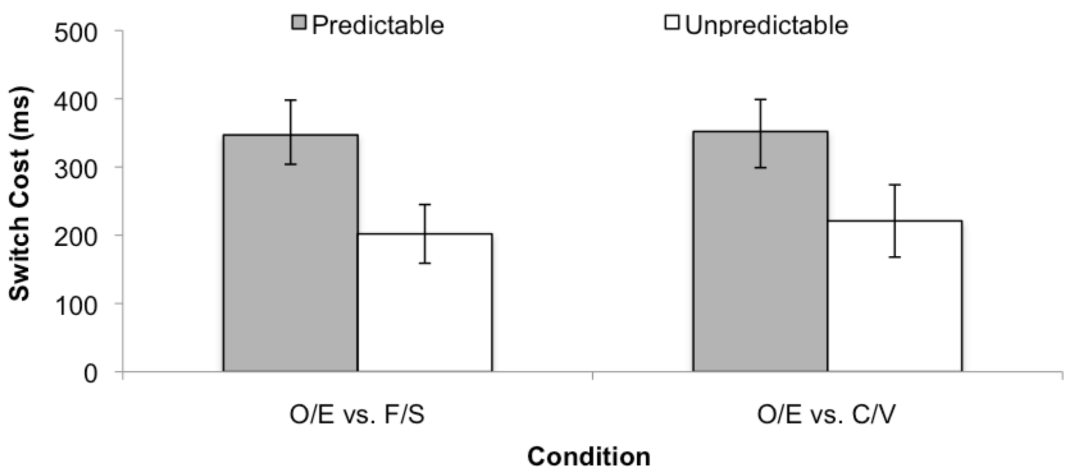


Figure 26: Graphical illustration of switch costs for the numerical task (O/E) when paired with the alphabetical (F/S or C/V) tasks in Experiment 11. Error bars represent the standard error of the mean (SE). Switch Cost = (switch trial RT – non-switch trial RT), Predictable = Predictable trial transition, Unpredictable = Random trial transition, H/L = high/low classification task, C/V = consonant/vowel classification task, O/E = odd/even classification task.

Finally, a mixed factors analysis of variance (ANOVA) where the within participants factors were task (odd/even vs. consonant/vowel task) and predictability (predictable vs. unpredictable trials) while the between participants factor was experiment (Experiment 10 vs. Experiment 11) was carried out. Only the main effect of predictability was found to be statistically significant [$F(1, 23) = 23.560$, $MS_e = 6817$, $p < .001$]. No difference in switch costs was found indicating that switch costs for the discussed condition remained unaffected across experiments.

Overall, switch costs in this experiment resemble closely that of the previous experiment. There was no similarity effect on switch costs either when a task was paired with a similar or dissimilar task. In addition, predictable switch costs were larger relative to unpredictable switch costs. This finding, along with the similar findings from the previous experiment suggest, as stated before, that the similarity effect, as described by Arrington et al. (2003), can only be uncovered under specific conditions.

Nevertheless, the reversed similarity effect found previously was not replicated here. The reasons behind this will be discussed in detail in the Discussion section and probably are related to task difficulty.

Overall, the present results provided additional evidence in favour of the idea that there are cases in which there is no task similarity effect when comparing similar tasks' against dissimilar tasks' switch costs. It seems therefore, that there are certain constraints that prohibit a task similarity or a reversed similarity effect to be uncovered in task switching experiments.

A detailed explanation behind these limitations and the cognitive processes responsible for them will be given in the Discussion section. As before, further analyses were carried out on the data.

4.3.2.3 RTs and error rates analysis

A similar analysis to the one described in the previous experiment was carried out on the present data. In general, the results from the RTs and error rates analysis are very similar to the ones found on the previous experiment and replicate once more the central findings of the thesis.

Specifically, a main effect of trial transition was found - switch trials were overall slower and less accurate relative to non-switch trials. In addition, a predictability effect was revealed – performance was faster and more accurate when advance foreknowledge for the upcoming trial was provided relative to when no foreknowledge was available.

Finally, the predictability x trial transition interaction was found, similarly to the previous experiment, in all conditions. Switch costs were larger on predictable relative to unpredictable cases. The detailed RTs and error analysis for the corresponding conditions is included in Appendices 54 to 56.

In addition to the above mentioned effects, when the first/second task was paired with the consonant/vowel task a main effect of task was found to be statistically significant. RTs for the first/second task were overall slower relative to the consonant/vowel task. Figure 27 provides a graphical illustration of the summary RT and error rate data for the condition of interest.

In contrast to the previous Experiment, when the odd/even task was paired with the consonant/vowel task a main effect of task was not found to be statistically significant. Figure 28 provides a graphical illustration of the summary RT and error rate data for the condition of interest.

Finally, when the odd/even task was paired with the first/second task, in addition to the central findings, a main effect of task was found to be statistically significant. RTs were slower for the first/second task relative to the odd/even task. Figure 29 provides a graphical illustration of the summary RT and error rate data for the condition of interest.

A task difficulty effect similar to that described on the previous experiment was also found here whenever two similar in difficulty tasks (as defined in the training analysis) were performed in a given block of trials. Specifically, a task difficulty effect was revealed when the consonant/vowel task was paired with the more difficult task of the experiment (first/second).

On training trials however, similarly to the previous experiment, no differences in difficulty were uncovered between the two tasks. A graphical illustration of the corresponding RTs across the training and experimental trials is shown in Figure 30.

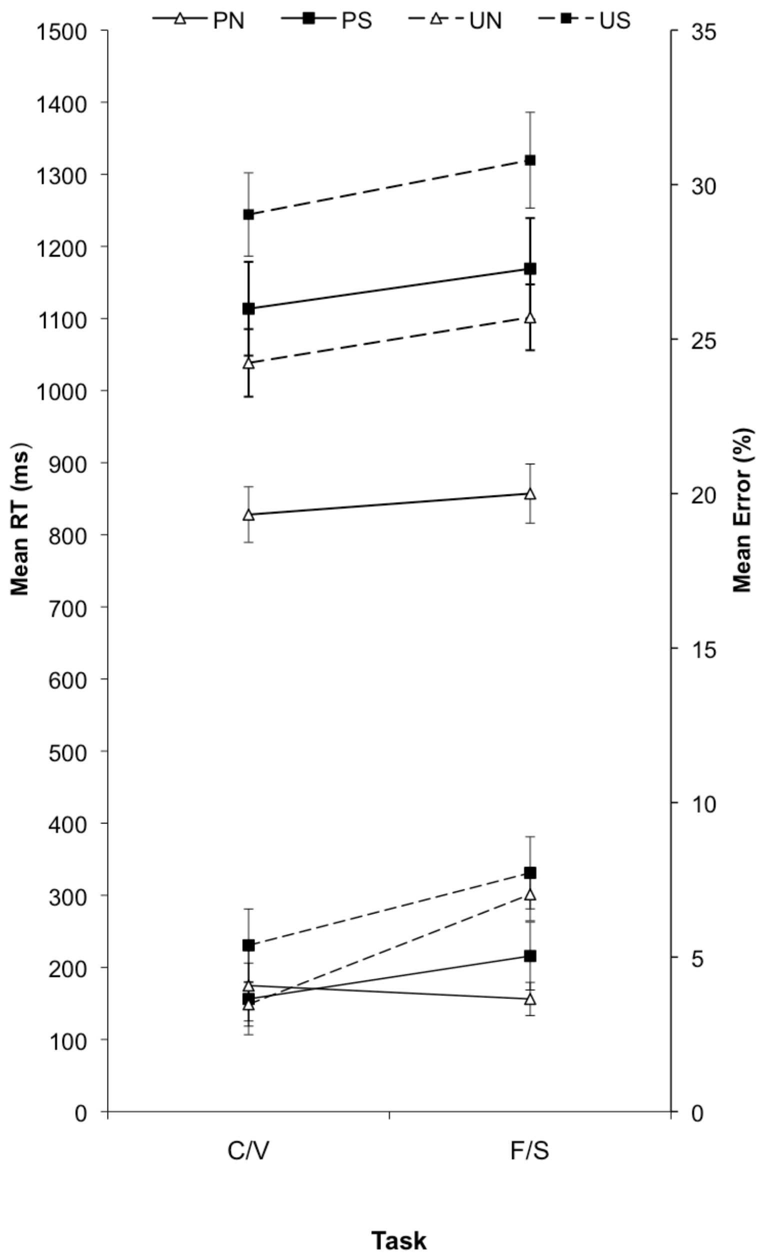


Figure 27: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 11. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials, C/V = consonant/vowel classification task, F/S = first/second classification task.

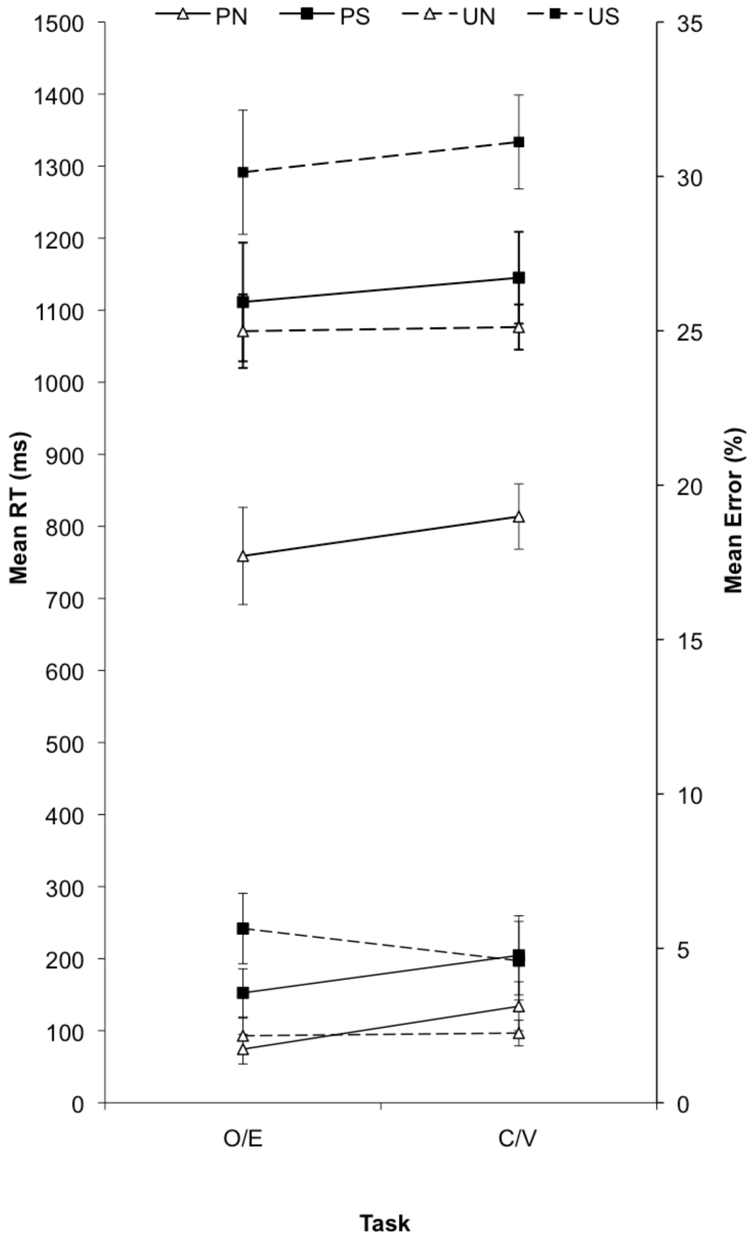


Figure 28: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 11. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials, C/V = consonant/vowel classification task, O/E = odd/even classification task.

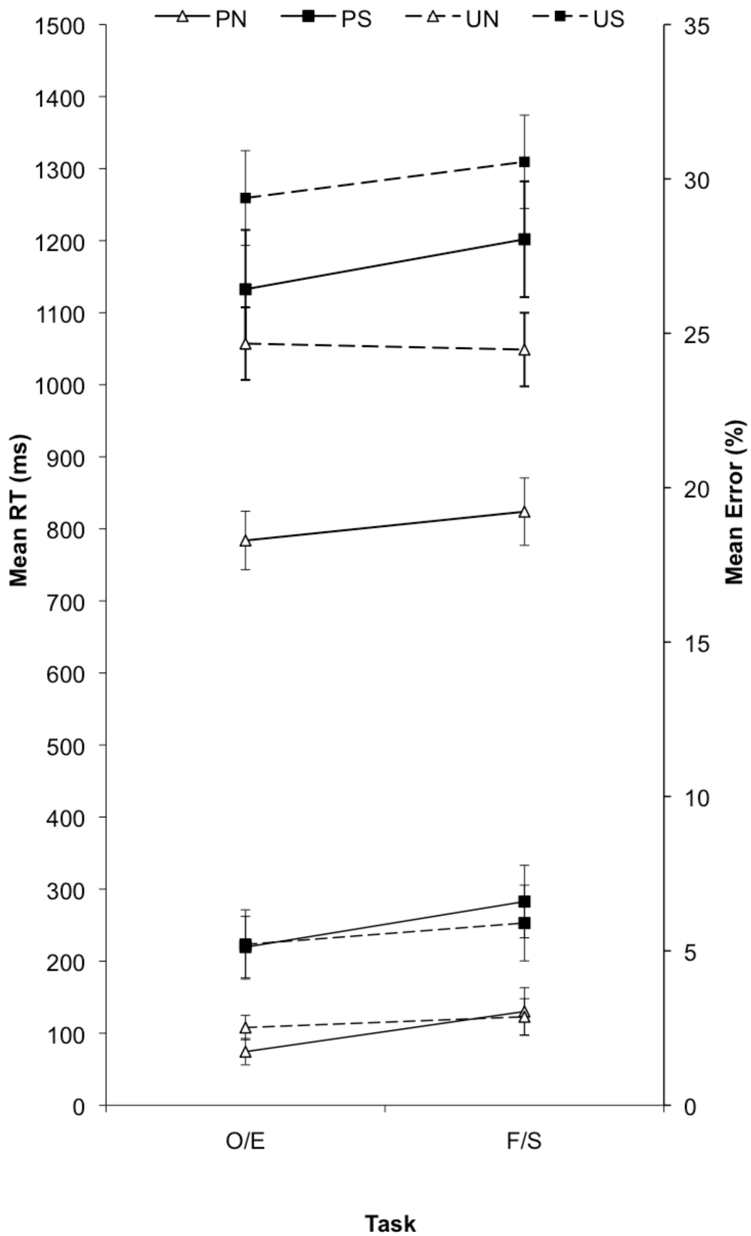


Figure 29: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 11. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch trials, PS = Predictable Switch trials, UN = Unpredictable Non-switch trials, US = Unpredictable Switch trials, F/S = first/second classification task, O/E = odd/even classification task.

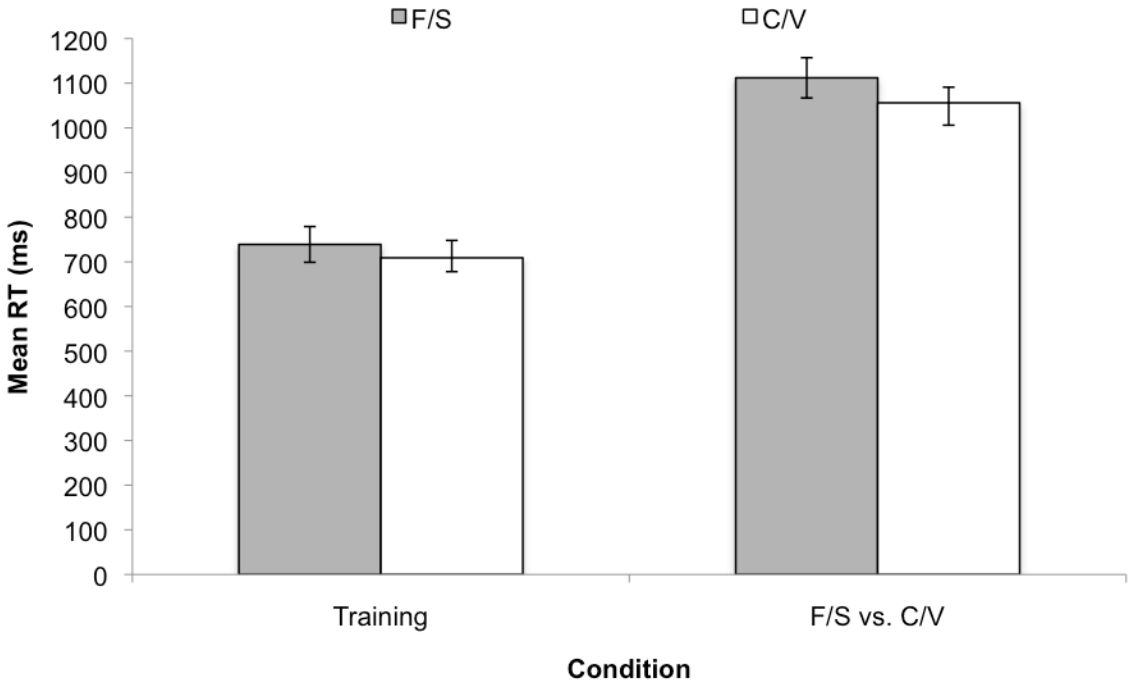


Figure 30: Graphical illustration of the RTs for the F/S and C/V tasks across the training and experimental trials in Experiment 11. Error bars represent the standard error of the mean (SE). F/S= first/second classification task, C/V = consonant/vowel classification task.

This finding replicates the previously discussed results and supports further the model's central ideas that, a) the discrepancy in difficulty between two tasks is a crucial determinant of performance in task switching conditions and, b) that there is an interplay between components of the two tasks implying that properties of the tasks in part affect performing the competing task. RT analysis in the consonant/vowel vs. odd/even task condition revealed that, in contrast to the previous experiment, a task difficulty effect between the two tasks was not found here. The pattern of the corresponding switch costs across the two experiments however was similar. This finding is mainly attributed to a slowing in the consonant/vowel task's RTs in the current experiment (1092 ms) relative to the previous experiment (958 ms). The RTs for the odd/even task remained relatively unaffected in the current experiment (1058 ms) relative to the corresponding RTs of the previous experiment (1027 ms). The slowing of the consonant/vowel task's RTs in the current experiment may be the result of an indirect task similarity effect. This idea will be discussed further shortly. A graphical illustration of the corresponding RTs across the two experiments is shown in Figure 31.

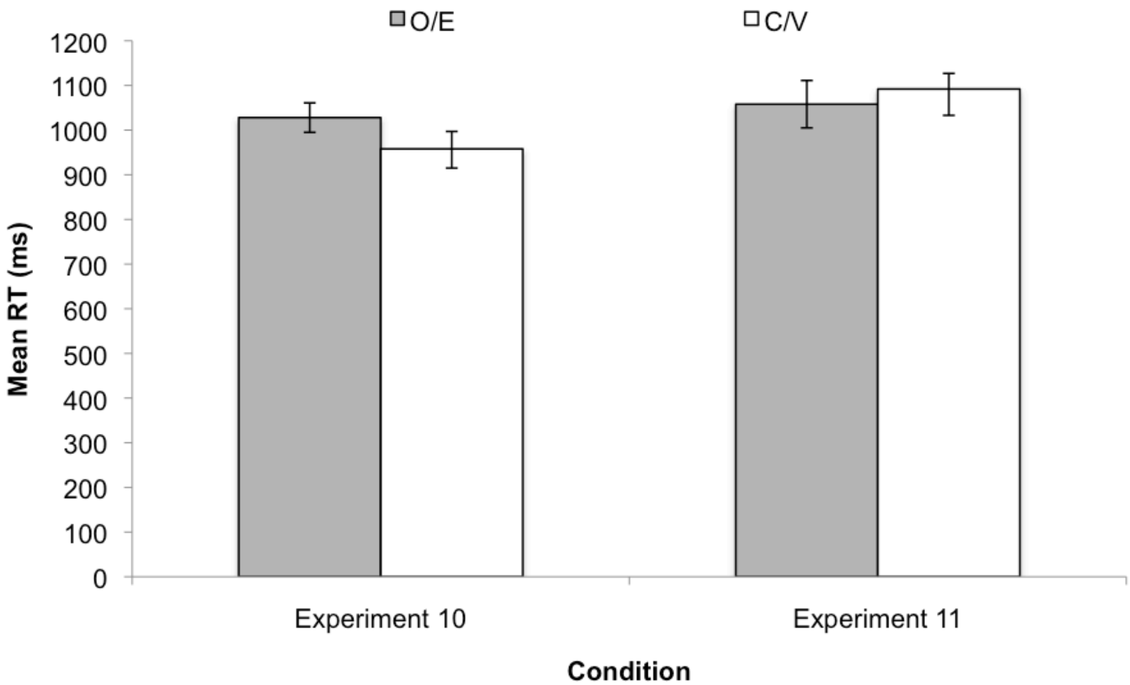


Figure 31: Graphical illustration of the RTs for the C/V and O/E tasks on the C/V vs. O/E condition across experiments. Error bars represent the standard error of the mean (SE). C/V= consonant/vowel classification task, O/E = odd/even classification task.

Once more, a task difficulty effect was not evident in any condition when the predictable non-switch trials' RTs for the two tasks were compared (paired t-test, $p > .05$).

4.4 DISCUSSION

In this experiment, the main effects of predictability and trial transition were also significant replicating the central findings of the previous experiments of the thesis. Moreover, switch costs were found to be overall larger in predictable relative to unpredictable cases. However, neither a task similarity (as described by Arrington et. al.) nor a reversed task similarity (as found in the previous experiment) was found in this experiment. The central reason behind this is probably related to a task difficulty effect interfering with task similarity.

In this experiment, the first/second task was found to be significantly more difficult relative to the odd/even task while the consonant/vowel task did not differ from either of the other two tasks. Therefore, for the same reason that there was no effect of task similarity in the previous experiment (apart from the reverse similarity effect discussed earlier) a task similarity effect was not uncovered in this experiment.

Specifically, when the results are compared across experiments notable similar patterns of performance arise. On the training session of Experiment 10 the odd/even task (651 ms) was found to be more difficult relative to the high/low task (607 ms). The consonant/vowel (627 ms) was found to be equally difficult with both the previous tasks. This pattern of task difficulty however, was altered during the main experiment. Notably, a task effect was found on blocks of trials where switching was required between the consonant/vowel (957 ms) and the odd/even task (1027 ms). In that case, in contrast to the training results, the consonant/vowel task was found to be easier relative to the odd/even task. That was the only difference in the pattern of task difficulty between the training and the main experimental trials.

Interestingly, from a task difficulty perspective, the same pattern was observed on the current experiment. On the training session the first/second task (739 ms) was found to be more difficult relative to the odd/even task (671 ms). The consonant/vowel task (709 ms) was equally difficult to both of the previously mentioned tasks. On the experimental trials, similarly to the previous experiment, the consonant/vowel task (1056 ms) was found to be easier when relative to the first/second task (1108 ms) on blocks of trials where a switch between the two was required. It seems that on experimental trials both the consonant/vowel and the more difficult task of each experiment became slower relative to the corresponding training trials. However, this increase in RTs was more profound for the more difficult task of the experiment.

Again, no other difference in the pattern of task difficulty between the training and the main experimental trials was found. It is evident, that in both cases on switch blocks of trials (mixed blocks) when the consonant/vowel task was performed along with the more difficult task of the experiment, a task difficulty effect was uncovered mainly due to an increased slowing, relative to training trials, of the more difficult task of the experiment relative to the consonant/vowel task. This task difficulty effect was not evident on training blocks of trials (pure blocks).

This pattern of results is in accord with the task switching model described in the thesis. Specifically, the model predicts that when switching between two tasks, a key determinant of performance is the relative discrepancy of their difficulty. This discrepancy determines in part performance for both tasks and directly implies a bidirectional link between them – activation of the relevant (*RTP* component), suppression of the irrelevant task (*ITS* component) is needed prior to the generation of a response on a given trial.

RTP is defined via model's Equation 7:-

$$RTP = TS_{(r)} \times ME$$

ITS is defined via Equation 8 of the model:-

$$ITS = TS_{(\mathrm{i})}$$

This finding cannot be attributed to a task similarity effect. It has been revealed that an identical pattern of results occurred between the two experiments where the same alphabetical task was paired with the more difficult task of the experiment that was either a numerical (Experiment 10) or an alphabetical task (Experiment 11).

In addition, in both experiments on training sessions the consonant/vowel task was found to be of equal difficulty with the odd/even task. Nevertheless, on two different cases on experimental trials the odd/even task was found to be more difficult (Experiment 10 – C/V = 957 ms, O/E = 1027 ms) and equally difficult (Experiment 11 – C/V = 1093 ms, O/E = 1058 ms) to the consonant/vowel task. It has to be noted here, that the sequences of stimuli involving switching between the consonant/vowel and odd/even tasks were identical between the two experiments. This different pattern of performance across the two experiments may be related to what someone may call, an indirect task similarity effect.

The indirect similarity effect may be the result of a central difference between the two experiments - the conceptual nature of the third task. In Experiment

10 the third task was the numerical and dissimilar to consonant/vowel, high/low task while on the present experiment the third task was the alphabetical and similar to the consonant/vowel, first/second task. It is probable therefore, that a conceptually similar task can affect performance on blocks of trials even in cases where it is not presented in these blocks.

In particular, a case might be that in Experiment 10 performance of the odd/even task could have been negatively affected by the fact that participants have been trained concurrently on the high/low and odd/even tasks. This may have resulted to the strengthening or establishment of a conceptual relationship between the two tasks. This relationship may have led, later on experimental trials, to an unintentional activation of the easier high/low task whenever the odd/even task was required. This occurrence consequently leads to conflict between the two tasks slowing down performance.

In the current experiment, concurrent training of the alphabetical first/second and consonant/vowel tasks had probably had the same effect to the one described previously, on the consonant/vowel task. The result is that while on the previous experiment, on experimental trials, the odd/event task was found to be more difficult relative to the consonant/vowel task, in the current experiment there are no differences in task difficulty between the two.

Specifically, a visual inspection of the data shows that this result is primarily attributed to a slowing in performance on the consonant/vowel trials in the current experiment. It seems that concurrent training of the consonant/vowel and first/second tasks resulted in an unintentional activation of the first/second task whenever a response to the consonant/vowel task was required. The result is a slowing of performance in the latter. The same effect could also be true for the first/second task. However, the current data do not allow the examination the latter assumption further.

In contrast to the consonant/vowel task, performance in the odd/even task remained relatively unaffected between the two experiments. This unchanged performance might be the result of a permanent interference of the high/low task - a relative easy and automatic task. Regardless of the experiment, whenever a response on the odd/even task was required interference from the high/low task occurred. These findings, along with the decrement of switch costs in the previous experiment where the high/low task is paired with the consonant/vowel task relative to when is paired with the odd/even task, suggest that task similarity at a conceptual level can affect performance in both a direct and an indirect way. In the first case, task interference can result if two conceptually similar tasks are presented within the same blocks of trials. In the latter case, task interference between tasks may occur if two conceptually similar tasks have been practised or have been performed recently even though they are not presented in the same block of trials. In either case, the resulting interference must be resolved prior to responding to a trial resulting in a slowing of performance.

4.5 GENERAL DISCUSSION

Two experiments were described in this chapter where the effect on switch costs of task similarity was studied. Overall, the basic effects described so far in the thesis were replicated throughout the conditions of both experiments. Switch trials were slower relative to non-switch trials and similarly unpredictable trials were slower than predictable trials. Switch costs were once again found to be larger on predictable cases relative to unpredictable cases. In addition, the current results in their majority seem to be in accord with the task switching model's assumptions. Primarily, task difficulty affected switch costs in both predictable and unpredictable cases. Moreover, as is mainly predicted by the model, switch costs are larger on predictable than on unpredictable cases. This pattern was found in every condition examined in the current chapter.

No task difficulty effect was found on predictable non-switch trials throughout the chapter verifying another basic assumption of the model – task-sets are maintained in WM when a task repetition is expected. An additive effect on switch costs was found in many cases in unpredictable cases resembling closely the pattern of results of Experiment 6 where an easy and a difficult task are presented equally often. In the current experiments, the RTs of the difficult task were larger relative to the easy task. They were equal in cases where the tasks were equally difficult or the relative discrepancy in difficulty between them was relatively small. This pattern of results seem to verify another central assumption of the model – the relative difficulty of the competing task-set affects the pattern of switch costs implying an interplay between the two competing tasks.

Task similarity was central to the experiments. A novelty in the current study is that similarity between tasks was manipulated at a conceptual level rather than a perceptual/attentional or response level as in the experiments discussed on the chapter's introduction. It was shown, in Experiment 10, that switching between two conceptually similar tasks could be harder than switching between two conceptually dissimilar tasks. Switch costs for the high/low task decreased when switching from a conceptually dissimilar task was required than when switching from a conceptually similar task.

This finding is at first sight counterintuitive and contradicts Arrington et. al. (2003) findings in the sense that it should be expected that the high/low task's switch costs should increase when switching from the dissimilar consonant/vowel task relative to switching from the similar odd/even task. Specifically, in blocks of trials where a switch between a numerical and an alphabetical task was required participants had to switch their attention to the relevant aspect of the stimulus (e.g., the digit or the letter character). That was not necessary in blocks of trials where they had to switch between numerical tasks. In that case, they knew that they will classify only digits and thus an attentional shift between the attributes of the stimulus was not required. In the latter case, it can be argued that the two tasks shared a component and thus were more similar than the first case.

Based on Arrington et. al. (2003) findings, it should be expected that this sharing of an attentional component would decrease switch costs for both tasks. Nevertheless, the opposite was true for the high/low task while switch costs remained unaffected for the odd/even task in both task similar and dissimilar conditions. The decrement in switch costs for the high/low task when performed with a conceptually dissimilar task can probably be attributed to the fact that conceptual similarity can lead to a more frequent activation of the irrelevant task relative to cases that task similarity is absent. This leads in turn to interference that needs to be overcome giving rise to additional switch costs.

The fact that task similarity had no effect on the odd/even task's switch cost was attributed to task difficulty. It seems that the odd/even task was too difficult in order for any task similarity effects to be detectable. It is highly possible that this difficulty is in part the result of a conceptual link with the high/low task. This link is causing a permanent interference even when the high/low task is not presented along the odd/even task in a given block of trials. The consonant/vowel task was paired in both conditions in Experiment 10 with a numerical task therefore a task similarity effect neither was expected nor revealed.

The assumption that a task can cause interference even when it is not immediately presented with another task is enhanced by the results of Experiment 11. Specifically, no direct similarity/reversed similarity effect was evident in any condition. The first/second task was more difficult relative to the odd/even task while the consonant/vowel did not differ from either task. No effect on switch costs was revealed for the first/second task regardless of the similarity of the competing task. Similarly to Experiment 10, it is possible that the consonant/vowel task caused interference in the first/second task resulting in no difference in performance for the latter task in any of the conditions described in the chapter. In a similar manner to the previous experiment, in Experiment 11 the odd/even task was paired in both conditions with a dissimilar alphabetical task therefore a task similarity effect neither was expected nor revealed.

An identical condition between the two experiments (consonant/vowel vs. odd/even) supported the assumption that a similar task can cause interference in an indirect way. Specifically, it was revealed that the consonant/vowel task was easier to perform relative to the odd/even task in Experiment 10 on experimental trials. That was not true for Experiment 11 where no difference in performance between the two tasks was revealed. Interestingly, in both experiments on training trials no difference in performance between the two tasks was evident. The difference found on the common condition between the two experiments was attributed to the third task involved on each experiment. Specifically, it was assumed that the lack of difference in performance between the two tasks in Experiment 11 could be attributed to the concurrent training of the consonant/vowel task with the conceptually similar first/second task. This concurrent training may have lead to an unintentional activation of the first/second task specifically for the experiment and in cases where the consonant/vowel task was required. This idea was supported by the fact that visual inspection of the RTs revealed a slowing for the consonant/vowel task in Experiment 11 relative to Experiment 10. The odd/even task remained relatively unaffected and this fact supported further the belief that the odd/even task has the inherited difficulty to elicit the well-trained high/low task constantly.

In addition, in both experiments the consonant/vowel task was found to be of equal difficulty relative to the most difficult task of the experiment of interest on training trials. However, in both experiments on experimental trials a task effect was uncovered when switching between the consonant/vowel and the most difficult task of the experiment. This finding is in accord with the notion that the relative discrepancy of difficulty between two tasks affects performance on both tasks in cases where switching between them is necessary. The task switching model described in the previous chapter can account for the effects discussed in the present chapter. Specifically, an unintentional activation of an irrelevant task-set might have occurred in cases where similar tasks were performed in the same block of trials or in the same experiment leading to a larger interference relative to cases were no such conditions apply. This increased interference can be mirrored in the *ITS* (irrelevant task suppression) parameter of the model. Increased values on the *ITS* can reflect adequately increased switch costs and RTs relative to when these values decrease (e.g., when task-set interference is small).

ITS is defined via Equation 8 of the model:-

$$ITS = TS_{(\mathrm{i})}$$

However, in most of the cases no differences in switch costs were found between similar-task switch trials and dissimilar-task switch trials. This was attributed to the level of difficulty of the tasks involved in these cases. Specifically, differences on switch costs were not found probably because indirect interference by a similar irrelevant task remained even in cases where this irrelevant task was not presented in the same block of trials as the relevant task. This task specificity can be viewed as an inherited difficulty under certain conditions (as in the case of the odd/even task) or experiment specific (as in the case of the consonant/vowel task – Experiment 11). It can be partially incorporated in the *TD* (task difficulty) parameter which is calculated from the training trials (as described in the task switching model analysis in Chapter 3). This parameter directly determines along with *TE* (task expectancy) the *TS* (task strength) parameter of the model.

This central component of the model is reflected in it's Equation 1:-

$$TS = TE \times TD$$

This parameter along with a correctly modulated *ME* (mental effort) in the *RTP* (relative task priming) for the task of interest can resemble adequately performance mirroring the effects described here.

RTP is defined via Equation 7 of the model:-

$$RTP = TS_{(r)} \times ME$$

4.6 CONCLUSIONS

In this series of experiments, the effect of task similarity on switch costs was studied. The similarity between the competing tasks was manipulated at a conceptual level rather than a perceptual/attentional or response level as in other studies. In that case and in contrast to past findings, task similarity was found to slow down RTs or increase switch costs - a reversed task similarity was evident. This occurred both in a direct way - when switching between two similar tasks was required on a given block of trials and in an indirect way - as when performance on a task was slowed down when it had recently been trained with a similar irrelevant task. There was not a single case where a task similarity effect, as described by Arrington et. al. (2003), was uncovered. In cases where performance was negatively affected, because of task similarity, this was attributed mainly to interference from a conceptually similar task. Interference can occur therefore, when two tasks share the same conceptual pathway and needs to be overcome prior to responding to a trial resulting in a slowing in performance.

In addition, evidence where provided regarding the effect on performance of the discrepancy of the difficulty between two tasks. It seems that when two tasks are performed together performance on both is altered similarly to when these tasks are performed independently. This finding supports further the notion that there is a bidirectional link between tasks under task switching conditions as predicted by the task switching model described in Chapter 3.

In conclusion, it seems that a) there can be constraints as to the conditions needed for a similarity effect to be uncovered, b) it is probable that task difficulty can interact with task similarity and, c) there can be cases were a reversed task similarity effect is possible.

5 TRIAL EXPECTATION EFFECTS

5.1 GENERAL INTRODUCTION

Up to this point, the way by which the interplay of endogenous and exogenous control (Chapter 2), unequal ratio of task presentation along with task difficulty (Chapter 3), and task similarity (Chapter 4) affect switch costs has been examined. Data from this series of experiments suggest so far that there are distinct differences in the way that executive processes manage, prepare and resolve interference between predictable and unpredictable task switching conditions. In predictable trials, it was suggested that switch costs are a result of strong endogenous control. On unpredictable trials, it was assumed that endogenous control still affects switch costs but in a more relaxed manner.

It was evident (Chapter 3) that the activation of the competing task-sets was modulated according to their probability to occur on the upcoming trial. This expectancy affected switch costs and clearly demonstrated that, in contrast to beliefs that unpredictable switch costs are driven mainly by exogenous factors - TSI (Sohn & Anderson, 2001), endogenous control plays a central role on unpredictable task switching.

These findings fit well with Norman and Shallice's (1986) framework, one of the first theories to emerge in the field. In their point of view, a procedural *schema's* readiness lies within a continua of long- and short-term activation that is a result of the interplay of, a) endogenous control, b) task availability or task readiness depending on their recency or frequency of use, and c) exogenous control (the presence of stimulus attributes that are associated with tasks sets). When conditions arise where a task switch is required, a supervisory attention system modulates accordingly the activation of the relevant and the irrelevant task-sets. Because endogenous control is effortful and if excessively applied it results in cognitive inflexibility, it is applied in a conservative manner. The relevant task is marginally more activated relative to the competing task(s) - just enough in order to be performed adequately.

Based on that framework, Monsell, Sumner and Waters (2003) proposed that participants voluntarily attenuate or restrain to some degree the task readiness according to the expectation of the probability of a further task switch. As discussed earlier in Chapter 1, Monsell, Sumner and Waters (2003) investigated TSR with predictable and unpredictable task switches. Participants had to classify as high/low and odd/even a digit on a given trial. There was a varied interval between the task cue and the presentation of the stimulus between blocks of trials. In their first experiment, the task switched predictably every two, four or eight trials. In their second experiment, the task switched every four trials and was relative to random switching.

Their aim was to support the idea that TSR is responsible for task switch costs and not TSI. Their hypothesis stated that if decay of TSI was responsible for task switch cost then the more trials that have elapsed since the use of task A the more difficult it would be to switch back to it. In addition, the effect would be enhanced due to the consecutive repetition trials of the competing task B due to priming. In that case, the accumulation of activation of the competing task B during these trials would be more effortful to inhibit. There would also be a gradual improvement in RTs across trials after switching from task A. If the above trends were absent then that would imply that, a) either TSI decays rapidly or, b) that one trial is sufficient to erase it or, c) TSI decays so slowly that two, four or eight trials are not sufficient to demonstrate the effect.

Results revealed that, after a task switch, there was a substantial decrease in RT between the first and the second trial of a run of similar size. No further improvement in RTs was observed in the consequent trials. It can be argued therefore, that only one trial was needed in order to recover from a task switch and that was true for all run lengths. This effect was also demonstrated in an experiment using a cuing paradigm with predictable runs of eight trials (Kelee & Rafal, 2000). These findings nevertheless have not been replicated by every study. A more gradual recovery of performance was shown in some cases (e.g., Mayr, 2001, Salthouse, Fristoe, McGuthry, & Hambrick, 1998, Meiran, 2000).

In their second experiment, Monsell et al. (2003) compared predictable vs. unpredictable sequences. They found that performance was in general poorer when foreknowledge of tasks (predictability) was not provided than when it was. Despite this though, switch costs were smaller on the unpredictable sequences than on the predictable one.

The theoretical interpretation of this finding suggested that the additional activation that has been induced in a task that has just been performed, is intentionally suppressed to a certain extent by the participant if a further task switch is probable. It was shown in Chapter 3 that participants could also attenuate task readiness according to their expectation of the probability of a given task to occur during a block of trials. In that case, it was not important if a further task switch is probable but rather whether a specific task was more probable to occur. Participants therefore, biased that task favorably throughout an unpredictable block of trials constantly. That was not true for predictable blocks of trials were the upcoming task was known in advance with absolute certainty. It has also to be noted that in Monsell, et. al. (2003) study the two tasks were equally probable to occur in a given block. It can be assumed therefore, that participants in their unpredictable condition of experiment 2 applied a more relaxed endogenous control on the relative activation of the competing task-sets relative to the two last experiments of Chapter 3.

Thus, it can be concluded that the strength of endogenous control and its influence on exogenous control is associated directly with, a) the probability of a task switch on the upcoming trial, or b) the probability of a specific task to be engaged in the upcoming trial. Finally, one of the questions that the researches raised in their work is whether this endogenous modulation of task-set activation occurs during or after the generation of a response. An attempt to answer this question will be made in this chapter's series of experiments.

In a similar manner, Sumner and Ahmed (2006), propose two factors that affect switch costs one of which is expectancy. First, control biases on a trial *n* are carried over and affect performance on a switch trial *n+1*. For instance, inhibition that was applied on task A in order to perform task B might be carried on and be present when task A must be performed again. Second, switch costs can be influenced by control factors through expectancies about the upcoming trial. As a run of non-switch trials is getting lengthier, participants may increasingly expect a task switch even if they have been informed that a task switch is equally probable at all times. Participants tend to expect more switches than repetitions on a series of trials – 'gamblers fallacy' (Kahneman & Tversky, 1972).

It is necessary at this point to attempt to define 'expectancy'. Expectancy can be classified as a voluntary top-down mechanism. Information stored in LTM is retrieved and manipulated in order to prepare the organism for an anticipated event. Due to its nature (endogenous, voluntary, non-automatic process) it probably needs time and effort in order to influence a response on an expected upcoming event relative to any exogenous automatic processes (e.g., priming).

This assumption was examined in a study that investigated patterns of sequential effects in serial 2-choice reaction time tasks. The aim was to demonstrate and localize automatic facilitation and subjective expectancy due to the 'gambler's fallacy' as processing mechanisms responsible for *repetition effects* on responses (Soetens, 1998). The repetition effect regards facilitation in RTs when the same response is given on succeeding trials as opposed to when a different response is required.

The findings of the above study are of interest to the thesis due to their resemblance with the assumptions stated in Chapter 3. In this series of experiments, switch costs were attributed to the interplay of task priming and a strategic modulation of task-sets' activation/inhibition according to the probability of a task to occur on the upcoming trial (expectancy). It is of interest to examine if the assumptions that will shortly be discussed fit into the assumptions stated earlier in the thesis.

In the study of interest, the *information reduction paradigm* (IRP) was central to the experiments conducted. A typical IRP experiment involves the mapping of two different stimuli on each of two response sets. In this kind of design three kinds of transitions are possible on succeeding trials, a) *identical trials* (I) - both stimulus and response are repeated, b) *different trials* (D) – a different stimulus requires a different response, and c) *equivalent trials* (E) – different stimulus requires the same response (Bertelson, 1965). Specifically, a four-stimulus, two-response task was used. Stimuli were presented on the four corners of an imaginary square with two dimensions (left-right and up-down). Response keys were either left – right or up – down.

Participants were asked to respond as to whether the stimulus appeared on the left/right side of the square (experiments 1 – 2) or the up/down side of the square (experiments 3 – 4). The left – right keys were used as response buttons for the first two experiments while for the latter two the up – down keys were used. Moreover, in experiments 1 and 3 a compatible mapping was used (e.g., the relevant stimulus dimension corresponded to the spatial dimension of the response) while the opposite was true for experiments 2 and 4 that had incompatible mappings.

Two RSIs were used throughout the study, a short (50 ms) and a long (1000 ms). The predictions were clear regarding the pattern of results in the two RSIs. In the short RSI no effect of a subjective expectancy effect should be evident due to the lack of an adequate time interval allowing for such an effect to take place and modulate performance. Any effect observed under such a short interval should be attributed to automatic facilitation – the effect is called automatic because it is not under the participants' control and results in a facilitation of the processing pathway due to residual traces left by continuous S-R cycles (Bertelson, 1961). This can result in a bypass of some central executive functions (Bertelson, 1963). The effect decays over time but in short intervals it can accumulate leading to observable effects on performance. Therefore, it was assumed that RTs on equivalent responses (E) should be faster relative to different responses (D). That should be true both for compatible and incompatible mappings.

However, in the long RSI a different pattern ought to emerge. Due to a subjective expectancy of a response change in the upcoming trial participants should be able to respond faster on the different trials (E>D) or equally fast (E=D) depending on the compatibility of the response mapping. The bottom line of these predictions is that in the long RSI the main determinant of performance is endogenously driven (subjective expectancy) in contrast to the short RSI where performance is being driven exogenously by the stimulus (automatic facilitation). The results verified the predictions stated above.

The previously discussed study involved only switches and repetitions of responses rather than complete task-sets. However, it is plausible to assume that the explanation given regarding the interplay of automatic facilitation and subjective expectancy may have application, at least to some extent, in a task switching paradigm. It should be clear by now that task-sets, which incorporate response mappings, are subject both to exogenous influences through task-set priming (e.g., due to recency or repetion) and endogenous control (e.g., due to preparation).

In this chapter's series of experiments, the central aim is to clarify whether the unpredictable switch costs discussed in the thesis and especially on Chapter 3 are attributed primarily to task priming due to the unequal task presentation or to a strategic modulation of task-sets' activation/inhibition due to expectancy. Taking into account the findings so far and the results in Soetens (1998) study it is reasonable to assume that the latter case is the most probable explanation - the RSIs used in

Chapter 3 (250, 600 and 1200 ms) exceed by far the short RSI (50 ms) that was used in his study whereas no RSI effect was evident.

This fact should rule out any strong effects of automatic facilitation/priming on switch costs. Moreover, the anatomical location of preparatory and switching cognitive components will be sought through a neuroimaging study. Results from this study will also be used in order to verify several parameters of the task switching model proposed earlier in the thesis. Finally, as in the previous chapters, a replication of the central findings of the thesis will be attempted.

5.2 EXPERIMENT 12

In this experiment the central aim is to clarify the relative contribution of priming/autogenous facilitation and task preparation due to subjective expectancy on switch costs. In order to achieve that, an experiment was designed where both priming and subjective expectancy were examined. Taking into account the results of Monsell et. al. (2003) it can be concluded that in predictable trials, after a task switch, only one trial of the switched-to task is enough for performance to reach a baseline. It is reasonable to assume therefore, that if a task is predictably repeated for two or three trials after a switch trial then control biases (e.g., priming) in favor of this task will have reached a level that could affect performance when a switch away from this task is required. On the other hand, if conditions apply where a task switch is expected more than a task non-switch prior to a trial then it can be expected that a subjective modulation of the competing task-sets will occur accordingly.

In order to achieve manipulating both priming and expectancy in a single experiment a relatively novel task switching paradigm was designed. In this paradigm, which will be explained in detail in the methods section, miniblocks of 5 trials are presented in a varied ITI (5.4 s – 9.2 s). The 4 first trials are always the same task and thus it can be expected that priming will build on these trials for the task repeated. The 5th trial however, can be either a predictable switch (AAAAB or BBBBA) or an unpredictable switch/non-switch trial (AAAA? or BBBB?).

Foreknowledge regarding the 5th trial is provided by a cue that is presented prior to the onset of the 1st trial. The cue informs participants either that a switch will be required on the 5th trial or that a switch or non-switch trial are equally probable to be presented.

It can be easily seen that in this design, miniblocks of trials that require switching tasks on the 5th trial constitute the 66% of the total miniblocks. Thus, alongside the bias from the gamblers fallacy it can be expected that a bias due to expectancy towards switching will occur under this situation. Therefore, conditions apply where both priming and expectancy will affect performance on the 5th trial of the unpredictable miniblocks.

The central prediction can be stated as follows: If priming is the main determinant of switch costs then on unpredictable non-switch minblocks RTs on the 5th trial will not differ from those of the preceding trials. On the other hand, if endogenous modulation of competing task-sets due to the subjective expectation of a task switch is the main determinant of switch costs, then RTs on these trials should be markedly slower relative to the RTs on the immediately preceding non-switch trials. This should occur because any priming that was accumulated on the previous trials should be inhibited endogenously because a task switch is expected. In that case, any RT slowing that occurs in an unpredictable non-switch trial should be significantly smaller relative to the switch costs observed on switch trials. That is probably because priming will still affect responses in favor of the task repeated on unpredictable non-switch trials.

Furthermore, it is expected that responses on the 1st trial of a miniblock should be slower relative to trials 2, 3 and 4 due to start-up costs. On the latter trials, RTs are expected to be similar implying that a baseline on performance has been reached. Finally, switch costs (5th – 4th trial's RT) is expected to be similar on predictable switch miniblocks relative to unpredictable switch miniblocks due to a preparation for a switch in both cases. Finally, any RT slowing observed on unpredictable non-switch trials is expected to be significantly smaller relative to switch costs observed in the other two kinds of miniblocks.

5.2.1 Method

5.2.1.1 Participants

Participants were 16 university students (14 females) with a mean age of 21.6 (5.9 SD) years old. The all took part on this experiment for either course credit or payment. They all reported having normal or corrected to normal vision and hearing while all were right-handed.

5.2.1.2 Design and stimuli

The tasks used in this experiment were identical to that used on Chapter 3 (digit classification tasks). Prior to the experimental trials, participants underwent training blocks of trials in an identical manner to that of Chapter 3.

The experiment included 60 miniblocks each comprising a sequence of 5 trials. On a given trial, a single digit was presented and the participant's task was to classify it according to its font colour. Red font signalled the parity task while green font signalled the magnitude task. In the first 4 trials of a miniblock participants had always to classify the same task (e.g., the parity task).

Prior to the onset of a miniblock a precue was presented for 5 s. The character 'U' indicated that the task may or may not change on trial 5 while 'S' indicated that the task would definitely change on trial 5. So following 'S' participants knew that the task would switch on trial 5 and following 'U' they could not predict whether that had to repeat or switch the current task on trial 5. Moreover, the precue was presented either in green or red font and thus signalled prior to the onset of the first trial the task that had to be performed on the first 4 trials of the miniblock.

Following the offset of the 5th trial feedback was presented for 1.35 s. Feedback consisted of 5 symbols presented in a row. The first symbol in the row indicated whether response on the first trial was right ('+' sign) or wrong ('-' sign), the second symbol corresponded to the response of the second trial and that was true for the rest of the symbols. From this experimental design, three kinds of miniblock emerged: a predictable switch miniblock, an unpredictable switch and an unpredictable non-switch miniblock. These miniblocks were presented in a random sequence and appeared equally often during the experiment (20 times each) while they were equally distributed according to task. For instance, there were 10 predictable switch miniblocks that started with a magnitude classification task (first 4 trials). These required a switch (5th trial) to a parity classification task. There were also 10 predictable switch miniblocks were exactly the opposite occured. That was also true for the unpredictable switch and non-switch miniblocks.

In general, across the experiment there were equal numbers of parity and magnitude trials, while there were equal numbers of left (even/low) and right (odd/high) key presses. In addition, a character that appeared in trial *n* never appeared on the immediate subsequent trial *n+1*. Specifically, on the 5th trial of a miniblock key presses were balanced according to the task and according to the responses given on the preceding 4th trial. For instance, in an unpredictable non-switch miniblock a 5th trial required half of the times a left key press (even/low) and was equally probable to be preceded from a trial that required a right or a left key press. In addition, the ITI between miniblocks varied between 5.4 s and 9.2 s.

Across the experimental trials a within participants design was used containing two factors: trial transition (switch or non-switch) and predictability (predictable or unpredictable).

During the ITI, a central fixation plus sign (0.4° x 0.4° of visual angle) was presented. In the pre-experimental training trials, the fixation sign was followed by a centrally presented digit. Digits were presented as black, bold, courier new, size 18 font (0.5° x 0.5° of visual angle).

On the experimental trials, the fixation plus sign was followed by the display of the precue in red or green font. Immediately after the offset of the precue the first digit appeared followed by the second digit and so on. As mentioned before, the participant's task was to classify the digit's parity (odd/even) when the character pair appeared in red font and the digit's magnitude (high/low) when the digit appeared in green font. Two versions of the experiment were created in which the presentation of the miniblocks varied in order to control for sequence effects. Each version was administered equally between the participants.

5.2.1.3 Apparatus

The software and hardware that was used in this series of experiments was identical to that used in the previous chapter.

5.2.1.4 Procedure

The procedure for the training and experimental trials was identical to that used in the experiments described up to this point.

5.2.1.4.a Training trials

The training session was identical to that of Chapter 3.

5.2.1.4.b Experimental trials

At the beginning of the experiment, written instructions were presented on the monitor. Participants were asked to read carefully the instructions and consequently press one of the response buttons to initiate the trials. A fixation point occurred immediately after and was followed by the precue that stayed on the screen for 5 s. Immediately following the presentation of the precue the first digit of the miniblock appeared and stayed on screen for a fixed interval of 1.5 s.

During this interval, participants had to give their response. At the end of each miniblock feedback was given for 1.35 s. A screen displaying 5 signs in a row and centrally so that the 3rd sign appeared centrally on the screen. Each sign corresponded to the performance on each trial of the preceding miniblock. A '+' sign in the first place of the row indicated a correct response on the first trial of the miniblock while a '-' sign on the 5th place of the row indicated an error response on the 5th trial of the miniblock.

The inter trial interval (ITI) between miniblocks was calculated from the offset of the feedback screen to the onset of the first trial of the miniblock and varied, as previously mentioned, between 5.4 s and 9.2 s. ITIs were calculated in linear manner for the 60 miniblocks and were distributed randomly across miniblocks for both experimental versions.

Participants were advised to slow down if they found out that they are making many mistakes.

5.2.2 Results

Error responses and very fast responses (less than 100 ms) were excluded from the analysis of RT data. As a result, an exclusion of 4.2% of scores has occurred prior to data analysis. For ease of exposition, the last trial of a mininblock will be referred from present onwards as 'target trial'. For the RT data analysis, the switch cost (target trial – 4th trial) for each one of the three different types of blocks was calculated and the results were entered into a one-way within participants analysis of variance (ANOVA).

Respectively for the error data analysis, the error rate of the target trial of each one of the three different blocks of trials was calculated and the results were entered into a one-way within participants analysis of variance (ANOVA). As before, the standard arcsine procedure was employed in order to transform error percentage rates prior to analysis (Keppel & Wickens, 2004).

5.2.2.1 RTs

The analysis revealed a statistically significant main effect of block type [$F(2, 30) = 22.837$, $MS_e = 3{,}760.689$, $p < .001$]. The ensuing HSD test revealed that the RT slowing on the unpredictable non-switch miniblocks was significantly smaller relative to that of the unpredictable and predictable switch miniblocks ($p < .05$, all comparisons; no other comparisons reached statistical significance).

In order to understand better the RT slowing for the unpredictable non-switch trials a paired t-test was run comparing the average RTs of the 4^{th} and target trial respectively. The results revealed that RT on the target trial was significantly slower relative to that of the 4^{th} trial, [$t(15) = -6.023$, $p < .001$, two-tailed test].

Therefore, despite of the fact that participants had to repeat the same tasks between the 4^{th} and the target trial on unpredictable non-switch miniblocks a slowing on RT occurred.

5.2.2.2 Error rates

Error rates were analysed in a different way relative to the RTs. Specifically, the error rates of the target trials of each one of the three different miniblocks were entered into a into a one-way within participants analysis of variance (ANOVA).

Despite of a trend towards more errors on switch trials no significant difference on accuracy between the different target trials was revealed. Figure 32 provides a graphical illustration of the average RTs and error rates for Experiment 12.

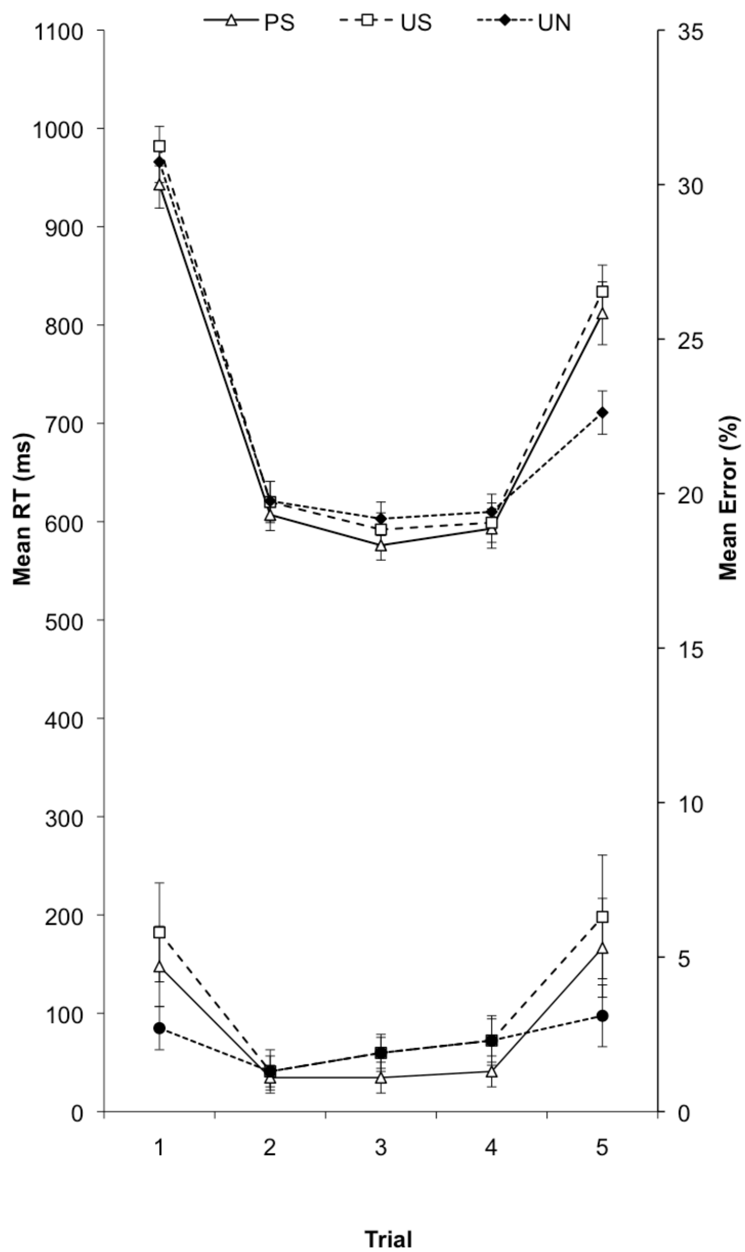


Figure 32: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 12. Means have been averaged over RSI. Error bars represent the standard error of the mean (SE). PS = Predictable Switch miniblock, UN = Unpredictable Non-switch miniblock, US = Unpredictable Switch miniblock.

5.2.3 Discussion

The overall picture of the results seems to correspond closely with the previous findings of the thesis. Switch costs were observed on switch trials in contrast to the predictable non-switch trials (trials 2, 3 and 4). Switch costs were larger on unpredictable and predictable switch relative to the RT slowing on unpredictable non-switch trials. The error rates did not differ in unpredictable non-switch trials relative to that found on the unpredictable and predictable switch trials. As predicted, a single trial after the start-up trial was enough in order for performance to reach an asymptotic baseline. These trials served both as a baseline (predictable non-switch trials) and as a priming factor for the relevant task-sets. It was assumed that participants would formulate a bias towards the preparation for a switch on unpredictable trials. This expectancy was attributed to the gamblers fallacy and/or the presence of more switch trials in the experiment. It was suggested that if top-down control through expectancy plays a key role in regulating task-sets on unpredictable trials then a RT slowing should be evident on unpredictable non-switch trials. The opposite should be true, that is no RT slowing on these trials, if bottom-up control through priming is the main regulator of switch costs.

The observed costs on the experimental data on unpredictable non-switch trials verified the predictions and supported the idea that the main determinant of performance should be the endogenous modulation of task-sets according to the expectancy for a task switch. Moreover, additional support for this account comes from the fact that switch costs on predictable and unpredictable switch trials did not differ. It seems evident that participants had enough time to prepare for a switch after the generation of a response during the remaining time of the stimulus fixed duration (1500 ms) and that is clearly reflected on the results. In an attempt to support further the idea that top-down control regulates performance on unpredictable cases, conditions where a bias towards repeating a task were designed and tested.

5.3 EXPERIMENT 13

The purpose of this experiment is to support the findings and assumptions of the previous experiment. In order to examine further the assumption that endogenous modulation of task-sets due to the subjective expectancy of a task switch has a central effect on switch costs, the expectation for the probability of a task switch was manipulated. In order to achieve that, predictable switch miniblocks were replaced by predictable non-switch miniblocks. In the present experiment therefore, the design required participants to repeat the primed task on the target trial in 2/3 of the total miniblocks. The current manipulation was also a good way to verify that the unequal presentation of switch and non-switch miniblocks affected switch costs in the previous experiment. The findings in the previous experiment were mainly attributed to the fact that participants where biased towards the preparation for a task switch in unpredictable trials.

If that assumption is true, then it can be expected that in this experiment participants will be biased to expect a task repetition in unpredictable miniblocks. In that case, it should be expected that a marked reduction in the unpredictable non-switch RT slowing observed in the previous experiment would be evident in the present experiment. Nevertheless, some costs may remain due to the constant effect of the gamblers' fallacy. Additionally, an increase in switch costs should be observed on unpredictable switch trials relative to the previous experiment due to the preparatory bias towards a task repeat. On predictable non-switch trials no differences on RTs should be observed between the baseline and the target trial implying that the task was maintained in WM in order to be readily available on the target trial. Start-up costs should not be altered relative to the previous experiment.

5.3.1 Method

5.3.1.1 Participants

Participants were 16 university students (14 females) with a mean age of 20.8 (5.1 SD) years old that took part on this experiment for either course credit or payment. They all reported having normal or corrected to normal vision and hearing while three were left-handed.

5.3.1.2 Design and stimuli

The design of this experiment was similar to the design of the previous experiment. The only difference here, is that instead of predictable switch blocks, predictable non-switch minblocks were presented. A non-switch target trial therefore was signalled by a precue that consisted of the letter 'R' and appeared before the onset of the first trial of the miniblock. In this experiment therefore, the precues were the letters 'R' and 'U'.

5.3.2 Results

Error responses and very fast responses (less than 100 ms) were excluded from the analysis of RT data. As a result, an exclusion of 6.4% of scores has occurred prior to data analysis. The analysis was identical to that of the previous experiment.

5.3.2.1 RTs

A statistically significant main effect of block type was revealed [$F(2, 30) = 121.629$, $MS_e = 3876$ $p < .001$]. The ensuing HSD test revealed that switch cost on the unpredictable switch miniblocks was significantly larger relative to the switch cost of the unpredictable and predictable non-switch miniblocks ($p < .05$, both comparisons; no other comparisons reached statistical significance). In order to examine more the switch cost for the unpredictable non-switch trial a paired t-test was run comparing the RTs of the 4^{th} and target trial respectively.

The results revealed that RT on the 4^{th} trial was significantly faster relative to that of the target trial [$t(15) = -3.823$, $p < .01$, two-tailed test]. Similarly to the previous experiment and despite of the fact that participants had to repeat the same tasks between the 4^{th} and the target trial on unpredictable non-switch miniblocks a slowing on RT occurred.

However, a cross-experimental comparison with an independent samples t-test of the RT slowing on non-switch miniblocks across the current and previous experiment revealed a significantly increased RT slowing for the previous experiment [$t(30) = 2.675$, $p < .05$, two-tailed test]. In a similar manner, a cross experimental comparison on unpredictable switch miniblocks revealed that switch costs on the current experiment were larger relative to that of the previous experiment [$t(30) = 2.899$, $p < .01$, two-tailed test]. For a graphical illustration of average RTs and error rates of Experiment 13 see Figure 33.

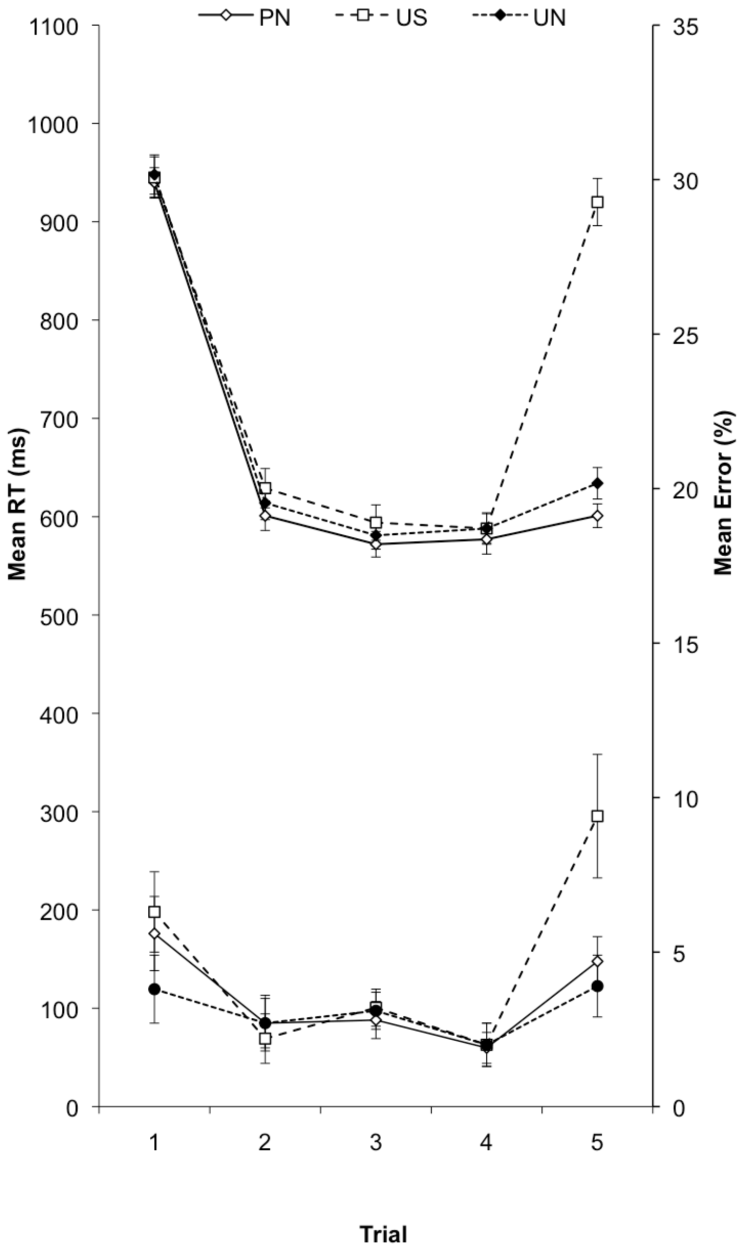


Figure 33: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 13. Means have been averaged over RSI. Error bars represent the standard error of the mean (SE). PN = Predictable Non-switch miniblock, UN = Unpredictable Non-switch miniblock, US = Unpredictable Switch miniblock.

5.3.2.2 Error rates

As before, error rates were analysed in a different way relative to the RTs. Specifically, the error rates of the target trials of each one of the three different miniblocks were entered into a one-way within participants analysis of variance (ANOVA). A difference on accuracy between the different target trials failed marginally to be revealed [$F(2, 30) = 3.302$, $MS_e = .049$, $p = .051$]. In particular, the error rate on the target trial on unpredictable switch blocks was 9.4%, on predictable non-switch blocks was 4.7% and finally the error rate on unpredictable non-switch blocks was 3.9%.

5.3.3 Discussion

The results are clear-cut and provide supporting evidence for the assumptions of the previous experiment. As expected, a marked reduction occurred on unpredictable non-switch RT slowing in this experiment relative to the previous one implying that participants were biased towards the preparation for a task repetition on unpredictable miniblocks. This assumption is further supported by the fact that switch costs on unpredictable switch trials increased relative to the previous experiment. As expected, performance on the target trial on predictable non-switch miniblocks did not differ from that observed on the baseline trials. This finding supports further the task switching model's idea that the relevant task-set is maintained in WM in order to be available for further use when a non-switch trial is expected.

The current results therefore, provide further evidence that an endogenous modulation of task-sets is not only feasible but rather is the main determinant of switch costs under unpredictable conditions.

The current experimental paradigm provided results that replicate and extend the previous findings of the thesis. For that reason, a modified version of this paradigm was designed aiming to reveal brain regions related to task switching, advance preparation and task maintenance processes. Central to the modified version was, a) to adhere to the neuroimaging protocols without, b) deviating from the behavioral findings of Experiment 12.

5.4 EXPERIMENT 14

The recent advancement in neuroimaging provided an invaluable tool in the exploration of the cognitive processes that underlie the switching of tasks. Over the past decade, the task switching paradigm has been used in fMRI studies both for clinical and research purposes. From a clinical point of view, studies that included patients suffering from focal damage, Parkinson's disease and ADHD revealed increased switch costs, increased error rates and in general disorganized performance in experiments that required switching between two tasks (King, Colla, Brass, Heuser, & von Cramon, 2007; Rogers, et al., 1998; Werheid, Koch, Reichert, & Brass, 2007).

In addition, regarding brain and especially prefrontal cortex development, neuroimaging data revealed that children younger than 6 years old are able to switch between two tasks and that performance in general improves with age (Dibbets & Jolles, 2006) while in older adults a general decrement in performance is evident (Mayr, 2001).

From a research perspective, it is established that in neuroimaging studies when event-related activation on non-switch trials is relative to that of switch trials, results reveal that numerous brain regions are more active when one is switching tasks than when not. These regions are usually located in the medial and lateral regions of the prefrontal cortex, sometimes in the parietal lobes, the cerebellum and other subcortical regions (Monsell, 2003; Sohn, Ursu, Anderson, Stenger, & Carter, 2000).

Specifically, a study revealed that regions in the anterior insula bilaterally, the left intraparietal sulcus, the lateral prefrontal and premotor cortex, the SMA/pre-SMA region and the cuneus/pre-cuneus were activated under task repetition conditions and were additionally activated when a task switch occurred (Dove, Pollman, Schubert, Wiggings, & von Cramon, 2000).

Regarding the localization of TSR, because several processes occur when switching relative to when repeating a task (extra processing of cue, change of stimulus-response mapping), it is very difficult to isolate only the occurrence of TSR by monitoring brain activity. Moreover, if a region X consists of an executive component that controls regions I, II and III, it would be very difficult to isolate this executive component since simultaneous differential activation of all four regions is expected. Therefore, the ‘source’ and ‘target’ of the control cannot be distinguished (Hopfinger, et al., 2000).

One approach to overcome such problems is the attempt to isolate brain activity that is related to preparation for a task switch. Usually, this methodology incorporates the use of long preparation intervals that help researchers observe brain activation that is not related to processing of the cue or employment of the relevant stimulus-response mapping.

One such study was conducted by Sohn and Anderson (2000). Participants were required to classify letters and digits by pressing a key. Each trial consisted of two stimuli presentations and lasted for 18 s while the tasks within each trial were separated by a 5 s ISI. Specifically, each trial began with the word ‘Ready’ (5 s), followed by task A (1 s), ISI (5 s), task B (1 s) and a black screen (6 s) followed by a new trial.

There were two main conditions, the foreknowledge and the no-foreknowledge condition. In the foreknowledge condition, there were two kinds of blocks of trials - the repetition and the switch blocks. In the repetition blocks task B was always the same as task A while on switch blocks task B always differed from task A. In the no-foreknowledge condition task B could randomly be either the same or different from task A.

The behavioral results revealed the typical findings in the task switching literature. Performance was better in the foreknowledge relative to the no-foreknowledge condition, while RTs were facilitated on non-switch than on switch trials. Analysis of the images derived during the, according to the authors, preparation period (‘Ready’ signal - offset of task B) revealed that the lateral prefrontal cortex (BA 46/45) and posterior parietal cortex (BA 40) are involved in endogenous preparation. In particular, higher activation was observed in the inferior lateral prefrontal cortex and superior posterior parietal cortex in the foreknowledge condition relative to the no foreknowledge condition.

In contrast, analysis of the images during the switch period (offset of task B – onset of next trial) showed that exogenous adjustment involves the superior prefrontal cortex (BA 8) and posterior parietal cortex (BA 39/40) in general. In that case, upon a task switch with no foreknowledge, activation in these areas was higher relative to the activation in task repeat trials. According to the authors, endogenous preparation and exogenous adjustment for a task switch may be independent processes involving different brain regions (Sohn, et al., 2000).

This conclusion is in contrast with the assumptions stated in Chapter 2 of the thesis suggesting that it is highly probable that endogenous and exogenous control may not be insulated completely from one another. It must be noted here, that in their study a brain area, the posterior parietal cortex (BA 40), was activated in both the foreknowledge and the no-foreknowledge condition. This finding also may suggest either, a) that endogenous and exogenous control may involve overlapping regions or, b) that endogenous preparation is feasible in the no-foreknowledge condition. While the relative activation of the discussed overlapping regions may be different under certain circumstances (e.g., foreknowledge vs. no-foreknowledge condition), it also suggests that common components may be activated in both cases.

Task preparation was also central to Brass and von Crammon's (2002) study that investigated task switching with a task-cueing paradigm. Participants were presented on each trial with digits ranging from 20 to 40 (except 30). The digits were presented within a frame (square or diamond) that acted as a cue. Their task, depending on the cue, was to judge by pressing a key whether a digit was smaller or greater than 30 or whether the digit was an odd/even number.

Each trial started with a fixation cross that remained on screen for 200 ms. Following that, the cue was presented for 1200 ms (cue-target condition) or the cue was presented concurrently with the digit (no-cue-target condition). In some trials, only the cue was presented on the screen (cue-only condition) and in some other, the screen was left blank (null events). The researchers assumed that contrasts between the cue-only and cue-target trials and cue-only and null events would allow for clear separation of preparation- and target-related control processes and the accompanying activated brain regions.

Analysis of the neuroimaging data derived form the cue-only trials and null events (preparation-related activation) revealed frontolateral activation in the inferior frontal junction (BA 6/8/44) in both hemispheres. Activation was also found in the middle frontal gyrus (BA 9), medial frontal gyrus (BA 6) and the dorsal premotor cortex bilaterally. In addition, the insula (BA 7) and the pre-supplementary motor area (BA 6) were also have been found to be activated. The parietal lobe was also activated along the intraparietal sulcus (BA 7) and the precuneus (BA 7).

The cue-target trials and cue-only trials contrast (target-related activation) revealed activation in the premotor cortex and the hand field of the motor cortex. Activation was found in the inferior frontal junction (IFJ) and the anterior cingulate cortex (ACC). Correlational analysis revealed that mainly two are the key components involved in task preparation: the IFJ and the pre-supplementary motor area (pre-SMA). The anatomical position of the IFJ, in the border of the premotor and prefrontal cortices makes it an ideal candidate for task management. The researchers suggested that the IFJ is responsible for implementing a task-set, which requires the selection of the relevant stimulus-response mappings for the expected task. On the other hand, the pre-SMA is a region that is strongly connected with the lateral prefrontal cortex and the lateral premotor cortex. It was assumed that while the front-lateral prefrontal cortex might be involved in the selection of cue-related task rules, the pre-SMA might bare responsibility for imposing these rules on a higher-order motor control level. Target related processing (cue-target vs. cue-only contrast) have been found to be related with activation in the ACC. It was proposed that the ACC is responsible for response conflict resolution that arises from the presentation of two competing task-sets and/or inhibition of the irrelevant to the current trial response (Brass & von Cramon, 2002).

The dissociation of preparatory processes was also studied using a variation of the Stroop paradigm (MacDonald, Cohen, Stenger, & Carter, 2000). Participants were given an instruction prior to each trial indicating whether they had to read the word or name the color. After a delay, the stimulus was presented and thus instruction-related processes (preparation) were separated temporally from stimulus-related processes. Instruction-related activity was evident in the dorsolateral prefrontal cortex (BA 9) in response to naming the color but not read the word (a more automatic response). According to the researchers, this pattern of activation is related with the expected increased requirement for top-down control in the color-naming task. This finding supports the notion that the dorsolateral prefrontal cortex (DLPFC) is responsible for the representation and maintenance task demands needed for such control. Instruction related activity was not observed in the ACC (BA 24/32). That was not the case however for response-related activity. In that case, the right ACC was found to be more active for incongruent, relative to congruent, color-naming trials, consisted with the assumption this brain region is responsible for conflict monitoring. The DLPFC was equally active in both congruent and incongruent responses. Overall, it is evident that a frontoparietal network is responsible for controlling task switching. This network includes areas like the IFJ, MFG, ACC, pre-SMA and IPS. This idea is supported further by a study regarding attentional control. Erickson et. al., 2005 suggest that a network including bilaterally the IFG, MFG, ACC, IPC, SPC and thalamus is actively involved in controlling attention. For a schematic representation of the discussed network of regions, see Figure 34.

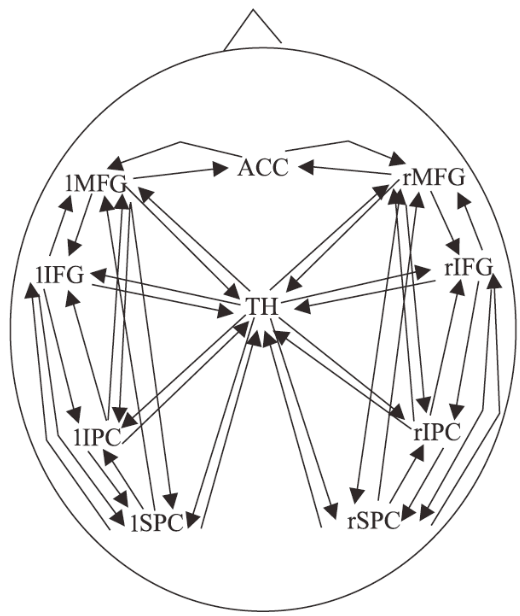


Figure 34: A schematic representation of the network of regions controlling attention. ACC = Anterior cingulate cortex, MFG = Middle frontal gyrus, IFG = Inferior frontal gyrus, IPC = Inferior parietal cortex, SPC = Superior parietal cortex, r = Right, and l = Left. From “A task equation modeling analysis of attentional control: an event-related fMRI study” by Kirk I. Erickson, Moon-Ho Ringo Ho, Stanley J. Colcombe, and Arthur F. Kramer (2005), *Cognitive Brain Research*, *22*, p. 351. Copyright 2004 Elsevier B.V.

It seems so far that especially important is the role of the left IFJ (BA 6/8/44) in task management and top-down control (task switching) and thus the pattern of activation in the left inferior frontal cortex will be examined thoroughly in the experiment. In addition, the ACC is responsible for managing and resolving conflicting responses (incongruent stimuli). The pre-SMA acts probably as a relay that imposes the selected by the DLPFC task-set rules to regions responsible for the generation of motor responses. Preparatory processes seem to involve the middle frontal and medial frontal/cingulate gyri (BA 9) along with the parietal lobe (BA 40/7). Therefore, any activity in these areas will be examined thoroughly.

The following experiment, a variation of Experiment 12, was designed to adhere to the neuroimaging protocols. Brain activation under the conditions of interest was examined by using fMRI. Based on the findings of Experiment 12, it was assumed that in unpredictable switch and non-switch miniblocks of trials participants would actively prepare for a task switch. In that case, activation in the left IFJ (BA 6/8/44) should not differ markedly within these conditions because it is assumed that in all 3 kinds of blocks of trials a shift in tasks is expected.

Nevertheless, if conditions apply in which pure blocks of non-switch trials vs. blocks of switch trials are compared then it can be expected more activation in this area on switching blocks relative to repeat blocks. That is because in circumstances where switches are required task management through effortful top-down control is a prerequisite for a successful response. Based on the literature, attention in the current experiment will be focused on the activation patterns of specific brain areas. Specifically, the distinct role in preparation of the middle and medial frontal/cingulate gyri (BA 9) along with any activity in the parietal lobe (BA 40/7) and especially the IPS will be examined. In these regions, a different pattern of activation should occur in cases of predictable switch trials when relative to unpredictable trials.

Since there is no intention to examine an immense number of other regions, conflict resolution and response generation are considered to be beyond the scope of this study therefore the roles of the ACC and the pre-SMA will not be studied here.

5.4.1 Method

5.4.1.1 Participants

Participants were 12 university students (7 females) with a mean age of 27 (4 SD) years old took part on this experiment. They all reported having normal or corrected to normal vision and hearing, and two were left-handed. Written consent was obtained for every participant. The study was approved by the York Neuroimaging Ethics Committee. Stimuli were back-projected onto a screen located into the magnetic bore approximately 57 cm from the participants' eyes.

5.4.1.2 Localizer scan

To identify regions responding selectively to task switching conditions and test the prediction that part(s) of the left inferior frontal cortex (e.g., IFJ) is involved in switching specific processing, a localizer scan was carried out for each participant. The main aim was to identify regions, especially in the left IFC, that exhibit selective activation under task switching conditions and then examine the activation pattern of these regions further in the event-related part of the experiment. Participants were presented with 24 miniblocks of trials. The tasks that participants had to perform were identical to the tasks described earlier. Each miniblock consisted of 6 trials with a duration of 1.5 s each and they were presented at a fixed ITI of 16.5 s. There were 2 kinds of miniblocks (repeat vs. switch). Repeat miniblocks were preceded by a cue ('R') for 3 s and consisted of the same task e.g., AAAAAA or BBBBBB. On the other hand, switch miniblocks were preceded by a cue ('S') and consisted of both tasks alternating every other trial e.g., ABABAB or BABABA.

The cue's font colour (red or green) signalled the task (parity or magnitude respectively) that had to be performed throughout a repeat miniblock. In the case of switch miniblocks, the cue's font colour signalled the task that had to be performed on the first trial of the miniblock. Miniblocks were counterbalanced according to type (repeat vs. switch) and task (parity vs. magnitude), and were presented in one of four previously pseudo-randomised sequences.

5.4.1.3 Event-related scan

Experiment 14' s behavioral paradigm was very similar to that of Experiment 12. However, several modifications to the original methodology have been made in order for the experiment to adhere to the neuroimaging protocols and limitations. In the current experiment the total number of miniblocks was increased from 60 to 90, whereas the number of trials within a miniblock was decreased from 5 to 4.

Moreover, the duration of the cue was 3 s and the ITI varied between 11 s and 18 s. No feedback was presented. Every other aspect of the experiment, including the training session, was kept the same as in Experiment 12.

5.4.1.4 Apparatus

Stimulus delivery and response capture in the fMRI experiments was performed using Presentation software (Version 9.70, www.neurobs.com) running on a Windows XP PC. In addition, a response box was used to collect the responses.

5.4.1.5 Imaging parameters

A GE 3 Tesla HD Excite MRI scanner at the York Neuroimaging centre (YNiC) at the University of York was used in order to carry out the experiment. An 8 channel phased-array head coil was used, radiofrequency tuned to 127.4 MHz. A gradient-echo EPI sequence was used to acquire 21 contiguous axial slices. (TR = 2 s, TE = 35 ms, FOV 19.2 cm x 19.2 cm, matrix size = 128 x 128, slice thickness 4.5 mm). These were coregistered to a T1-weighted anatomical volume (1 mm^3 x 1.13 mm^3 x 1.13 mm^3) from each participant. To help with registration, a T1-FLAIR weighted image was taken in the same plane as the EPI slices.

5.4.1.6 fMRI analysis

Analysis was carried out using FEAT (FMRI Expert Analysis Tool) Version 5.63, part of FSL (FMRIB's Software Library, www.fmrib.ox.ac.uk/fsl). Time-series statistical analysis was carried out using FILM with local autocorrelation correction (Woolrich, Ripley, Brady, & Smith, 2001). Z (Gaussianised T/F) statistic images were thresholded using clusters determined by Z > 2.3 and a (corrected) cluster significance threshold of *P* = 0.05 (Worsley, Evansy, Marretty, & Neeliny, 1992). Motion correction was followed by spatial smoothing (Gaussian, FWHM 6mm) and temporal high-pass filtering (cut off, 0.01 Hz). The individual subject data was entered into a higher-level group analysis using a mixed effects design (FLAME). First, the functional data was transformed onto a high-resolution T1-anatomical image before being coregistered onto the standard MNI brain (ICBM152).

For the localizer scan, task switching-selective regions of interest (ROI) were determined by the contrast switch > repeat miniblocks thresholded at $P < 0.001$ (uncorrected). The time series of the resulting filtered MR data at each voxel of interest was converted from units of image intensity to percentage signal change by subtracting and then normalizing the mean response of each scan ([x−mean]/mean x 100). All voxels in a given region were then averaged to give a single time series in each region for each subject.

For the event-related scan, the approach was different. Two contrasts that involved the target trial plus a time window of 3 s after the offset of the trial were applied in order to determine regions responsible for task switching, task maintenance and task preparation. The first contrast (predictable switch > unpredictable switch) aimed at determining regions responsible for task preparation while the second (unpredictable switch > unpredictable non-switch) intended at determining regions responsible for task switching and task maintenance. The time series of the resulting filtered MR data was calculated in a similar manner to the localizer scan. The time series was calculated from the onset of the cue and for a time window of 22 s. Individual miniblocks were normalized by subtracting every time point by the 3 s point (onset of the 1st trial of the miniblock) for that miniblock.

The normalized data were then averaged to obtain the mean time course for each miniblock type. The relative BOLD responses between the different conditions in the event-related and localizer scans were then compared. Specifically the questions were, a) whether task switching regions determined as important in the localizer scan will exhibit similar BOLD response in the event-related scan, b) whether the course of the time series will have an earlier peak on predictable task switch conditions (predictable switch > unpredictable switch) relative to unpredictable conditions and finally, c) whether there are independent regions related to task-set maintenance (unpredictable switch > unpredictable non-switch). Statistical images were thresholded at $P < 0.001$ uncorrected or corrected for multiple comparisons at $P < 0.05$ corrected.

5.4.2 Behavioral Results

Error responses and very fast responses (less than 100 ms) were excluded from the analysis of RT data. As a result, an exclusion of 1.2% of scores has occurred prior to data analysis. For the RT data analysis, the difference between the target trial and the 3rd trial for each one of the three different types of blocks was calculated and the results were entered into a one-way within participants analysis of variance (ANOVA).

Respectively for the error data analysis, the error rate of the target trial of each one of the three different blocks of trials was calculated and the results were entered into a one-way within participants analysis of variance (ANOVA). As before, the standard arcsine procedure was employed in order to transform error percentage rates prior to analysis (Keppel & Wickens, 2004).

5.4.2.1 RTs

The analysis revealed a statistically significant main effect of block type, [$F(2, 20) = 5.420$, $MS_e = 3536$, $p < .05$]. An HSD test revealed that the RT slowing on the unpredictable non-switch miniblocks was significantly smaller relative to the switch costs of the unpredictable and predictable switch miniblocks ($p < .05$, both comparisons; no other comparisons reached statistical significance).

Similarly, to the previous analyses, a paired t-test was run comparing the RTs of the 3rd and target trial on non-switch miniblocks. The results revealed that RT on the target trial was significantly slower relative to that of the 3rd trial, [$t(10) = -6.023$, $p < .001$, two-tailed test]. As in Experiment 12, despite the fact that participants had to repeat the same task between the 3rd and the target trial on unpredictable non-switch miniblocks a slowing on RT occurred on the latter.

5.4.2.2 Error rates

The error rates of the target trials of each one of the three miniblocks were entered into a one-way within participants analysis of variance (ANOVA). Results were as in Experiment 12, no significant difference on accuracy between the different target trials was revealed. It seems clear therefore, that overall the present behavioral results resembled closely the results of Experiment 12. A graphical illustration of the average RTs and error rates of Experiment 14 is provided in Figure 35.

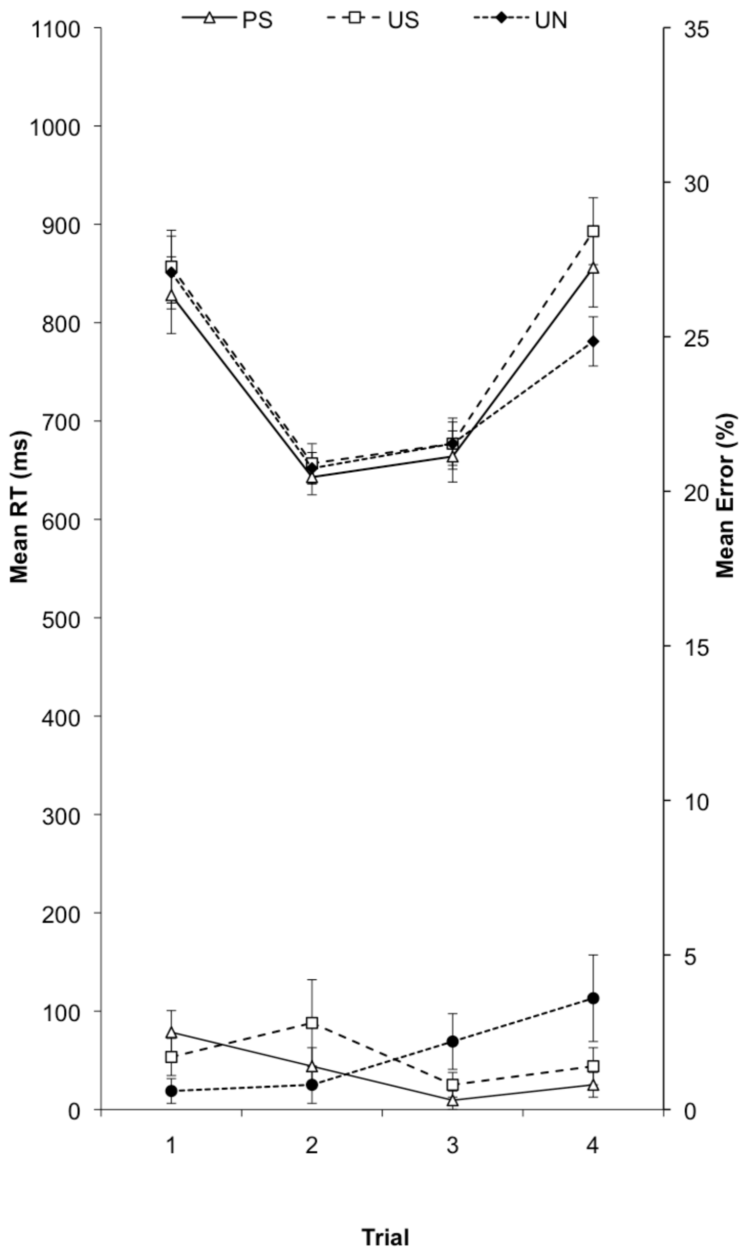


Figure 35: Graphical illustration of the RTs and error rates for the conditions of interest in Experiment 14. Means have been averaged over RSI. Error bars represent the standard error of the mean (SE). PS = Predictable Switch miniblock, UN = Unpredictable Non-switch miniblock, US = Unpredictable Switch miniblock.

5.4.3 Neuroimaging Results

5.4.3.1 Localizer scan

High activity on switching blocks was observed, among others, in the left inferior frontal gyrus (BA 45), the left superior temporal gyrus (BA 22), right middle frontal gyrus (BA 6), right precentral gyrus (BA 44), anterior cingulate cortex (BA 46), and right postcentral gyrus (BA 3). Further details in regard to the regions showing activity in the localizer scan are provided in Figure 36.

Area (anatomical/Brodmann)	Hemisphere	Cluster size	x	y	z	Z score
Inferior Frontal Gyrus/45	Left	10106	-48	24	26	9.09
Precuneus/7	Left	6099	-8	-76	48	8.81
Insular Cortex	Right	2208	32	22	4	6.15
Superior Temporal Gyrus/22	Left	367	-62	-44	6	5.11
Middle Frontal Gyrus/6	Right	340	40	-4	44	4.5
Precentral Gyrus/44	Right	26	66	10	8	3.31
Corpus Callosum	Left	25	-14	32	6	3.12
Anterior Cingulate Gyrus	Left	13	-8	26	24	3.15
Callosal Body	Left	10	-2	6	14	2.68
Precentral Gyrus/6	Right	8	50	8	38	2.76
Superior Temporal Gyrus/22	Right	7	72	-38	16	2.83
Superior Temporal Gyrus	Left	5	-50	-26	-4	2.64

Figure 36: Anatomical/Brodmann area, hemisphere, cluster size (voxels), coordinates and Z scores for regions showing activation on switch relative to non-switch miniblocks in the localizer scan for Experiment 14.

These regions correspond closely with models of networks of brain regions regarded as responsible for attentional control (Erickson, Ho, Colcombe, & Kramer,

2005) and task switching (Shallice, Stuss, Picton, Alexander, & Gillingham, 2008a). This pattern of activation was expected and clearly reveals a network of regions that controls the switching of tasks. Activation, as expected, was marked in the lateral prefrontal cortex and especially the left IFG (BA 45). This region is regularly discussed in the task switching literature and is thought to play a central role in task switching (Matsubara, Yamaguchi, Xu, Yamashita, & Kobayashi, 2002; Shallice, et al., 2008a; Swick, Ashley, & Turken, 2008). In order to study the related activity in more detail the mean time courses of voxels in this ROI were defined for each individual. The time course for the average BOLD responses in the left IFG is shown in Figure 37.

The results indicated that the left IFG was more activated when participants had to switch between two tasks relative to when they had to repeat the same task in a block of trials. In particular, activation dissipated after the first trials on repeat blocks of trials while on switch blocks it dissipated after the offset of the last trial of the block.

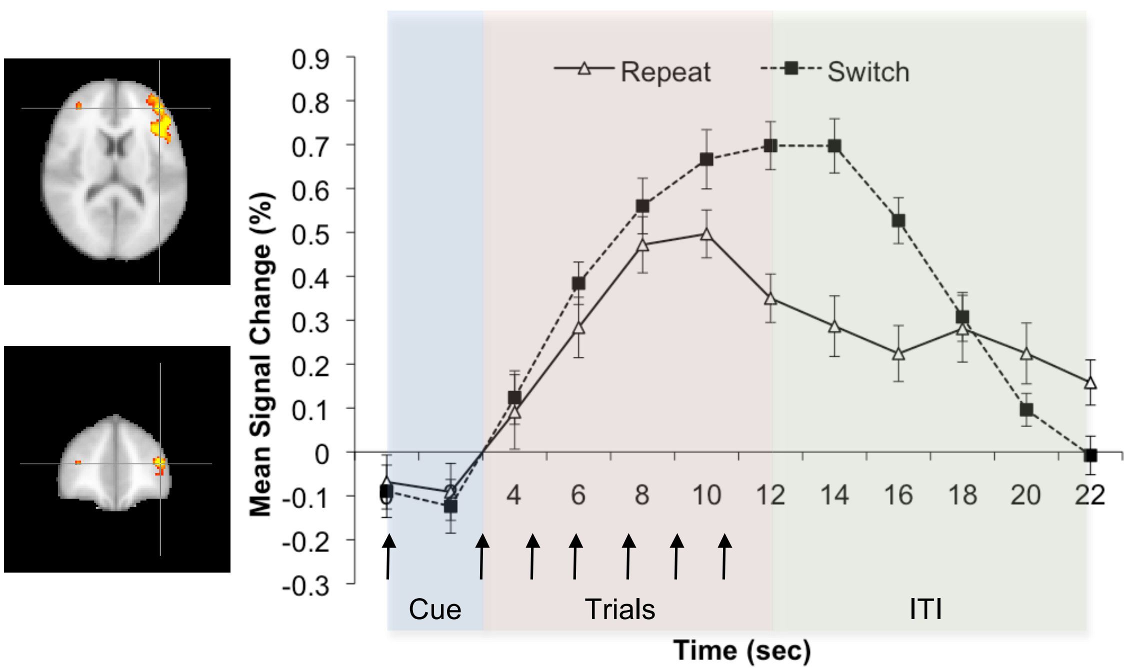


Figure 37: Graphical illustration of the average BOLD response in the left IFG (BA 45) in the localizer scan (Experiment 14). Arrows indicate the onset of the precue and the onset of each trial. Error bars represent the standard error of the mean (SE). Repeat = Repeat miniblocks, Switch = Switch miniblocks, Cue = Precue, Trials = Trials 1 to 6, and ITI = Intertrial interval.

In sum, the results from the localizer scan revealed that a network of regions is responsible for the switching of tasks. This network includes brain regions that have been associated with task switching in past studies.

One of these regions, the left IFG, was found to be highly activated on switch blocks of trials revealing that way its prominent role in task switching. Its activation pattern will be studied further in the event-related scan where predictable and unpredictable trials occur.

5.4.3.2 Event-related scan

Similarly to the previous scan, analysis was performed in the mean time course for the previously defined ROI (left IFG). The pattern of activation was similar to that seen on the switch blocks of the localizer scan. It was evident from the onset of the first trial to the offset of the target trial. Nevertheless, there was no difference in BOLD signal between the 3 conditions.

This activation occurred prior to the onset of the target trial indicating that probably a switching preparatory process is taking place despite the presence or absence of foreknowledge about the target trial.

This pattern of results along the pattern of results in the localizer scan verifies central assumptions of the thesis – common processes occur between predictable switch, unpredictable switch and unpredictable non-switch trials while it is probably related to the participants' expectation about a task switch on the upcoming trial on unpredictable cases in the current experiment. The time course for the average BOLD responses in the left IFG is shown in Figure 38.

Subsequently, a whole-brain group analysis was performed in order to determine the general pattern of brain activity throughout the event-related scan. Brain activation was compared for the 3 conditions within a time window of 4.5 s starting from the onset of the target stimulus in order to reveal differences in brain activation during the target period across conditions.

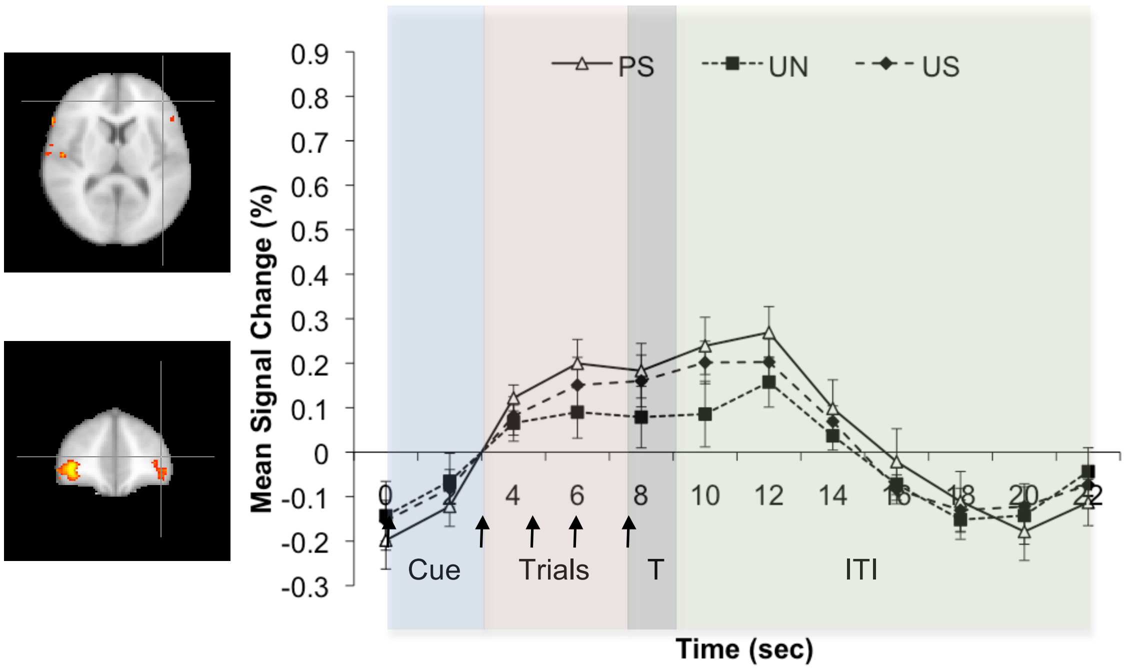


Figure 38: Graphical illustration of the average BOLD response in the left IFG (BA 45) in the event-related scan (Experiment 14). Arrows indicate the onset of the precue and the onset of each trial. Error bars represent the standard error of the mean (SE). PS = Predictable Switch miniblocks, UN = Unpredictable Non-switch miniblocks, US = Unpredictable Switch miniblocks, Cue = Precue, Trials = Trials 1 to 3, T = Last trial, and ITI = Inter-trial interval.

5.4.3.2.a US > UN contrast

Several brain regions were activated when participants had to unpredictably switch relative to when they had to unpredictably repeat a task. In detail, the precentral gyrus (BA 6), the inferior parietal lobule (BA 40), the posterior cingulate (BA 30), the cingulate gyrus (BA 23) were the most activated areas while less activated areas included among others the postcentral gyrus (BA 2), the precuneus (BA 7) and the superior parietal lobule (BA 7). Further details regarding brain activity in the contrast of interest are provided in Figure 39.

The pattern of activation revealed from this contrast was relative to that of the localizer scan. This comparison aimed to find commonalities between two task switching cases run under different conditions. Common activity between the two conditions was found on parts of the cingulate gyrus. This finding provided further evidence for the essential role of this region in conflict resolution, task management and executive processing.

Area (anatomical/Brodmann)	Hemisphere	Cluster size	x	y	z	Z score
Precentral Gyrus/6	Left	202	-31	-12	46	3.1
Inferior Parietal Lobule/40	Left	49	-42	-34	46	2.84
Posterior Cingulate/30	Left	30	-2	-44	18	2.96
Cingulate Gyrus/23	Left	26	-2	-24	26	2.78
Superior parietal Lobule/7	Left	16	-18	-54	66	2.76
Postcentral Gyrus/2	Right	16	54	-24	44	2.64
Superior Parietal Lobule/7	Left	10	-28	-46	62	2.62
Precuneus/7	Left	7	-14	-76	46	2.68
Precuneus/7	Left	6	-14	-62	48	2.65
Superior Parietal Lobule/7	Left	5	-14	-62	60	2.58
Superior Parietal Lobule	Right	5	36	-42	48	2.59

Figure 39: Anatomical/Brodmann area, hemisphere, cluster size (voxels), coordinates (mm) and Z scores for regions showing activation on unpredictable switch relative to unpredictable non-switch target trials in the event-related scan for Experiment 14.

5.4.3.2.b PS > US contrast

In order to study the preparation effect, brain activation was compared between the predictable and unpredictable switch miniblocks. High activity was found in the inferior frontal (BA 46), middle frontal (BA 9,10), inferior parietal lobule

(BA 39), precentral (BA 3), cingulate (BA 8) and postcentral gyri (BA 3). Details regarding the regions involved in this contrast are provided in Figure 40.

Area (anatomical/Brodmann)	Hemisphere	Cluster size	x	y	z	Z score
Inferior Frontal Gyrus/46	Right	319	40	46	0	3.33
Middle Frontal Gyrus/10	Left	173	-36	56	-2	3.35
Inferior Parietal Lobule	Right	144	50	-52	36	3.01
Inferior Parietal Lobule/39	Left	107	-50	-66	36	2.95
Middle Frontal Gyrus/9	Right	69	46	22	36	2.9
Middle Frontal Gyrus/9	Left	66	-42	26	34	2.81
Middle Frontal Gyrus/45	Left	61	-46	36	-12	2.94
Precentral Gyrus/3	Right	43	54	-4	24	3.05
Cingulate Gyrus/8	Left	42	-2	30	38	3.18
Postcentral Gyrus/3	Right	21	40	-22	54	2.74
Postcentral Gyrus/3	Left	16	-42	-14	32	2.88
Postcentral Gyrus/3	Right	14	44	-12	34	2.72
Inferior Frontal Gyrus/45	Right	13	62	24	10	2.75
Inferior Parietal Lobule/40	Left	11	-44	-56	50	2.67
Inferior Frontal Gyrus/45	Left	8	-46	44	-4	2.59
Precentral Gyrus/13	Right	7	52	-12	10	2.79
Inferior Frontal Gyrus/45	Left	7	-46	26	-2	2.66

Figure 40: Anatomical/Brodmann area, hemisphere, cluster size (voxels), coordinates (mm) and Z scores for regions showing activation on predictable switch relative to unpredictable switch target trials in the event-related scan for Experiment 14.

Activation in a portion of the right middle frontal gyrus (BA 9) was found once again in the analysis and its activity was studied in more detail. This region was defined separately for each individual and further analysis was performed on the mean time courses of voxels in this region.

Similar analysis in the same ROI in the localizer scan revealed that there was not any difference between switch and non-switch blocks of trials. The time courses for the average BOLD responses in the rMFG (BA 9) for the event-related and localizer scans are shown in Figure 41.

Visual inspection of the data revealed that the pattern of activation of the unpredictable non-switch miniblocks resembled closely that of the predictable switch miniblocks while it seemed that it was markedly different from the respective unpredictable switch miniblocks. In order to examine further the pattern of differences across the three conditions further analysis was carried on the BOLD responses in the rMFG.

The mean time course for each condition was subtracted from each one of the other two conditions and the confidence intervals for the resulted mean difference scores were calculated. The average BOLD response differences in the rMFG (BA 9) for the conditions of interest are shown in the top graph in Figure 42. Similar analysis will be carried over for the rest of the contrasts discussed in the remaining of the chapter.

Results revealed that activation was higher in the predictable switch than on the unpredictable switch condition. Interestingly, there were no significant differences between the predictable switch and unpredictable non-switch activity. Activity in the latter was significantly different from that of the unpredictable switch condition.

Similar analysis to the previous one was carried for the cingulate gyrus (BA 8). This region was hypothesized that has a key role in task preparation. As before, analysis in the same ROI in the localizer scan revealed that there was not any difference between switch and non-switch blocks of trials.

The time course for the average BOLD responses in the cingulate gyrus (BA 8) for the event-related and localizer scans is shown in Figure 43.

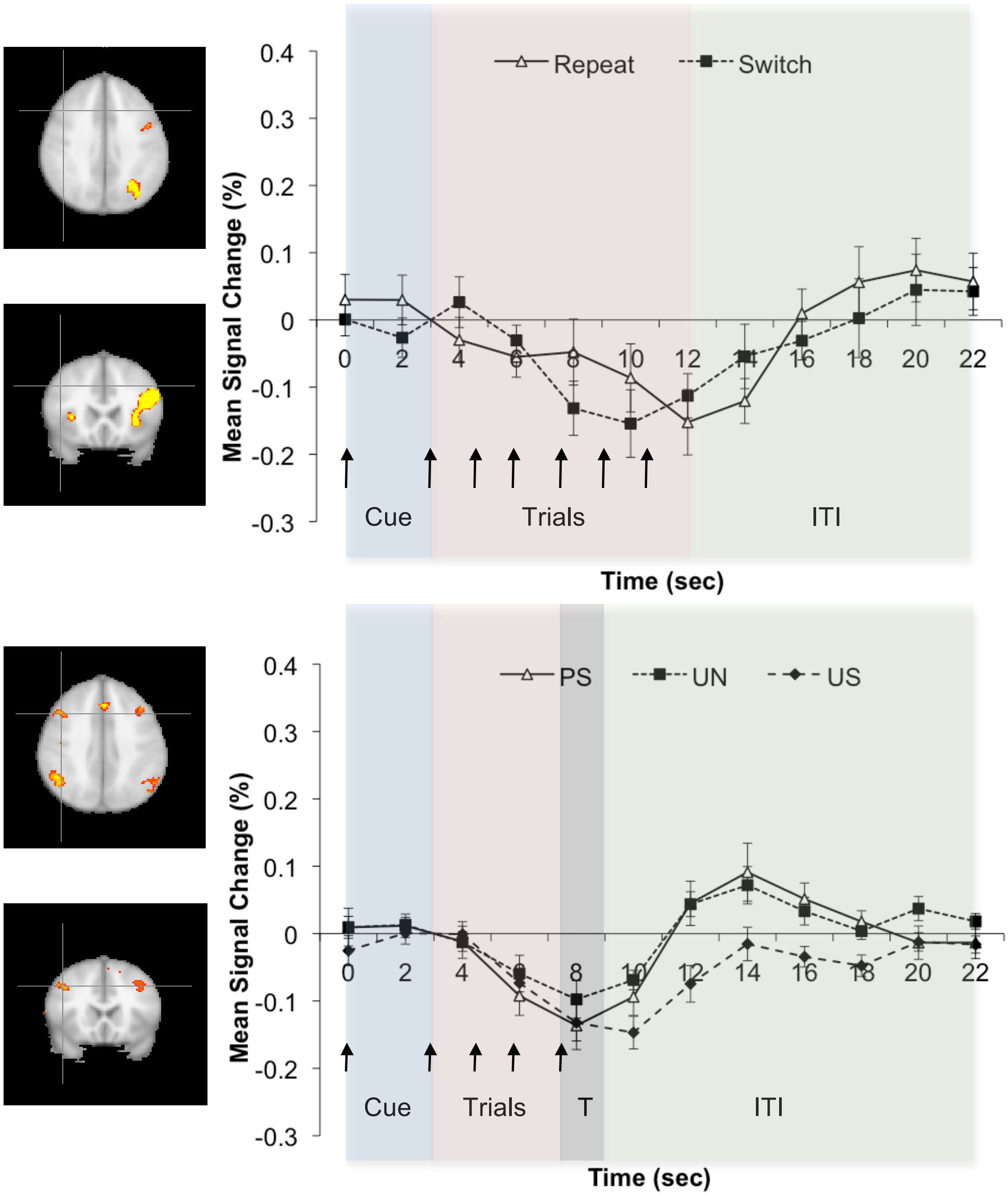


Figure 41: Top graph – localizer scan, bottom graph – event-related scan. Graphical illustration of the average BOLD response in the right MFG (BA 9) in Experiment 14. Arrows indicate the onset of the precue and the onset of each trial. Error bars represent the standard error of the mean (SE). PS = Predictable Switch miniblocks, UN = Unpredictable Non-switch miniblocks, US = Unpredictable Switch miniblocks, Cue = Precue, Trials = Trials 1 to 3, T = Last trial, and ITI = Inter-trial interval.

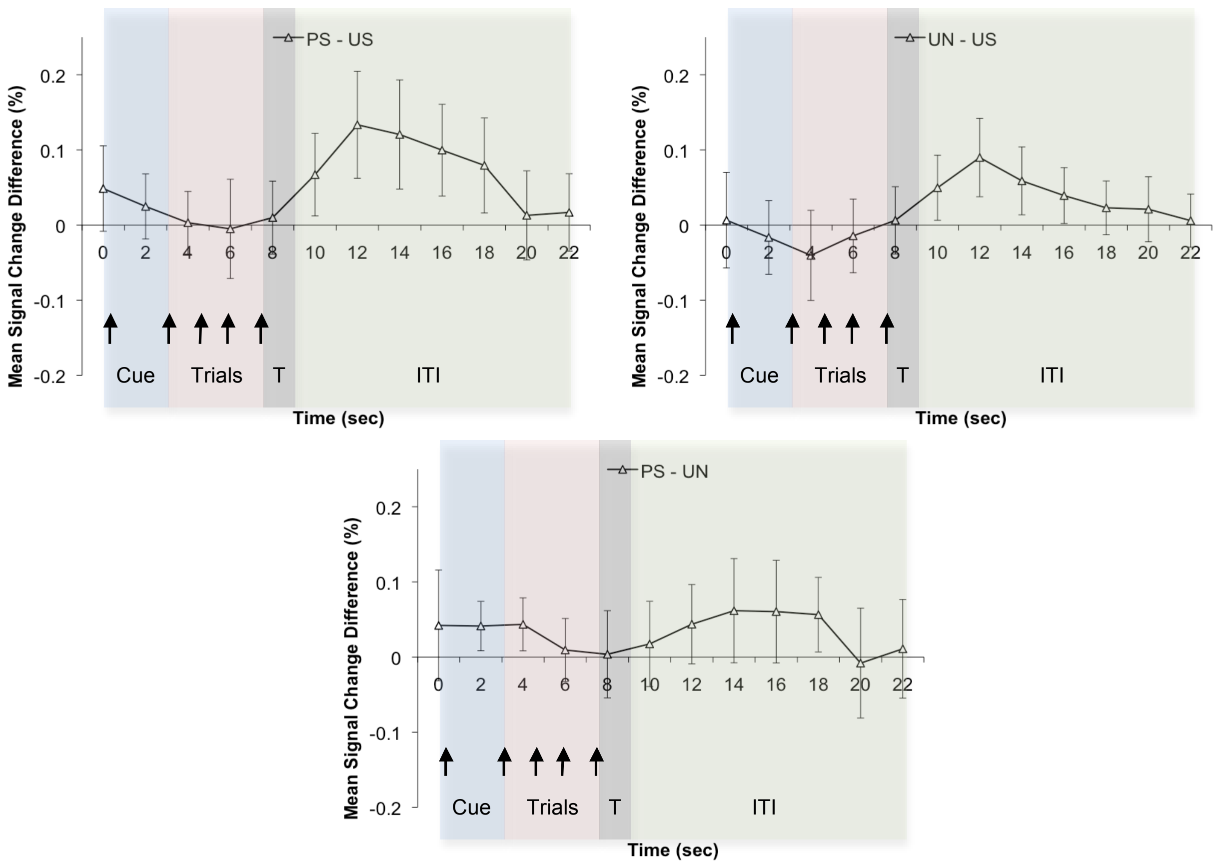


Figure 42: Graphical illustration of the average BOLD response differences in the right MFG (BA 9) in Experiment 14. Top left graph - PS minus US, top right graph - UR minus US graph, and bottom graph - PS minus US. Arrows indicate the onset of the precue and the onset of each trial. Error bars represent the standard error of the mean (SE). PS = Predictable Switch miniblocks, UN = Unpredictable Non-switch miniblocks, US = Unpredictable Switch miniblocks, Cue = Precue, Trials = Trials 1 to 3, T = Last trial, and ITI = Inter-trial interval.

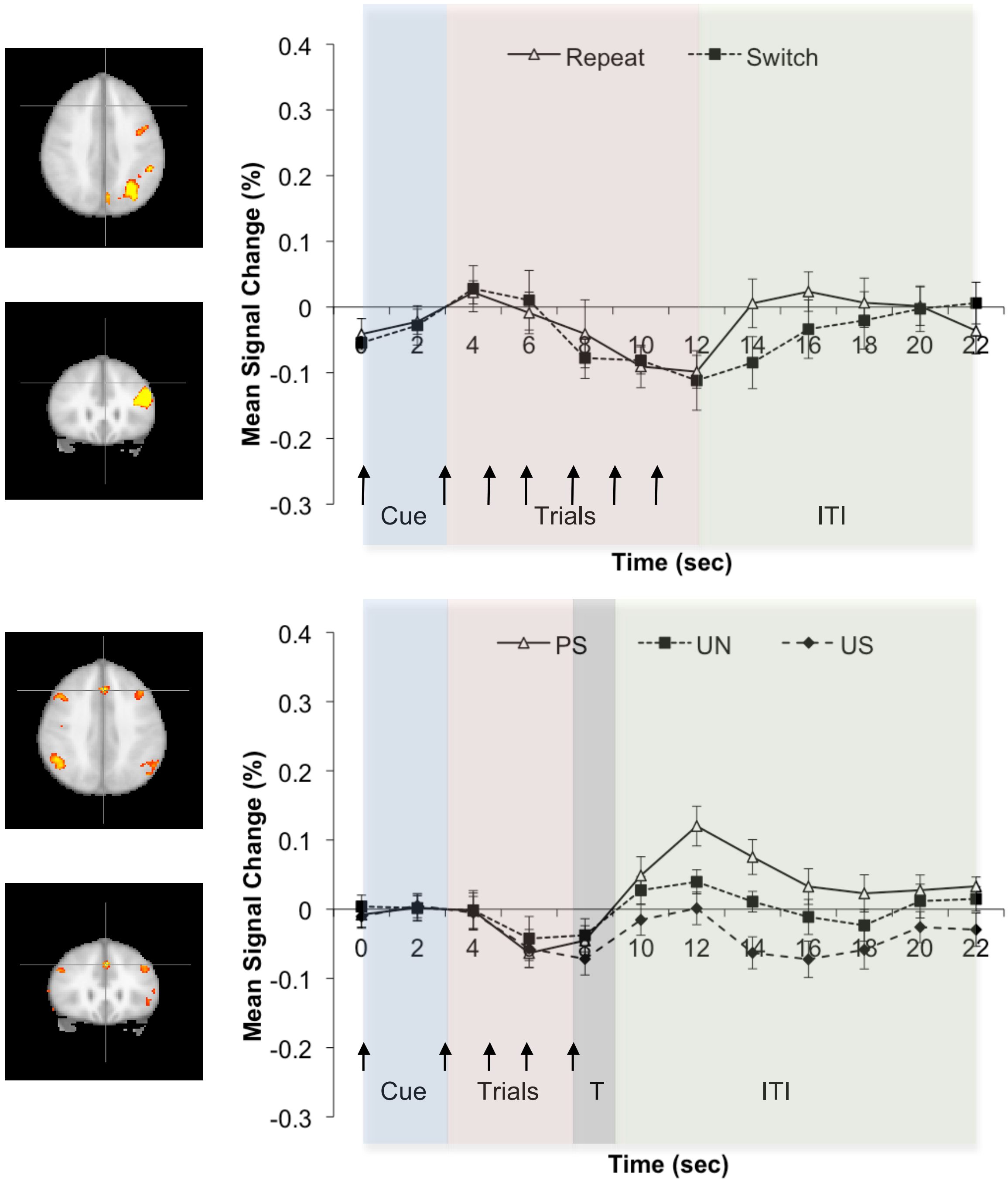


Figure 43: Top graph – localizer scan, bottom graph – event-related scan. Graphical illustration of the average BOLD response in the cingulate gyrus (BA 8) in Experiment 14. Arrows indicate the onset of the precue and the onset of each trial. Error bars represent the standard error of the mean (SE). PS = Predictable Switch miniblocks, UN = Unpredictable Non-switch miniblocks, US = Unpredictable Switch miniblocks, Cue = Precue, Trials = Trials 1 to 3, T = Last trial, and ITI = Inter-trial interval.

The average BOLD response differences analysis revealed that activity in the predictable switch condition was higher relative to that of the unpredictable conditions. No difference was found between the latter two conditions. The average BOLD response differences in the cingulate gyrus (BA 8) for the conditions of interest are shown in the top graph in Figure 44. Notably, it was observed that there was a backward shift of 2 s in the peak signal time course in this region relative to the peak signal time course observed in the rMFG (12th s vs.14th s respectively). In order to test this observation statistically, the peak signal time point (e.g., the 12th sec.) of each individual for both regions was entered into a paired samples t-test.

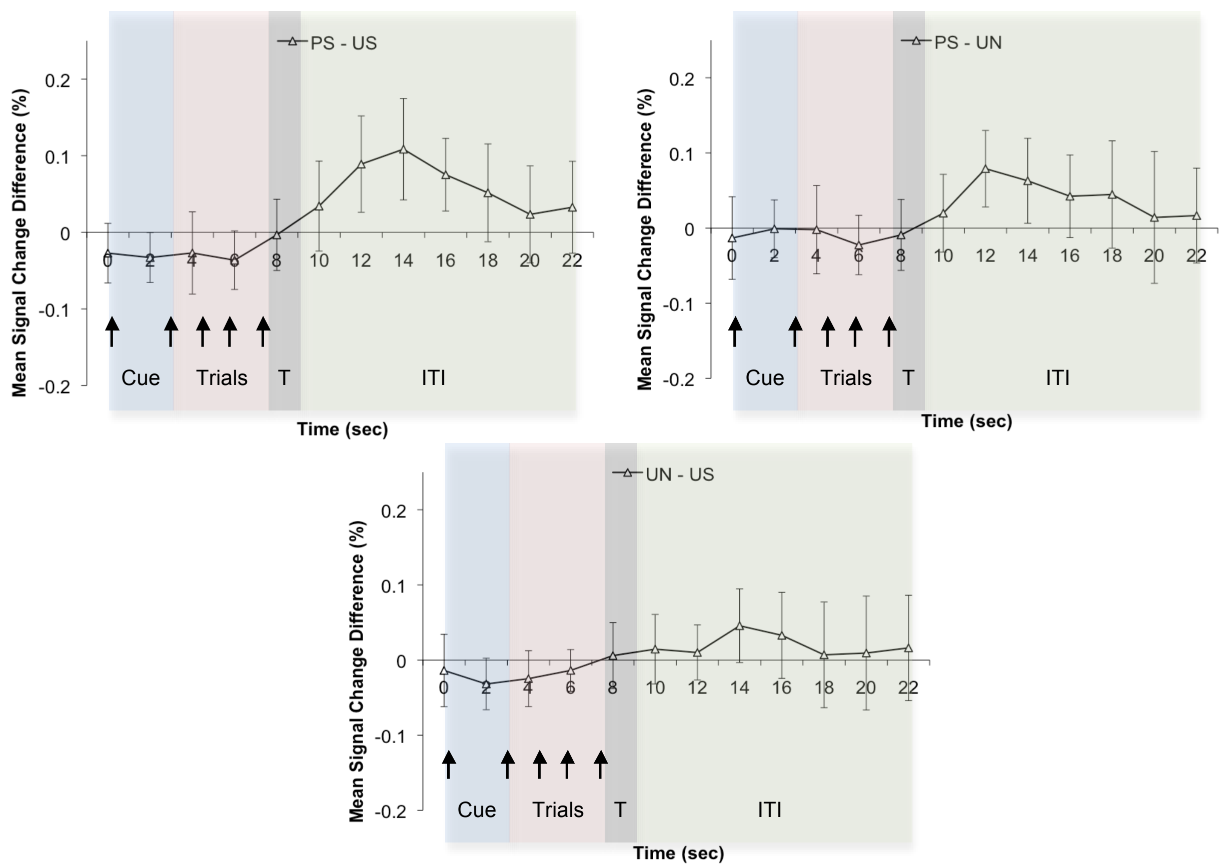


Figure 44: Graphical illustration of the average BOLD response differences in the cingulate gyrus (BA 8) in Experiment 14. Top left graph - PS minus US, top right graph - PS minus UN graph, and bottom graph - UN minus US. Arrows indicate the onset of the precue and the onset of each trial. Error bars represent the standard error of the mean (SE). PS = Predictable Switch miniblocks, UN = Unpredictable Non-switch miniblocks, US = Unpredictable Switch miniblocks, Cue = Precue, Trials = Trials 1 to 3, T = Last trial, and ITI = Inter-trial interval.

Results revealed the there was a significant backward shift in the peak signal time course in the cingulate gyrus activation, [$t(10) = -2.708$, $p < .01$, two-tailed test] for the majority of the participants tested. Nevertheless, reservations are preserved as to whether this earlier, in relation to the other regions tested, peak of activation is an indication of a preparatory process or a result of the variation of the BOLD response across different brain regions (Robson, Dorosz, & Gore, 1998).

It is known that there is variation of the BOLD response across regions, probably the result of underlying differences in the vasculature, and it constitutes a challenge in regard to the interpretation of absolute timing parameters (Miezin, Maccotta, Ollinger, Petersen, & Buckner, 2000). It is evident that this brain area is involved in some kind of preparatory processing however part of the supporting evidence, the fact that activation initiates before the onset of the target stimulus, maybe the result of mere coincidence.

5.4.3.2.c UN > US contrast

This contrast aimed at revealing brain regions that were responsible for task-set maintenance. Only the right inferior parietal lobule (BA 40) was activated when participants unpredictably repeated task relative to when they unpredictably switched task. Further details regarding the regions revealed from this contrast are provided in Figure 45.

Area (anatomical/Brodmann)	Hemisphere	Cluster size	x	y	z	Z score
Inferior Parietal Lobule/40	Right	24	52	-54	46	2.9
Inferior Parietal lobule/40	Right	11	50	-54	38	2.62

Figure 45: Anatomical/Brodmann area, hemisphere, cluster size (voxels), coordinates (mm) and Z scores for regions showing activation on unpredictable non-switch relative to unpredictable switch target trials in the event-related scan for Experiment 14.

BOLD responses in the same ROI in the localizer scan were similar between switch and non-switch blocks of trials. The time course for the average BOLD responses in the rIPL (BA 40) for the event-related and localizer scans is shown in Figure 46.

The average BOLD response difference analysis showed that activation was higher on the unpredictable non-switch relative to the predictable and unpredictable switch conditions. There was no difference between the latter two conditions. The average BOLD response differences in the rIPL (BA 40) for the conditions of interest are shown in Figure 47.

In sum, results from the event-related scan revealed that a frontoparietal network controls the switching of tasks. Specifically, activation in a region found to have a central role in the switching of tasks (left IFG) was found to have a similar pattern of activation across conditions.

This finding supports the idea that common processes occur on predictable switch and unpredictable cases indicating that participants were biased towards preparing for a task switch on unpredictable cases.

Selective activation was found in the cingulate gyrus for the predictable switch trials. This activation had a backward shift of 2 s in relation to the activation of other areas tested. This fact supported further that this region is involved in some kind of advance preparation however reservations were kept regarding this finding due to the variation of the BOLD response across brain regions. Selective activation was also found on the rIPL for unpredictable non-switch trials suggesting that this region is probably responsible for task-set rules maintenance.

Finally, the average BOLD response differences analysis revealed that the rMFG was activated on both predictable switch and unpredictable non-switch trials. Further analysis in the other regions did not reveal a pattern of activation similar to that found on the rMFG. It seems that activation in the rMFG is somehow related to the activation of the cingulate gyrus and rIPL.

As mentioned earlier similar patterns of brain activation have been found in other studies regarding attention and task switching. Specifically, in their study of attentional control Erickson et. al., 2005 argue that a network including bilaterally the IFG, MFG, ACC, IPC, SPC and thalamus is actively involved in controlling attention.

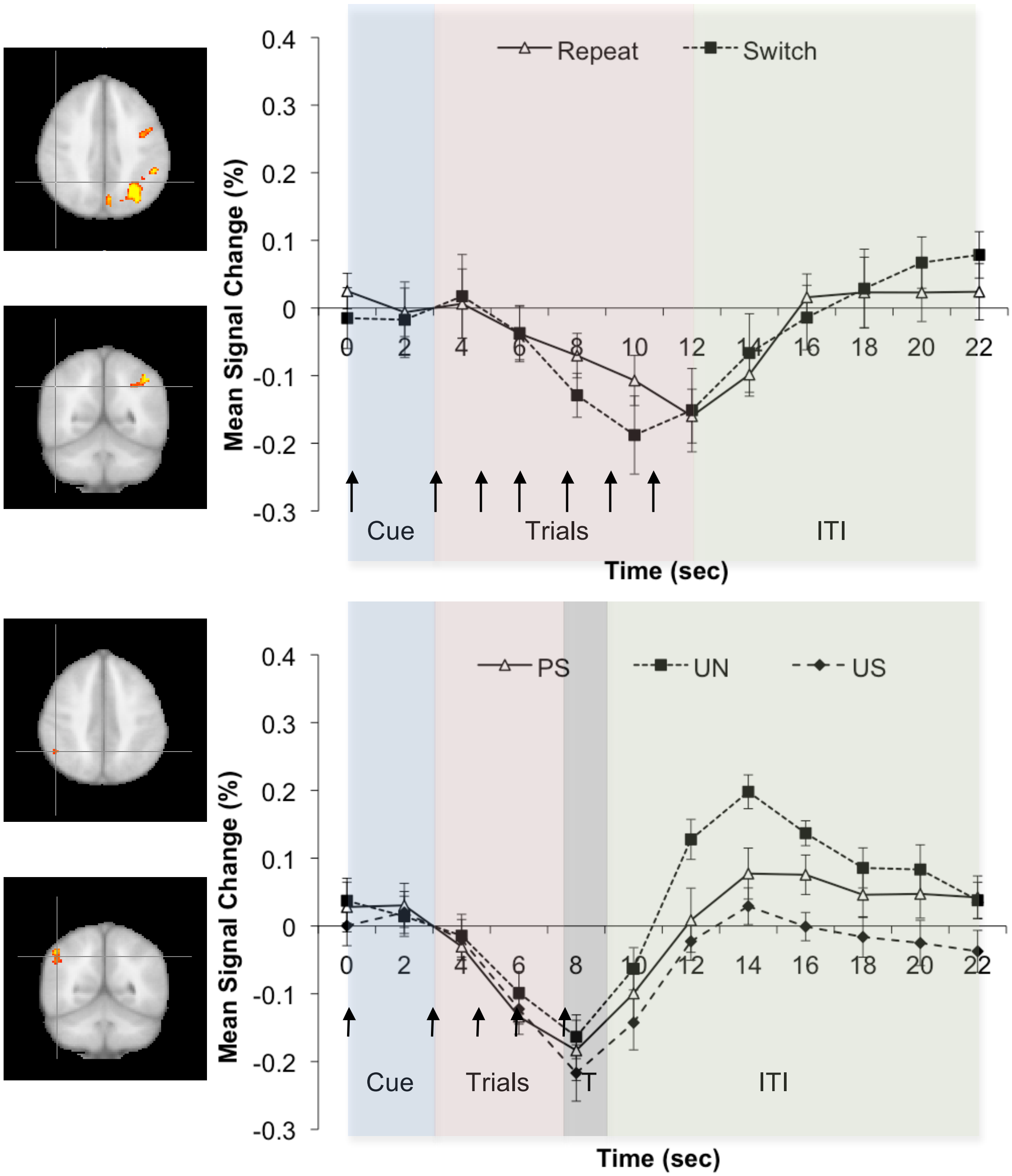


Figure 46: Top graph – localizer scan, bottom graph – event-related scan. Graphical illustration of the average BOLD response in the right IPL (BA 40) in Experiment 14. Arrows indicate the onset of the precue and the onset of each trial. Error bars represent the standard error of the mean (SE). PS = Predictable Switch miniblocks, UN = Unpredictable Non-switch miniblocks, US = Unpredictable Switch miniblocks, Cue = Precue, Trials = Trials 1 to 3, T = Last trial, and ITI = Inter-trial interval.

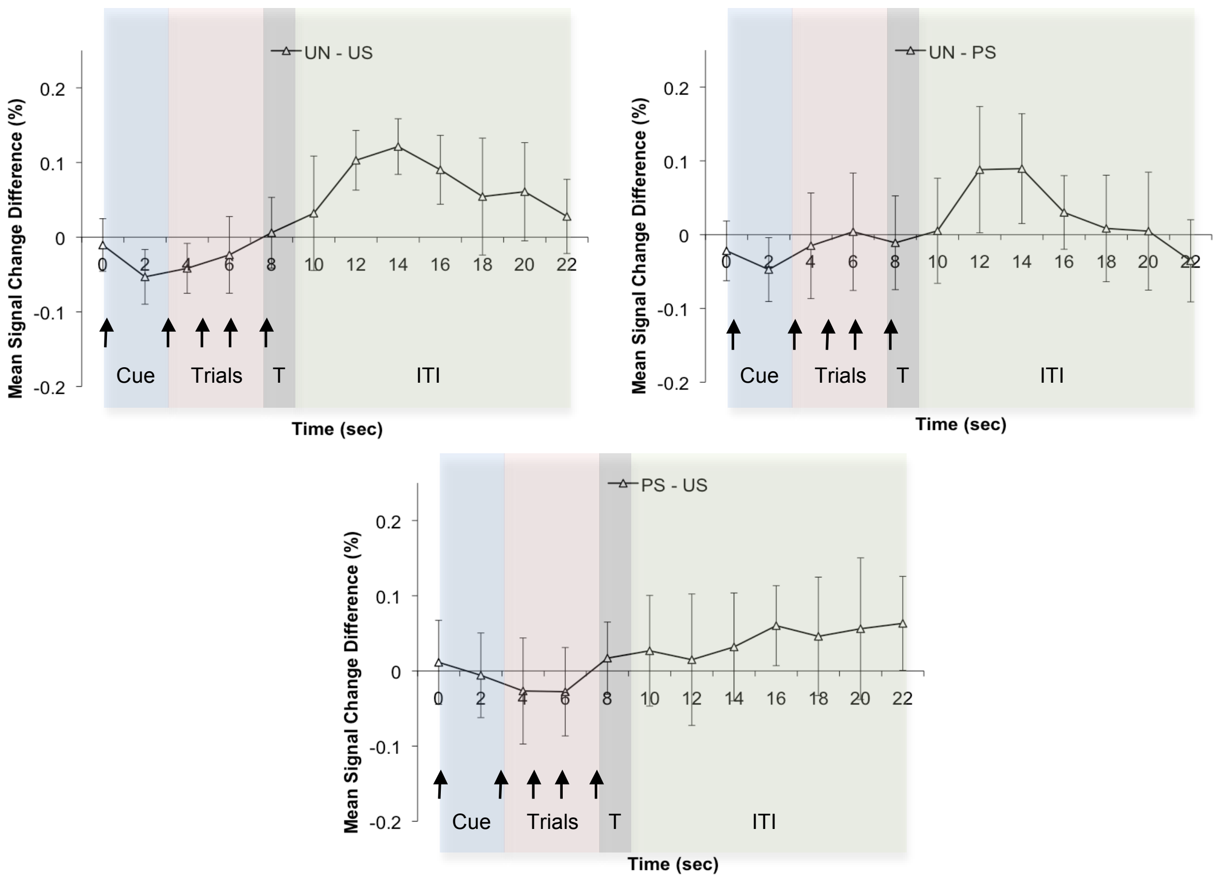


Figure 47: Graphical illustration of the average BOLD response differences in the right rIPL (BA 40) in Experiment 14. Top left graph - UN minus US, top right graph - UN minus PS graph, and bottom graph - PS minus US. Arrows indicate the onset of the precue and the onset of each trial. Error bars represent the standard error of the mean (SE). PS = Predictable Switch miniblocks, UN = Unpredictable Non-switch miniblocks, US = Unpredictable Switch miniblocks, Cue = Precue, Trials = Trials 1 to 3, T = Last trial, and ITI = Inter-trial interval.

5.4.4 Discussion

Interestingly, a network of bilateral connections between regions related to the current study (MFG, ACC, IFG and IPC) seems to be actively involved in attentional control. It is essential therefore, to examine further the relationship between these regions in the current study. Figure 48 provides a schematic representation of the network or regions as proposed by Erickson and the network of regions found in the current study. For a detailed report of the activated regions in the current study, see Figure 40.

In general, the behavioral results are in accordance with that of Experiment 12. Switch costs were observed on switch trials and they did not differ on unpredictable and predictable switch trials. Unpredictable non-switch trials RT slowing was observed once again and was smaller relative to both unpredictable and predictable switch costs. In brief, the modifications made on the original paradigm did not seem to affect the behavioral effects revealed in Experiment 12. The current study replicated adequately the previous findings.

The neuroimaging results revealed clearly that a frontoparietal network is involved in task switching. This pattern of activation was different between the localizer and the event-related scan suggesting that there are clear differences in the cognitive components involved in these two different task switching conditions.

Specifically, activation was evident in the lateral prefrontal cortex (BA 45) when participants went through switch blocks relative to repeat blocks. Similar activation has been found also in other studies (Dove, et al., 2000; Kimberg, Aguirre, & D'Esposito, 2000; Konishi S., et al., 1999; Konishi S., et al., 1998; Sohn, et al., 2000). It is likely therefore, that the IFG is related with a cognitive process responsible for task switching.

Interestingly, when activation in the same region was examined in the event-related scan, where participants went through predictable switch and unpredictable switch/non-switch miniblocks of trials, the pattern of activation was found to be similar across the three conditions.

This pattern of activation was not surprising since it was assumed that participants would actively prepare, at least to some extent, for a task switch even in cases where no foreknowledge regarding the task of the upcoming trial was provided.

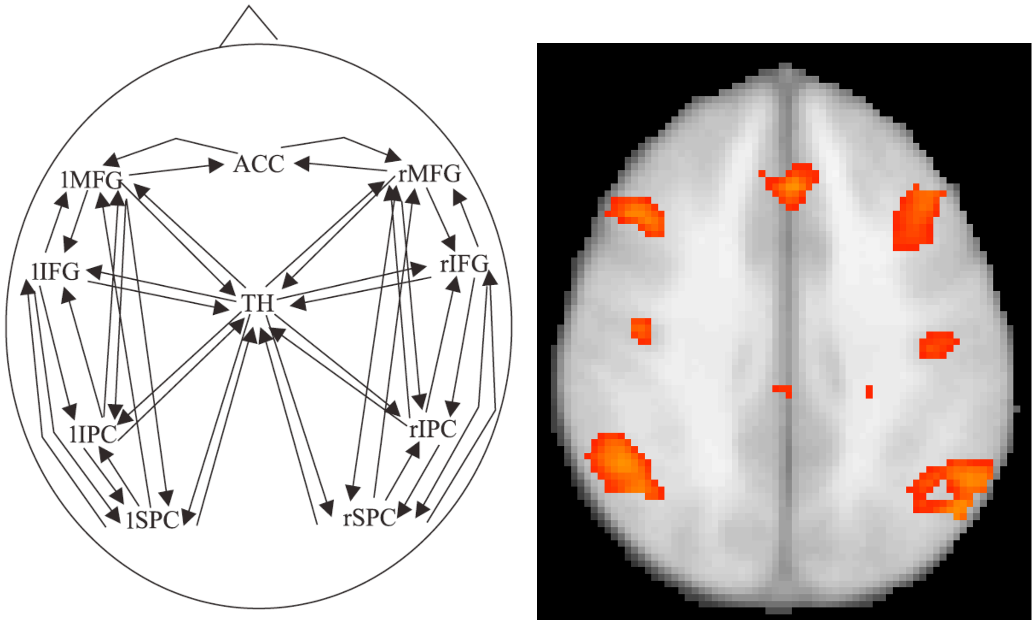


Figure 48: Left: A schematic representation of the network of regions controlling attention, Right: Network of regions activated on the PS (Predictable switch miniblocks) vs. US (Unpredictable switch miniblocks) on the event-related scan of Experiment 14. ACC = Anterior cingulate cortex, MFG = Middle frontal gyrus, IFG = Inferior frontal gyrus, IPC = Inferior parietal cortex, SPC = Superior parietal cortex, r = Right, and l = Left.

From “A task equation modeling analysis of attentional control: an event-related fMRI study” by Kirk I. Erickson, Moon-Ho Ringo Ho, Stanley J. Colcombe, and Arthur F. Kramer 2005, *Cognitive Brain Research*, *22*, p. 351. Copyright 2004 Elsevier B.V.

Specifically, it is logical to expect activation in this region in predictable switch miniblocks because the cognitive system is preparing itself for a task switch due to advance foreknowledge. The interesting thing here, is that this pattern is also observed under unpredictable conditions, as predicted, and in advance of the target trial. It seems therefore probable, that in cases where no foreknowledge is available, but nevertheless a task switch is more expected than a task repeat, a cognitive effort is made in order to bias the cognitive system in favor of a task switch.

Evidence for a distinct preparatory region, activated only when foreknowledge is provided, was found in the cingulate gyrus (BA 8). Activation in this area was only observed when participants knew that they would have to switch tasks on the last trial of the miniblock. This brain region has also been found to be involved in task switching in a variety of other task switching studies as well. It is thought to be closely related with executive processes such as updating the correct S-R mappings for a given trial and various forms of conflict resolution (Aarts, Roelofs, & Turennout, 2009; Dreher & Grafman, 2003; Konishi S., et al., 2002; Sohn, et al., 2000).

Analysis also revealed that a specific region was specifically activated when a task repetition was required on the last trial of the miniblock of trials. A region in the inferior parietal cortex, the rIPL (BA 40) was more activated when a task repetition relative to when a task switch occurred. The parietal cortex, among other things, is thought to host part or parts of WM processes (Jonides, et al., 1998; Ravizza, Delgado, Chein, Becker, & Fieza, 2004). Other task switching studies have regularly revealed the contribution of this region in task switching conditions (Dove, et al., 2000; Kimberg, et al., 2000; Konishi S., et al., 2002; Konishi S., et al., 1998; Rushworth, Paus T., & Sipila, 2001; Sohn, et al., 2000).

Specifically, regarding the functional role of the rIPL in attention it is suggested that this region is responsible, among others, for maintaining attention on the current tasks goals (Singh-Curry & Husain, 2009). Therefore, it can be assumed that in the current study the rIPL is involved in the active maintenance of task-set rules.

Another region that was found to be activated was the rMFG (BA 9). The pattern of activation in the rMFG (BA 9) revealed that this region was selectively activated under predictable switch and unpredictable non-switch conditions. The MFG is though to be a brain region that among others encompasses WM processes and the execution and maintenance of a task-set (Cohen, Botvinick, & Carter, 2000; Kimberg, et al., 2000; MacDonald, et al., 2000; Milham, et al., 2001). The pattern of activation in the rMFG reveals that there was a concurrent activation of the cingulate gyrus – rMFG and respectively of the rIPL – rMFG. A plausible explanation in regard to this finding is that on predictable switch conditions the cingulate gyrus prepares for a task switch and communicates information to rMFG (WM). On the other hand, the rIPL maintains task-set components used in the previous trial and communicates this information to rMFG (WM) when a task non-switch trial occurs. Further discussion regarding the activity of the discussed regions and their relationship will be made in the General Discussion section.

Concluding, the current experiment's behavioral results replicated those of experiment 12 and provided additional evidence in support of core assumptions of the thesis. In addition, it has provided neuroimaging evidence for a network with distinct elements regarding task preparation (cingulate gyrus), task maintenance (rIPL) and task switching (left IFG). These components are probably related with some part of WM (rMFG) with which they communicate. Interesting was the finding that a distinct task switching region (IFG) was found to be activated equally in predictable and unpredictable conditions in the event related scan while that was not true for the localizer scan. This finding suggests that it is possible that an endogenous preparatory component is in play when a task switch is unpredictable but more expected that a task repetition.

These findings will be discussed further in the following section where among others the correspondence of the neuroimaging results (activated brain regions) and the various components of the task switching model will be examined.

5.5 GENERAL DISCUSSION

In the last empirical chapter of the thesis, a series of experiments was run where probability about a task switch on the upcoming trial varied in unpredictable conditions. Specifically, the main aim in this chapter was, a) to study in detail the contribution of priming/autogenous facilitation and task preparation due to subjective expectancy on switch costs and, b) provide neuroimaging data in support of the main assumptions of the chapter and the thesis. The neuroimaging results and their correspondence with the proposed task switching model's components will be discussed in detail in the final part of this section.

In Experiment 12, participants were tested in conditions such as to make them expect a task switch on the last trial of an unpredictable miniblock of trials despite the fact that unpredictable switch and non-switch trials were equally probable to occur. In addition, miniblocks of trials were designed in such a way as to maximize priming of a task prior to either a switch or non-switch trial. There were predictable switch trials and unpredictable switch/non-switch trials.

In general, the results replicate the findings previously discussed in the thesis. There were obvious switch costs when a task switch was required whereas responses on switch trials were in general slower relative to non-switch trials.

Evidence for a central contribution of top-down task preparation in unpredictable cases came from the RT slowing in unpredictable non-switch miniblocks of trials. On the target trial on these miniblocks, and despite the fact that the current to the trial task was primed, a slowing on RTs was observed relative to the previous trials of the miniblock. This slowing was attributed to a top-down preparation for a task switch due to the subjective expectancy for a task switch on unpredictable cases.

In order to test this assumption further, Experiment 13 was run. In this experiment, conditions applied that made participants expect a task repetition instead of a task switch on unpredictable minblocks of trials. The results once again replicated the overall findings of the thesis, switch costs were larger when a task switch rather than when a task repeat was required. There was no slowing on RTs on predictable non-switch trials. The assumptions of the previous experiment were supported by this experiment’s results. There was a marked decrease of RT slowing on unpredictable non-switch trials relative to Experiment 12.

Moreover, a significant increase on switch costs on unpredictable switch trials occurred when participants expected a task repeat rather than when they were expecting a task switch on unpredictable trials. In addition, in Experiment 13 error rates on unpredictable switch trials were larger relative to the other trials but nevertheless marginally failed to reach a statistical significant level. Such a trend was not observed on Experiment 12.

Finally, on predictable non-switch trials where no preparation for a task switch is expected, no slowing on RTs on the target trial of the miniblock was observed relative to the previous trial of the miniblock. The overall findings in these experiments suggest that in contrast to current trends in the literature a top-down regulation of task-sets is not only feasible but is probably the main determinant of switch costs under unpredictable conditions.

On the last experiment, neuroimaging evidence that would support the current chapter’s and overall the thesis’ assumptions were sought. The design of Experiment 14 was a slight modification of Experiment 12 in order for the experiment to abide to the neuroimaging protocols and limitations. Speed and accuracy results replicated the results of Experiment 12. The neuroimaging findings revealed that a network of regions was activated when a task switch either was certain or expected. This network of regions corresponds closely with networks of brain regions regularly discussed in the task switching and attention literature.

Specifically, the left IFG (BA 45) was selectively activated when participants went through switch blocks in the localizer scan and not when they went through repeat blocks of trials. This pattern was expected as the BA 45 region is regularly discussed in the task switching literature.

In particular, a prominent suggestion in the literature is that the left IFG is critical for task management and in particular for response inhibition (Matsubara, et al., 2002; Swick, et al., 2008). Effective response inhibition is essential when task-set conflict arises. For instance, in task switching blocks of trials, like the ones used in the localizer scan, it is expected that task-set conflict will arise on every trial resulting in a tendency to respond to the irrelevant to the trial task. In order to respond correctly, the left IFG probably inhibits the irrelevant to the trial response. On repeat blocks of trials activation of the IFG dissipates shortly after the presentation of the startup trial simply because no conflict in task-sets occurs.

This pattern of activation was not observed in the event-related scan. In this case, activation in this region was similar between the three different conditions tested (predictable switch, unpredictable switch/non-switch) indicating that common processes related to task management occurs across the three conditions. These processes may be related to endogenous control and in the case of unpredictable trials prepare the cognitive system according to the expectations regarding the upcoming trial.

In Experiment 14, participants were biased to expect that a task switch is more probable than a task non-switch on unpredictable miniblocks. In that case, a similar pattern of activation was expected across unpredictable and predictable switch miniblocks in a region strongly related to task switching.

Results revealed exactly that – a region responsible for task switching (as defined in the localizer scan) was similarly activated in all three conditions indicating that participants were expecting a task switch regardless of the type of miniblock they were going through. On predictable repeat blocks (localizer scan), activation in the left IFG dissipates as a predictable repetition of trials occurs. This finding supports the idea that the cognitive processes related with this region are essential for task switching and are not necessary when a task is predictably repeated on successive trials. Overall, this pattern of activation is in line with the assumptions that, a) endogenous control in the form of expectations regulates performance on unpredictable cases and, b) there are common processes between predictable switch and unpredictable cases that are not shared by predictable non-switch cases.

Condition-specific activation was found on several regions according to the condition of interest. It seems therefore, that top-down regulation due to expectation involves some parts and not the whole network responsible for the switching of tasks. One of these regions, the cingulate gyrus (BA 8), was selectively activated when participants knew that they would change tasks on the target trial on predictable switch miniblocks. The cingulate gyrus has been regularly associated to task-set preparation and endogenous control in general. In particular, a possible explanation is that when a task switch is certain on the upcoming trial an update in S-R mappings occurs probably prior to the onset of the upcoming trial. Indications in support of this assumption comes from the earlier peak of activation found in this region. Nevertheless, as explained earlier due to the variation of the BOLD response across brain regions this finding maybe the result of mere coincidence.

It seems that despite the fact that common top-down processing seems to occur in the left IFG for both predictable and unpredictable cases this is not the case for the cingulate gyrus. It is probably not adaptive to update the current S-R mappings if full foreknowledge about a task switch is not provided. It is possible that expectation about a task switch leads to a bias rather than a full preparation (as in the case of full foreknowledge) towards a task switch and thus affects only specific regions.

Interestingly, in past studies the same area (BA 8) has been widely associated with exogenous control. Specifically, it has been associated with exogenous adjustment, an update of S-R mappings and conflict resolution (Brass & von Cramon, 2002; Sohn, et al., 2000). While the current data clearly show that the cingulate gyrus (BA 8) is involved in some kind of endogenous control (advance preparation) they do not rule out the suggestion that this area is involved in exogenous control as well. It has been suggested in Chapter 2, that endogenous and exogenous controls are not completely insulated from one another and therefore may involve common cognitive components. The pattern of activation in the cingulate gyrus (BA 8) in the current study along with the pattern of activation in the prementioned studies provides neuroimaging evidence in support of this claim.

Selective activation was also observed on the rIPL (BA 40) when a task repeat occurred. It has been suggested that this region is responsible among others for maintaining attention on the current tasks goals (Singh-Curry & Husain, 2009). Based on this idea, an assumption that can be made is that the rIPL is a region that is associated with the active maintenance of a task-set's representations when task non-switch trials occur. In cases where a task switch occurs this information may be, either inhibited or replaced by the relevant to the trial task-set representations. Certainty for this assumption cannot be derived from the present data. Information from the cingulate gyrus and rIPL is probably communicated to the rMFG (BA 9), a region that was also found to be activated in task switching experiments (Braver, Reynolds, & Donaldson, 2003; Dreher & Berman, 2002; Dreher & Grafman, 2003; Konishi S., et al., 2002). The rMFG is thought to be a brain region that among others encompasses WM processes and the execution/maintenance of a task-set (Cohen, et al., 2000; Kimberg, et al., 2000; MacDonald, et al., 2000; Milham, et al., 2001).

The idea that the cingulate gyrus and the right IPL communicate information to WM is supported further by the pattern of activation found on the rMFG (BA 9). In particular, the pattern of activation on the rMFG revealed that similar activation was observed for predictable switch and unpredictable non-switch trials while no activation occurred on unpredictable switch cases. This pattern of activation suggests that there is a concurrent activation of the cingulate gyrus – rMFG (predictable switch cases) and rIPL – rMFG (unpredictable non-switch cases). This pattern is not observed on unpredictable switch cases because neither full foreknowledge (predictable trials) about a task switch nor a task repetition (non-switch trials) occurs and therefore neither the cingulate gyrus nor the right IPL are showing activity resulting in no influence in the rMFG.

In conclusion, taking into account that there is an attentional/task switching network involving these areas and that the rMFG is responsible for WM processes and the execution and maintenance of task-sets then the relationship of these regions within the network should be as follows, a) the rMFG is connected with the other areas described in this study and plays a central role in task switching, b) activity in the cingulate gyrus is related to task preparation and seems to affect activation in the rMFG, c) task representations on the rIPL are maintained and is communicated to the rMFG for further use when a task repeat is required and, d) activation was common for all conditions in the left IFG thus suggesting that partial task preparation may occur even when a task switch is unpredictable but nevertheless more expected that a task repetition.

5.5.1 Neuroimaging Results and Task Switching Model

It is essential to establish a connection between the neuroimaging findings and the assumptions/components stated on the model described in Chapter 3. A critical parameter in the model was the advance preparation (*AP*) component. This component reflects any cognitive processes that are responsible for the preparation of the cognitive system prior to the onset of the upcoming trial when full foreknowledge about a task switch is provided. Consequently, it was assumed that this component only affects switch costs under predictable switch trials because this is the only case where full foreknowledge about a task switch is present. The neuroimaging data revealed that such a cognitive component might be anatomically located in the cingulate gyrus (BA 8). Activation in this area was found only under predictable switch conditions. This pattern supports the existence of a (*AP*) component that affects switch costs on predictable switch cases.

RT for the predictable switch trials is given in Equation 4 of the model:-

$$RT_{\text{Pred-Sw}} = CP - AP + TSR$$

A central assumption of the thesis is that under predictable non-switch conditions, task components are maintained in some part of WM. This assumption is reflected in the model in the task maintenance component (*TM*). Evidence for the existence of such a component comes from the pattern of activation found in the rIPL (BA 40). Activation in this region was evident only in the unpredictable non-switch condition. It was assumed that information is retained in this region for further use and is retrieved if the task performed on trial *n* needs to be performed on trial *n+1*.

The RT on a predictable non-switch trials is given by Equation 3 of the model:-

$$RT_{\text{Pred-NSw}} = CP + TM$$

In addition, the effect of this region can reflect processes related to the repetition bias (*rb*) component found only on unpredictable non-switch trials of the model. The *(rb)* component assumes that task-set components that have already been used on trial *n* are easier to be activated on trial *n+1* relative to components that were suppressed on trial *n*.

In particular, on unpredictable cases, components that were used on trial *n-1* are partially active in a part of WM prior to trial *n*. If these components are required on trial *n,* then they are more readily available (task priming) relative to components that were not used and are not loaded in WM. Faster RTs on unpredictable non-switch trials relative to unpredictable switch trials due to the effect of task priming on the first are expected. Evidence in support of this idea comes from Experiment 10 where the high/low task was paired with a similar/dissimilar task. A reduction on switch costs was found on unpredictable cases when the high/low task was paired with the similar task relative to when it was paired with the dissimilar task.

This was mainly a result of a speeding of RTs of the high/low task on unpredictable non-switch trials on the first case relative to the second case. It was assumed that repetition bias (*rb*) is more effective on blocks of trials where similar tasks are presented because common conceptual task-set components *are held active constantly in WM* leading to an extra bias (relative to when switching between dissimilar tasks) towards the activation of the more recently performed task.

RT for the unpredictable non-switch trials is given in Equation 10:-

$$RT_{\text{Unpred-NSw}} = CP + TSR \times rb$$

Concluding, when response to a non-switch trial is required then task components are retrieved from a subcomponent of WM where they are maintained. In the present case, this subcomponent is probably the rIPL.

Finally, the irrelevant task suppression (*ITS*) subcomponent of the (*TSR*) component of the model is supposed to reflect the inhibitory mechanism of the cognitive system. This mechanism is essential in order for the irrelevant to the trial task-set to be inhibited.

In addition, in cases where a task switch is expected with certainty or is more probable to occur than a non-switch trial, suppression of the irrelevant task-set's components may initiate prior to the onset of the upcoming trial. In the model, this component is found on predictable switch and unpredictable switch/non-switch conditions suggesting that there is a common process between these different conditions. This process is not shared by predictable non-switch trials.

TSR is given by the model's equation 5:-

$$TSR = COI + RTP + ITS$$

In particular, in Experiments 12 and 14 in the predictable condition, a task switch is certain while in the unpredictable condition is expected more than a task repetition. Thus, in all three cases conditions apply in which the irrelevant to the upcoming trial task-set should be suppressed fully or partially. Therefore, the (*ITS*) component should exhibit activation in all three conditions.

The neuroimaging results provided evidence in favor of this idea revealing that an area related to task inhibition, the IFJ (BA 45), is activated equally for all the previously mentioned conditions. This pattern of activation was not found on predictable non-switch trials - activation in the localizer scan for the same region was higher on switch relative to repeat blocks. In the latter, it dissipated after the first trials indicating that it was not essential for performance. Inhibition is essential when a switch expected fully or partial while it is unnecessary when a task repetition is fully expected.

The direct or indirect interplay of the cingulate gyrus (*AP*) and rIPL (*TM/rb*) are communicating information to WM prior to the response generation. This process is incorporated in common processes (*CP*) component of the model. The present findings suggest that WM or part of it is probably located on the rMFG (BA 9).

5.6 CONCLUSIONS

The final series of experiments have provided further evidence regarding the central role of endogenous control in unpredictable switch costs. Specifically, results have shown that expectancy about the type of trial (switch or non-switch) contributes more on switch costs relative to task priming. This is evidence in favor of theories that assume that switch costs are mainly the result of endogenous control (e.g., TSR account) rather than those that favor exogenous control (e.g., TSI account).

In addition, the present findings demonstrate that under unpredictable conditions, endogenous control (advance preparation) is not only feasible but rather is the main determinant of switch costs. This is in contrast with theories that suggest that under unpredictable conditions advance preparation is impossible while related to the trial cognitive processes initiate after the onset of the trial and is driven mainly by the stimulus attributes (exogenous control).

Finally, the neuroimaging data revealed a network of regions that was responsible for advance preparation, task-set maintenance and task-set inhibition. This network was assumed to communicate information to a region that was associated with WM.

In addition, the pattern of activation in the cingulate gyrus (BA 8) provided further evidence in support of the claim that endogenous and exogenous controls are not completely insulated from one another.The neuroimaging data along with the behavioral data provided further evidence in support of the task switching model that was presented on Chapter 3.

6 THESIS SUMMARY AND CONLUDING REMARKS

6.1 THESIS SUMMARY

The purpose of the thesis was to explore the cognitive processes that underlie the switching between simple cognitive tasks. Task predictability was central to the experiments and these were designed in order to compare switching under predictable and unpredictable cases. This manipulation allowed for an adequate assessment of the cognitive system that controls the switching of tasks. A summary of the main findings of this assessment is summarized briefly in the following sections.

6.1.1 Task Congruency and Task Crosstalk Effects

In Chapter 2, the interplay of endogenous and exogenous control processes was studied across predictable and unpredictable cases. Stimuli of two types were used, univalent and bivalent. Bivalent stimuli are thought to elicit interference between tasks because they elicit, in contrast to univalent stimuli, both task-sets concurrently upon a trial. This interference must be resolved in order for the appropriate response to be given.

In general, participants' performance was better on predictable than on unpredictable cases. Nevertheless, switch costs were smaller on unpredictable trials relative to predictable trials. This variation of switch costs was mainly attributed to performance on predictable non-switch trials. Performance on these trials was facilitated the most relative to the other types of trials. What was strongly suggested by this basic result is that when a task is predicted to repeat on the upcoming trial, then the task-set is maintained and primed in WM. The only uncertainty that remains regards the appropriate response set that will be needed in order to respond on the trial. Every other process relating to the competing task-set is not needed and is thus suppressed.

Further evidence regarding this idea comes from the examination of crosstalk effects. Crosstalk effects were smaller on predictable than on unpredictable cases. Again, this pattern of effect was carried by the predictable non-switch trials. It seems that when a task relevant attribute of the stimulus is presented then it automatically invokes the associated task-set causing interference. This effect was minimal on predictable non-switch trials indicating that the irrelevant to the trial task-set may indeed be strongly suppressed prior to the onset of the trial.

The locus of this effect was sought in Experiments 2 and 4 as it was not clear from Experiments 1 and 3. In Experiment 2, participants knew in advance the lateral position of the characters - letters were always presented on the right and digits always on the left side of the stimulus pair. Crosstalk effects were in general reduced relative to Experiments 1 and 3. Experiment 4 revealed that performance on univalent trials was better relative to that on bivalent trials. That was true even when the irrelevant attribute of the bivalent stimulus was unrelated to any task-set (e.g., neutral trials – Experiment 1). The pattern of results of Experiments 2 and 4 suggested the presence of a stimulus encoding that occur early on task-set processing stages and clearly affect performance on task switching.

Congruency effects were not found in the RT data. Nevertheless, these were apparent in the accuracy data. Performance was in general less accurate on incongruent switch trials relative to the other trials. Based on this finding, it was speculated that in contrast to crosstalk effects that occur on early processing stages, congruency effects occur at later stages of processing (presumably at the decisional/response stage of processing).

Finally, Chapter 2 has provided evidence that endogenous and exogenous processes are not completely insulated from one another. Predictability seems to clearly interact with exogenous factors as revealed from the interaction of crosstalk and predictability effects. It appears that task foreknowledge activates the appropriate task-set on a given trial in WM. When the appropriate character is easy to identify (e.g., when a fixed character position on a neutral trial) and the task is to be repeated then crosstalk is minimized. The issue raised from the results of Chapter 2 is how does task activation occur? Does it involve a boost in activation of the relevant to the trial task, suppression of the irrelevant task's activation or both? Chapter 3 addressed this question.

6.1.2 Task Expectancy and Task Difficulty Effects

A more detailed manipulation of exogenous control was studied on Chapter 3 relative to Chapter 2. Instead of the 'on/off' state (on-crosstalk, off-no crosstalk) used in the experiments in the previous chapter, an unequal ratio of task presentation was introduced. In addition, task difficulty varied across the two components. The aim was to study in detail how endogenous control manages exogenous interference caused by an easy or a difficult task when the frequency of task presentation was varied across different experiments. Performance was again studied under predictable and unpredictable conditions.

In general, the results replicated Chapter 2 findings - performance was found to be better on predictable relative to unpredictable cases while it was worse on switch relative to non-switch trials. Regarding the difficulty effect, interesting patterns of results were uncovered. On predictable non-switch trials, no difficulty effect was observed throughout Experiments 6 – 8. This finding supports further the idea described previously that when a task repetition is expected on the upcoming trial then the task-set is maintained in WM. In that case, the only uncertainty remaining regards the appropriate response set that is needed in order to respond adequately. The competing task-set and its related processes are suppressed.

Interestingly, regardless of task priming (equal ratio, presented more or presented less often in relation to the competing task) switch costs remained relatively unaffected on predictable trials. Specifically, switch costs were larger on difficult relative to easy cases. However, that was not the case for unpredictable cases where switch costs were modulated according to the task ratio of presentation. In Experiment 6, the two tasks were presented equally often. Switch costs on unpredictable trials were of an equivalent size while RTs were slower overall for the difficult task. That was not the case for Experiment 7, where the easy task was presented more often relative to the difficult task. Switch costs and overall RTs were smaller for the easy task. Finally, in Experiment 8 the difficult task was presented more often. A different pattern of results relative to the previous two experiments was observed on unpredictable trials. Switch costs were additive (as found in Experiment 6) while the difficulty effect was reversed - RTs were slower for the easy task. As stated earlier, the pattern of results on predictable trials remained unaffected regardless of the ratio of task presentation.

Based on these findings, it seems that endogenous control manages in a different way exogenous control in predictable and unpredictable cases. On predictable cases, the upcoming task is known in advance of the trial with absolute certainty. This fact leads to a strong top-down management of the activation/inhibition biases of the two tasks.

Despite of the fact that several studies and task switching models suggest that in unpredictable conditions there is a complete absence of endogenous control, the current series of experiments suggests otherwise. It seems that under unpredictable cases, endogenous control manages the control biases of the two tasks according to the probability of the tasks to occur on the upcoming task. This flexible top-down control seems to be related to expectation. Specifically, when a task is more probable to occur on the upcoming trial then a top-down bias occurs in favor of this task and against the competing task. Task priming cannot be excluded as a possible contributor in performance on unpredictable cases as endogenous control seems to be more relaxed on these cases. The relative contribution of expectancy and priming was clarified in Chapter 5.

In order to encapsulate the idea that top-down control manages the activation/inhibition biases according to expectation a model was developed that included among others a task difficulty, expectancy, task activation and suppression of irrelevant task's activation component. The model managed to adequately simulate the original data.

The interesting pattern of results between two tasks of unequal difficulty observed in this series of experiments led to the need to investigate further how two tasks relate and affect each other. What components do they share? Does sharing components increases or decreases switch costs?

6.1.3 Task Similarity Effects

On Chapter 4, numerical and alphabetical tasks were presented on predictable and unpredictable cases based on whether or not they shared similar components. It was assumed that switching between tasks similar in nature (e.g., two numerical tasks) would be easier than between dissimilar tasks (e.g., switching from a numerical to an alphabetical task).

In general, the results replicated the findings described in the previous chapters. Performance, in terms of speed and accuracy, was better on predictable than on unpredictable cases while performance on switch trials was comparably worse than on non-switch trials. Switch costs were overall larger on predictable relative to unpredictable cases.

A task difficulty effect was also found replicating the results of the previous chapter. Performance on what was deemed as the more difficult task was always worse relative to the easier task. This difficulty effect was not evident on predictable non-switch trials throughout the other experiments. This finding provided additional support to the idea that on predictable non-switch trials the relevant task-set is maintained in WM for further use on the upcoming trial.

Notably, it was revealed that when two tasks are performed in the same block of trials relative to when they are performed individually the relative discrepancy of difficulty between them is altered. This finding supported further the idea that there is a bidirectional link between the two tasks when these are performed in the same block of trials.

While in the literature task similarity is mainly assumed to reflect operations at the perceptual/attentional or response levels, in the current series of experiments it was assumed to reflect operations at a conceptual level. In these studies switching between similar tasks was found to be easier that the other way around. This finding was not replicated in the present experiments. This was partially attributed to interference that can be caused between conceptually similar task-sets even when the tasks are not presented in the same block of trials.

In contrast to past studies, it was found in Experiment 10 that switching between similar tasks can be more difficult than switching between dissimilar tasks – a reversed similarity effect. It should be noted that when participants switch between similar tasks they also switch between less task components relative to switching between dissimilar tasks. As a consequence the present finding seems counterintuitive. Specifically, when switching between similar tasks (i.e., two numerical tasks) an attentional shift between the characters was not required relative to when participants were required to switch between an alphabetical and a numerical task. In the latter case, on every switch trial they had to change their focus of attention to either the digit or the letter of the character pair.

The current pattern of results was explained on the basis of exogenous interference that may be the result of switching between two conceptually similar tasks. Specifically, conceptual similarity can lead to an unintentional activation of the irrelevant task leading to interference that needs to be suppressed before a response is given. Such interference should not occur when switching between conceptually dissimilar tasks leading to smaller switch costs.

Finally, the present data were found to be in accord with central assumptions of the task switching model namely that, a) a task-set is maintained in WM when it is known that will be needed in the immediate upcoming trial and, b) there is a bidirectional link between tasks that affects their performance when these are performed in the same block of trial.

6.1.4 Trial Expectation Effects

In the final empirical chapter of the thesis, the effect of task expectation was examined in somewhat different circumstances. The main aim was to provide further evidence that expectation is the main determinant of performance on unpredictable cases and not task priming. In addition, neuroimaging data were sought that will fit the predictions of the explicit model discussed on Chapter 3.

Once again the results replicated the previous findings - performance was better on non-switch trials relative to switch trials while performance on predictable trials was better relative to unpredictable trials. Interestingly, in Experiment 12 an RT slowing was found on unpredictable non-switch trials. This finding was attributed to the fact that participants were biased by the experiment's conditions to expect that a task switch is more probable relative to a task repeat.

In order to verify this assumption Experiment 13 was carried out. In that experiment, participants were biased in such a way as to expect that a task repetition was more probable on unpredictable trials than a task switch. RT slowing on unpredictable non-switch trials was significantly reduced in relation to Experiment 12. In addition, switch costs on unpredictable switch trials were significantly increased in relation to the previous experiment. These findings suggested that expectations regarding the nature of the upcoming trial clearly affected performance on unpredictable cases. The contribution of task priming seems to play a less central role relative to trial expectations in determining performance in cases where no foreknowledge regarding the upcoming trial is provided.

Experiment 14 was a slightly modified version of Experiment 12 in order to adhere to the neuroimaging protocols and constraints. Behavioral results replicated those reported in Experiment 12. The neuroimaging results revealed that a network of regions was activated when a task switch was required or expected. This network corresponds closely reflected the brain regions that are regularly discussed in the task switching and attention literature. Moreover, several of the regions exhibited activation consistent with the existence of central components suggested in the task switching model discussed on Chapter 3.

Specifically, the left IFG (BA 45) exhibited task switching specific activation when performance in switch blocks was relative to that in non-switch blocks of trials in the localizer trials. However, in the experimental trials this region was found to be active in a similar manner under all three kinds of trial blocks (predictable switch, unpredictable switch/non-switch blocks of trials). This pattern of activation was anticipated since it was assumed that in all kinds of blocks participants either were certain or biased to expect that a task switch would occur on the upcoming trial. This finding probably suggests that these types of trials share a common component that is not shared by the predictable non-switch trials. The best candidate is the *ITS* (irrelevant task suppression) component of the task switching model which is shared by all kinds of trials except the predictable non-switch trials.

Another region that was found to be selectively activated on predictable switch trials is the cingulate gyrus. It seems therefore, that the model's component that can be associated with the cingulate gyrus is the *AP* (advance preparation) component. This component implies preparation that occurs prior to the onset of the trial and it is evident only on predictable switch trials. Therefore, the task switching model's components seem to correspond closely with the neuroimaging data. In addition, this region has been regularly related with processes involving exogenous control. In the current experiment, this region was clearly associated with endogenous control. This finding is not contradicting existing findings but rather complements them as it supports the idea, stated in Chapter 2, that exogenous and endogenous control processes may not be completely insulated from each other.

Selective activation was found in the rIPL on unpredictable non-switch trials. This activation seems to correspond with the *rb* and *TM* components found, respectively, only on unpredictable and predictable non-switch trials of the model. It seems that when a task-set has been immediately used on one trial then on the next trial it is, in a sense, reinstated. In that case, less effort is needed in order to reinstate the task because its components are partially active in WM.

Finally, the cingulate gyrus and the rIPL seem to communicate information to a part of WM located in the rMFG. Activation was found selectively for predictable switch and unpredictable non-switch trials while that was not the case for unpredictable switch trials. In the latter, neither full foreknowledge (predictable trials) about a task switch nor a task repetition (non-switch trials) occurs and therefore neither the cingulate gyrus nor the rIPL was activated resulting in no communication of information in the rMFG.

6.2 IMPLICATIONS

Many different factors can affect task performance. From the work presented in the thesis it seems that task crosstalk, task difficulty, task similarity and expectancies regarding the upcoming trial may have a crucial implications for task performance. These effects seem to vary as a factor of predictability. When the level of expectancy changes from complete foreknowledge to partial or no foreknowledge about the upcoming task/trial the cognitive strategy that the participants use in order to cope with the circumstances becomes more flexible relative to the strategy that they utilize under predictable cases.

Overall, the current results have shown that researchers in the field should consider the presence of endogenous control in unpredictable cases as a determinant of task performance. Task and trial expectancies affect performance on unpredictable cases and should be taken into account when thinking about the issues. Moreover, the relative difference in difficulty between two tasks seems to affect performance in such a way as to lead to asymmetrical switch costs in some cases and in some other cases not. Therefore, the tasks combined in a task switching experiment should be chosen with care and with proper consideration of inherent task difficulty. An efficient way to assess task difficulty is to compare performance on these tasks across pure blocks of trials. This assessment can be similar to the one made on Chapter 3 in order to define the relative weight of the TD (task difficulty) component for each task on each condition of the discussed task switching model. What one should expect is that ideally, a) equal in difficulty tasks should result in equal switch costs (as reported in Chapter 4), b) small discrepancies in tasks' difficulty should result in reversed asymmetry effects on switch costs (as reported in Chapter 3 and 4) and, c) large discrepancies in difficulty should result in asymmetry effects on switch costs (as reported in Meuter & Allport, 1999).

It is important from an academic perspective, that the current experiments have revealed cases where a simple comparison across switch costs was not sufficient to explain performance. Predominantly, switch costs were found to be smaller in unpredictable than in predictable cases while speed and accuracy was better in the latter. This counterintuitive finding could not have been understood if a break down of switch costs into switch and non-switch trials RTs has not been made. What the data revealed is that switch costs are larger in predictable cases mainly because of large performance benefits that accrue on non-switch trials. It seems therefore, that the cognitive system adopts a more flexible strategy under unpredictable cases at the expense of overall speed and accuracy. Caution must be exercised in future because switch costs analysis reveals only part of the picture regarding the cognitive processes that underlie the switching of tasks and not the whole of it.

The neuroimaging data in this study provided information on how the brain controls attention and task switching. It seems that not a single region but rather a network of regions cooperate in order to coordinate switching between tasks. This network is not located in a single cortical region but rather involves several regions and structures.

In addition, localization of cognitive function in the brain is a very demanding goal and needs many studies in order to allow scientists to draw safe conclusions regarding the link between brain activity and cognitive functioning. Rarely is a single brain region responsible for a single cognitive function. The norm is that a brain region is responsible for several cognitive functions (e.g., the cingulate gyrus, is among others, responsible for managing task interference and advance task preparation) The present study is one of the studies that provides behavioural data explained in terms of cognitive components that are later linked, via neuroimaging data, onto specific brain regions. Therefore, it provided additional information regarding cognitive processes (like task maintenance and task preparation) and the brain regions that these involve (rIPL and cingulate gyrus respectively).

From a practical point of view, this information can provide an invaluable tool in the development of protocols regarding the assessment of normal and abnormal brain activity. For instance, in the case of neurosurgical operation incision near structures like the rMFG or left IFG should be approached with caution. Damage on these structures may result in cognitive deficits (e.g., these may produce a task switching deficit – see Shallice, Stuss, Picton, Alexander, & Gillingham, 2008b) resulting in an inability to perform everyday tasks like driving a car.

At a more general level, these results do have more far-reaching implications for training and design contexts. The central question that must be made prior to the design of such contexts has to do with what aspect of performance is more valuable for these. Is speed and accuracy valued more at expense of cognitive flexibility or speed and accuracy should be sacrificed in favour of the latter? It seems that on an assembly line it is preferable to train and present employees with predictable sequences of tasks. This pattern of presentation will increase their generic performance (speed and accuracy) and thus productivity. However, is this kind of training adequate for air combat? The answer is probably not. A dogfight is characterised by unexpected events so efficient training for a combat pilot should primarily emphasize on the exercise of cognitive flexibility at the expense of the minimum possible losses of speed and accuracy of reaction.

Overall, the current results must be taken into account in the training and design of other settings as well. Education can be improved by taking into account the optimal level of variability, ratio, similarity and difficulty of learning tasks that students should be exposed to. In that case, the aspects of the learning tasks combined and their frequency of presentation should be carefully taken into account. For instance, should students in elementary schools write, verbalize and draw pictures during a course? If yes, in what ways should they alternate between these tasks? In what frequency these tasks should be required during the course? Is the task combination proper? Based on this logic, training in various settings, ranging from luggage screening and assembly lines to medical personnel assisting doctors in operations, should utilize the current results in order for these settings to be adequately designed.

A challenge for the current results is that they reveal effects that are measured in milliseconds and therefore it is arguable if they can be generalised in everyday life where task switching involves more complex tasks such as being interrupted by having to answer the phone. Nevertheless, effects reported in the field seem to reflect fundamental cognitive operations that probably can be generalised in performance in more complicated tasks relative to the tasks reported in the present and other studies.

A nice example of this generalisation is the comparison found in the literature between results in studies involving simple tasks and studies involving tasks that are more complex. In the first case, studies involve classification of digits and letters by pressing a button (generation of a motor response) while in the latter they involve naming numerals in either a dominant or a non-dominant language (generation of a verbal response). Generating verbal responses involves higher cognitive functions relative to generating a motor response. In many respects, these studies report similar effects (e.g., switching tasks in more difficult than repeating a task – switch costs). It is reasonable to assume that similarities should be found if a comparison of the present results is made to a study that involves everyday tasks such as switching between writing a text message on the mobile phone and cooking dinner.

Clinical tests involving task switching performance based on expectancy and task difficulty may serve as indexes for brain flexibility. This can be achieved by creating speed, accuracy and switch cost norms on task switching experiments involving task expectancy and task difficulty. These norms can serve as indices regarding normal ability to switch effectively between two tasks. Consequently, marked deviations from the norms may indicate pathology or increased cognitive ability. Based on these results clinicians should be able to understand better cognitive development and analyze further several brain dysfunctions like ADHD, Parkinson's disease and schizophrenia (Dibbets & Jolles, 2006; Karayanidis, et al., 2006; King, Colla, Brass, Heuser, & von Cramon, 2007; Mayr, 2001; Rogers, et al., 1998).

A more accurate design, based on the way that stimuli are presented and the combination of tasks required, in cockpits, human-computer interface, feedback screens and other sensitive equipment will result in faster and more accurate responses in very delicate and crucial occupations like pilots, surgeons and air traffic controllers. Driving a car can be safer and repetitive work like luggage screening can be enhanced if it is known adequately which tasks and how these will be include in these environments.

Concluding, the thesis does provide pointers to future work. It would be very interesting to examine performance in similar conditions to the ones described here but presenting three or more tasks during a block of trials. In addition, experiments that manipulate the relative difficulty between the different component tasks ought to be considered in a bid to can shed more light on the nature of asymmetrical switching costs described in the thesis and in the literature.

APPENDICES

Appendix 1: Reaction times ANOVA for Experiment 1.

	F	df	Significance
Main effect of group	0.024	2, 33	p = .976
Main effect of predictability	175.640	1, 33	p < .001
Main effect of trial transition	108.529	1, 33	p < .001
Main effect of congruency	235.629	2, 66	p < .001
Predictability x group	0.200	2, 33	p = .819
Trial transition x group	1.855	2, 33	p = .172
Congruency x group	0.416	4, 66	p = .797
Predictability x trial transition	29.316	2, 33	p < .001
Predictability x trial transition x group	1.005	2, 33	p = .377
Predictability x congruency	2.212	2, 66	p = .118
Predictability x congruency x group	0.512	4, 66	p = .727
Trial transition x congruency	21.935	2, 66	p < .001
Trial transition x congruency x group	1.194	4, 66	p = .322
Predictability x trial transition x congruency	6.204	2, 66	p < .01
Predictability x trial transition x congruency x group	0.856	4, 66	p = .495

Appendix 2: Errors ANOVA for Experiment 1.

	F	df	Significance
Main effect of group	000.730	2, 33	p = .489
Main effect of predictability	010.374	1, 33	p < .01
Main effect of trial transition	073.006	1, 33	p < .001
Main effect of congruency	014.352	2, 66	p < .001
Predictability x group	000.051	2, 33	p = .951
Trial transition x group	000.001	2, 33	p = .999
Congruency x group	000.297	4, 66	p = .297
Predictability x trial transition	000.949	2, 33	p = .337
Predictability x trial transition x group	000.335	2, 33	p = .717
Predictability x congruency	007.178	2, 66	p < .01
Predictability x congruency x group	000.363	4, 66	p = .834
Trial transition x congruency	010.219	2, 66	p < .001
Trial transition x congruency x group	000.978	4, 66	p = .426
Predictability x trial transition x congruency	000.030	2, 66	p < .05
Predictability x trial transition x congruency x group	000.742	4, 66	p = .742

Appendix 3: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 250 ms group level of Experiment 1.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Non-Trial transition				
Congruent	753	135	1.1	4.0
Incongruent	750	147	1.2	3.9
Neutral	633	101	1.2	4.0
Trial transition				
Congruent	1235	296	3.3	1.4
Incongruent	1245	285	5.2	2.0
Neutral	1008	259	2.9	1.1
Unpredictable				
Non-Trial transition				
Congruent	1024	150	1.2	4.2
Incongruent	1001	103	3.1	3.8
Neutral	861	129	1.3	5.5
Trial transition				
Congruent	1398	302	2.5	2.8
Incongruent	1426	229	8.2	2.8
Neutral	1194	256	2.9	2.0

Appendix 4: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 600 ms group level of Experiment 1.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Non-Trial transition				
Congruent	756	159	1.7	4.4
Incongruent	737	147	1.1	3.1
Neutral	632	106	1.3	4.8
Trial transition				
Congruent	1230	361	3.1	1.9
Incongruent	1231	388	4.8	2.3
Neutral	981	354	3.8	1.1
Unpredictable				
Non-Trial transition				
Congruent	1062	159	2.4	6.3
Incongruent	1065	149	2.6	3.8
Neutral	880	180	1.2	3.8
Trial transition				
Congruent	1389	342	2.5	2.7
Incongruent	1367	327	6.6	4.2
Neutral	1160	344	3.9	2.0

Appendix 5: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 1200 ms group level of Experiment 1.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Non-Trial transition				
Congruent	836	130	2.1	6.9
Incongruent	817	136	2.3	5.5
Neutral	701	140	2.6	5.6
Trial transition				
Congruent	1144	280	3.3	11.3
Incongruent	1187	303	7.4	8.3
Neutral	943	297	4.9	7.9
Unpredictable				
Non-Trial transition				
Congruent	1142	212	2.5	6.9
Incongruent	1154	212	4.0	4.4
Neutral	917	188	2.0	6.3
Trial transition				
Congruent	1352	285	5.3	11.6
Incongruent	1367	272	8.9	10.0
Neutral	1137	285	4.4	10.8

Appendix 6: Reaction times ANOVA for Experiment 2.

	F	df	Significance
Main effect of group	0.705	1, 33	p = .501
Main effect of predictability	89.006	1, 33	p < .001
Main effect of trial transition	135.827	1, 33	p < .001
Main effect of congruency	90.808	2, 66	p < .001
Predictability x group	0.173	2, 33	p = .842
Trial transition x group	5.617	2, 33	p < .01
Congruency x group	0.124	4, 66	p = .973
Predictability x trial transition	6.945	1, 33	p < .05
Predictability x trial transition x group	1.463	2, 33	p = .081
Predictability x congruency	3.797	2, 66	p < .05
Predictability x congruency x group	1.247	4, 66	p = .300
Trial transition x congruency	18.773	2, 66	p < .001
Trial transition x congruency x group	0.707	4, 66	p = .590
Predictability x trial transition x congruency	2.345	2, 66	p = .104
Predictability x trial transition x congruency x group	1.179	4, 66	p = 0.328

Appendix 7: Errors ANOVA for Experiment 2.

	F	df	Significance
Main effect of group	0.082	1, 33	p = .921
Main effect of predictability	41.229	1, 33	p < .001
Main effect of trial transition	5.630	1, 33	p < .05
Main effect of congruency	0.322	2, 66	p = .726
Predictability x group	3.696	2, 33	p < .05
Trial transition x group	6.254	2, 33	p < .01
Congruency x group	1.744	4, 66	p = .151
Predictability x trial transition	1.086	1, 33	p = .305
Predictability x trial transition x group	6.519	2, 33	p < .01
Predictability x congruency	3.942	2, 66	p < .05
Predictability x congruency x group	3.360	4, 66	p < .05
Trial transition x congruency	2.652	2, 66	p = .078
Trial transition x congruency x group	3.209	4, 66	p < .05
Predictability x trial transition x congruency	0.032	2, 66	p = .969
Predictability x trial transition x congruency x group	1.004	4, 66	p = .412

Appendix 8: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 250 ms group level of Experiment 2.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Non-Trial transition				
Congruent	699	118	1.7	5.8
Incongruent	667	111	1.8	4.4
Neutral	642	113	2.5	5.8
Trial transition				
Congruent	1228	349	3.4	1.9
Incongruent	1194	297	6.9	7.5
Neutral	1079	294	3.8	4.2
Unpredictable				
Non-Trial transition				
Congruent	1003	209	3.1	6.4
Incongruent	943	171	2.7	6.4
Neutral	828	134	4.6	5.4
Trial transition				
Congruent	1422	363	4.0	5.3
Incongruent	1423	312	6.0	10.9
Neutral	1235	306	4.7	9.4

Appendix 9: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 600 ms group level of Experiment 2.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Non-Trial transition				
Congruent	693	153	1.3	6.7
Incongruent	677	125	2.2	7.0
Neutral	624	91	3.5	5.9
Trial transition				
Congruent	1055	352	2.5	2.0
Incongruent	1015	289	1.8	5.2
Neutral	868	224	3.7	3.6
Unpredictable				
Non-Trial transition				
Congruent	992	189	3.5	7.3
Incongruent	937	158	4.5	6.1
Neutral	857	118	3.7	4.6
Trial transition				
Congruent	1301	326	6.3	5.3
Incongruent	1284	300	4.8	7.0
Neutral	1127	280	6.4	7.4

Appendix 10: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 1200 ms group level of Experiment 2.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Non-Trial transition				
Congruent	718	53	3.5	1.2
Incongruent	707	47	3.9	2.5
Neutral	631	29	5.5	0.9
Trial transition				
Congruent	1014	87	3.1	2.3
Incongruent	1015	80	2.0	6.3
Neutral	860	69	2.3	3.4
Unpredictable				
Non-Trial transition				
Congruent	1011	60	4.2	3.1
Incongruent	1007	64	4.2	4.0
Neutral	899	46	3.8	1.3
Trial transition				
Congruent	1235	71	6.3	2.4
Incongruent	1188	68	6.0	7.5
Neutral	1062	64	2.1	6.6

Appendix 11: Reaction times ANOVA for Experiment 3.

	F	df	Significance
Main effect of group	1.192	2, 33	p = .164
Main effect of predictability	100.852	1, 33	p < .001
Main effect of trial transition	121.051	1, 33	p < .001
Main effect of congruency	213.542	2, 66	p < .001
Predictability x group	2.488	2, 33	p = .099
Trial transition x group	2.887	2, 33	p = .070
Congruency x group	0.980	4, 66	p = .425
Predictability x trial transition	14.895	2, 33	p < .001
Predictability x trial transition x group	0.955	2, 33	p = .395
Predictability x congruency	11.228	2, 66	p < .001
Predictability x congruency x group	2.514	4, 66	p = .05
Trial transition x congruency	3.679	2, 66	p < .05
Trial transition x congruency x group	1.610	4, 66	p = .182
Predictability x trial transition x congruency	15.660	2, 66	p < .001
Predictability x trial transition x congruency x group	0.543	4, 66	p = .705

Appendix 12: Errors ANOVA for Experiment 3.

	F	df	Significance
Main effect of group	1.290	2, 33	p = .289
Main effect of predictability	9.820	1, 33	p < .01
Main effect of trial transition	29.709	1, 33	p < .001
Main effect of congruency	22.955	2, 66	p < .001
Predictability x group	0.834	2, 33	p = .443
Trial transition x group	0.857	2, 33	p = .434
Congruency x group	1.377	4, 66	p = .251
Predictability x trial transition	2.436	2, 33	p = .128
Predictability x trial transition x group	0.074	2, 33	p = .929
Predictability x congruency	2.177	2, 66	p = .121
Predictability x congruency x group	1.126	4, 66	p = .352
Trial transition x congruency	5.556	2, 66	p < .01
Trial transition x congruency x group	0.152	4, 66	p = .962
Predictability x trial transition x congruency	0.511	2, 66	p = .602
Predictability x trial transition x congruency x group	0.481	4, 66	p = .749

Appendix 13: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 250 ms group level of Experiment 3.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Non-Trial transition				
Congruent	880	146	1.6	3.9
Incongruent	880	189	2.2	5.0
Neutral	764	148	1.2	5.0
Trial transition				
Congruent	1383	285	2.7	2.8
Incongruent	1380	260	4.4	1.7
Neutral	1158	289	3.4	3.1
Unpredictable				
Non-Trial transition				
Congruent	1158	212	2.1	4.2
Incongruent	1158	199	2.9	3.4
Neutral	881	151	1.8	4.4
Trial transition				
Congruent	1450	228	2.6	3.0
Incongruent	1463	212	5.9	4.4
Neutral	1196	205	2.5	3.9

<u>Appendix 14</u>: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 600 ms group level of Experiment 3.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Non-Trial transition				
Congruent	865	144	0.3	4.7
Incongruent	885	187	1.3	3.6
Neutral	727	151	0.1	4.4
Trial transition				
Congruent	1286	262	1.7	2.0
Incongruent	1236	252	5.7	1.0
Neutral	1037	304	0.4	1.0
Unpredictable				
Non-Trial transition				
Congruent	1154	134	1.4	5.2
Incongruent	1110	123	4.2	3.6
Neutral	904	117	1.4	4.2
Trial transition				
Congruent	1406	229	2.3	3.8
Incongruent	1386	208	7.0	4.7
Neutral	1242	226	4.6	3.1

Appendix 15: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 1200 ms group level of Experiment 3.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Non-Trial transition				
Congruent	782	213	2.1	3.9
Incongruent	777	176	2.5	3.8
Neutral	658	140	1.4	5.7
Trial transition				
Congruent	1074	319	3.4	6.1
Incongruent	1088	298	6.0	6.1
Neutral	853	251	3.8	7.6
Unpredictable				
Non-Trial transition				
Congruent	1136	261	2.6	7.9
Incongruent	1116	230	7.4	6.8
Neutral	852	183	2.9	7.0
Trial transition				
Congruent	1285	366	3.5	1.2
Incongruent	1323	343	10.0	1.5
Neutral	1024	302	5.6	1.1

Appendix 16: Reaction times ANOVA for Experiment 4 (CIN).

	F	df	Significance
Main effect of predictability	039.135	1, 23	p < .001
Main effect of trial transition	152.386	1, 23	p < .001
Main effect of congruency	147.673	2, 46	p < .001
Predictability x trial transition	034.912	1, 23	p < .001
Predictability x congruency	019.536	1, 23	p < .001
Trial transition x congruency	003.694	2, 46	p < .05
Predictability x trial transition x congruency	005.037	2, 46	p < .05

Appendix 17: Reaction times ANOVA for Experiment 4 (NU).

	F	df	Significance
Main effect of predictability	023.535	1, 23	p < .001
Main effect of trial transition	124.177	1, 23	p < .001
Main effect of congruency	019.385	1, 23	p < .001
Predictability x trial transition	007.743	1, 23	p < .05
Predictability x congruency	003.564	1, 23	p = .072
Trial transition x congruency	000.109	1, 23	p = .745
Predictability x trial transition x congruency	000.886	1, 23	p = .356

Appendix 18: Errors ANOVA for Experiment 4 (CINU).

	F	df	Significance
Main effect of predictability	014.586	1, 23	p < .01
Main effect of trial transition	049.532	1, 23	p < .001
Main effect of congruency	020.549	3, 69	p < .001
Predictability x trial transition	045.240	1, 23	p < .001
Predictability x congruency	000.255	3, 69	p = .879
Trial transition x congruency	006.992	3, 69	p < .001
Predictability x trial transition x congruency	005.378	3, 69	p < .01

Appendix 19: Mean and standard error of reaction time, percentage error rates and outlier elimination for Experiment 4.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Non-Trial transition				
Congruent	845	191	2.4	7.3
Incongruent	843	189	2.7	8.4
Neutral	666	115	1.8	6.3
Univalent	650	105	1.0	7.0
Trial transition				
Congruent	1300	313	5.0	8.2
Incongruent	1326	274	12.2	14.8
Neutral	1037	249	4.8	7.5
Univalent	1010	242	5.2	7.6
Unpredictable				
Non-Trial transition				
Congruent	1193	298	5.2	15.4
Incongruent	1156	280	6.9	14.3
Neutral	832	168	3.1	8.9
Univalent	770	141	2.2	8.5
Trial transition				
Congruent	1419	302	4.0	7.8
Incongruent	1469	329	9.3	16.9
Neutral	1121	288	4.0	8.4
Univalent	1077	254	5.0	11.3

Appendix 20: Reaction times ANOVA for Experiment 5.

	F	df	Significance
Main effect of cuing	74.619	1, 35	p < .001
Main effect of trial transition	101.840	1, 35	p < .001
Main effect of congruency	109.214	2, 70	p < .001
Cuing x trial transition	10.827	2, 70	p < .01
Cuing x congruency	14.044	2, 70	p < .001
Trial transition x congruency	3.642	2, 70	p < .05
Cuing x trial transition x congruency	2.801	2, 70	p = .068

Appendix 21: Errors ANOVA for Experiment 5.

	F	df	Significance
Main effect of cuing	13.245	1, 35	p < .001
Main effect of trial transition	35.147	1, 35	p < .001
Main effect of congruency	14.906	2, 70	p < .01
Cuing x trial transition	4.985	2, 70	p < .05
Cuing x congruency	1.826	2, 70	p = .169
Trial transition x congruency	1.387	2, 70	p = .257
Cuing x trial transition x congruency	2.270	2, 70	p = .111

Appendix 22: Mean and standard error of reaction time, percentage error rates and outlier elimination for Experiment 5.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Precued				
Non-Trial transition				
Congruent	978	40	4.0	7.3
Incongruent	936	37	4.5	7.0
Neutral	785	26	3.8	6.2
Trial transition				
Congruent	1150	50	5.1	8.3
Incongruent	1125	47	7.9	8.0
Neutral	921	35	6.2	7.5
Unpredictable				
Non-Trial transition				
Congruent	1196	49	4.0	10.9
Incongruent	1165	43	6.3	9.5
Neutral	900	28	3.6	9.4
Trial transition				
Congruent	1379	50	6.7	7.7
Incongruent	1426	51	11.0	7.9
Neutral	1137	41	8.3	9.7

Appendix 23: Reaction times ANOVA for Training Session, Experiment 6.

	F	df	Significance
Main effect of group	0.365	2, 21	p = .699
Main effect of difficulty	16.502	1, 21	p < .01
Difficulty x group	0.638	2, 21	p = .538

Appendix 24: Errors ANOVA for Training Session, Experiment 6.

	F	df	Significance
Main effect of group	1.067	2, 21	p = .362
Main effect of difficulty	7.725	1, 21	p < .05
Difficulty x group	2.365	2, 21	p = .118

Appendix 25: Mean and standard error of reaction time, percentage error rates and outlier elimination for the Training Session, Experiment 6.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
		250 ms		
Easy Task	633	25	3.1	0.7
Difficult Task	690	31	13.5	0.7
		600 ms		
Easy Task	585	38	2.3	0.4
Difficult Task	641	62	8.8	0.7
		1200 ms		
Easy Task	615	48	4.4	0.3
Difficult Task	644	38	3.3	0.7

Appendix 26: Reaction times ANOVA for Experiment 6.

	F	df	Significance
Main effect of group	0.177	2, 21	p = .839
Main effect of predictability	17.080	1, 21	p < .001
Main effect of difficulty	13.395	1, 21	p < .01
Main effect of trial transition	156.609	1, 21	p < .001
Predictability x group	0.126	2, 21	p = .882
Difficulty x group	0.595	2, 21	p = .561
Trial transition x group	0.684	2, 21	p = .515
Predictability x difficulty	1.781	1, 21	p = .196
Predictability x difficulty x group	1.313	2, 21	p = .290
Predictability x trial transition	16.649	1, 21	p < .01
Predictability x trial transition x group	0.217	2, 21	p = .807
Difficulty x trial transition	7.387	1, 21	p < .05
Difficulty x trial transition x group	0.387	2, 21	p = .684
Predictability x difficulty x trial transition	30.671	1, 21	p < .001
Predictability x difficulty x trial transition x group	0.794	2, 21	p = .465

Appendix 27: Errors ANOVA for Experiment 6.

	F	df	Significance
Main effect of group	0.071	2, 21	p = .932
Main effect of predictability	7.510	1, 21	p < .05
Main effect of difficulty	4.688	1, 21	p < .05
Main effect of trial transition	25.392	1, 21	p < .001
Predictability x group	0.286	1, 21	p = .754
Difficulty x group	0.172	2, 21	p = .843
Trial transition x group	0.150	2, 21	p = .862
Predictability x difficulty	0.010	2, 21	p = .920
Predictability x difficulty x group	0.517	2, 21	p = .603
Predictability x trial transition	0.700	1, 21	p = .412
Predictability x trial transition x group	0.124	2, 21	p = .884
Difficulty x trial transition	9.772	1, 21	p < .01
Difficulty x trial transition x group	1.694	2, 21	p = .208
Predictability x difficulty x trial transition	1.676	1, 21	p = .209
Predictability x difficulty x trial transition x group	1.698	2, 21	p = .207

Appendix 28: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 250 ms group level of Experiment 6.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Easy Task				
Non-Trial transition	730	73	1.7	3.0
Trial transition	980	99	2.7	2.9
Difficult Task				
Non-Trial transition	704	68	2.2	5.5
Trial transition	1210	118	4.9	2.4
Unpredictable				
Easy Task				
Non-Trial transition	869	49	2.3	4.5
Trial transition	1129	53	3.3	3.4
Difficult Task				
Non-Trial transition	907	44	2.3	4.8
Trial transition	1201	61	5.3	3.0

Appendix 29: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 600 ms group level of Experiment 6.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Easy Task				
Non-Trial transition	685	60	1.8	2.2
Trial transition	925	55	1.7	2.2
Difficult Task				
Non-Trial transition	710	60	1.6	5.0
Trial transition	1104	91	4.7	2.1
Unpredictable				
Easy Task				
Non-Trial transition	827	45	2.0	2.6
Trial transition	1049	72	4.0	4.5
Difficult Task				
Non-Trial transition	961	113	3.0	5.0
Trial transition	1159	131	4.8	3.4

Appendix 30: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 1200 ms group level of Experiment 6.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Easy Task				
Non-Trial transition	661	58	2.1	3.9
Trial transition	974	105	2.2	2.0
Difficult Task				
Non-Trial transition	664	50	1.0	4.8
Trial transition	1132	121	3.9	2.2
Unpredictable				
Easy Task				
Non-Trial transition	836	55	3.3	3.8
Trial transition	1068	85	3.1	5.0
Difficult Task				
Non-Trial transition	846	58	2.5	5.0
Trial transition	1109	102	6.5	4.3

Appendix 31: Reaction times ANOVA for Training Session, Experiment 7.

	F	df	Significance
Main effect of group	4.041	2, 21	p < .05
Main effect of difficulty	5.746	1, 21	p < .05
Difficulty x group	1.566	2, 21	p = .232

Appendix 32: Errors ANOVA for Training Session, Experiment 7.

	F	df	Significance
Main effect of group	0.261	2, 21	p = .773
Main effect of difficulty	2.874	1, 21	p = .105
Difficulty x group	3.015	2, 21	p = .071

Appendix 33: Mean and standard error of reaction time, percentage error rates and outlier elimination for the Training Session, Experiment 7.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
		250 ms		
Easy Task	746	68	3.8	0.6
Difficult Task	746	61	2.6	1.2
		600 ms		
Easy Task	594	19	4.3	0.1
Difficult Task	644	28	6.4	0.5
		1200 ms		
Easy Task	570	26	3.4	0.0
Difficult Task	604	31	4.9	0.1

Appendix 34: Reaction times ANOVA for Experiment 7.

	F	df	Significance
Main effect of group	2.334	2, 21	p = .122
Main effect of predictability	13.483	1, 21	p < .01
Main effect of difficulty	28.643	1, 21	p < .001
Main effect of trial transition	155.178	1, 21	p < .001
Predictability x group	2.420	2, 21	p = .113
Difficulty x group	4.441	2, 21	p < .05
Trial transition x group	0.711	2, 21	p = .503
Predictability x difficulty	13.841	1, 21	p < .01
Predictability x difficulty x group	1.948	2, 21	p = .168
Predictability x trial transition	0.172	1, 21	p = .682
Predictability x trial transition x group	1.704	2, 21	p = .206
Difficulty x trial transition	22.499	1, 21	p < .001
Difficulty x trial transition x group	0.288	2, 21	p = .752
Predictability x difficulty x trial transition	0.210	1, 21	p = .651
Predictability x difficulty x trial transition x group	0.106	2, 21	p = .900

Appendix 35: Errors ANOVA for Experiment 7.

	F	df	Significance
Main effect of group	0.079	2, 21	p = .924
Main effect of predictability	0.807	1, 21	p = .379
Main effect of difficulty	1.912	1, 21	p = .181
Main effect of trial transition	4.487	1, 21	p < .05
Predictability x group	0.219	2, 21	p = .805
Difficulty x group	0.309	2, 21	p = .737
Trial transition x group	0.939	2, 21	p = 407
Predictability x difficulty	15.059	1, 21	p < .001
Predictability x difficulty x group	3.035	2, 21	p = .07
Predictability x trial transition	4.070	1, 21	p = .057
Predictability x trial transition x group	0.941	2, 21	p = .406
Difficulty x trial transition	62.532	1, 21	p < .001
Difficulty x trial transition x group	0.173	2, 21	p = .842
Predictability x difficulty x trial transition	0.004	1, 21	p = .950
Predictability x difficulty x trial transition x group	0.050	2, 21	p = .952

Appendix 36: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 250 ms group level of Experiment 7.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Easy Task				
Non-Trial transition	801	67	4.3	5.3
Trial transition	1115	101	1.8	1.6
Difficult Task				
Non-Trial transition	745	71	1.0	1.6
Trial transition	1194	120	3.5	1.9
Unpredictable				
Easy Task				
Non-Trial transition	833	65	2.1	3.1
Trial transition	1095	96	0.8	4.5
Difficult Task				
Non-Trial transition	804	53	1.7	5.9
Trial transition	1214	96	6.3	5.9

Appendix 37: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 600 ms group level of Experiment 7.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Easy Task				
Non-Trial transition	594	14	4.5	4.3
Trial transition	773	38	0.8	2.2
Difficult Task				
Non-Trial transition	591	18	0.8	5.3
Trial transition	928	77	4.7	4.5
Unpredictable				
Easy Task				
Non-Trial transition	657	24	4.1	4.9
Trial transition	892	50	1.2	5.5
Difficult Task				
Non-Trial transition	757	48	1.9	7.0
Trial transition	1147	96	8.0	4.7

Appendix 38: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 1200 ms group level of Experiment 7.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Easy Task				
Non-Trial transition	622	53	3.7	4.5
Trial transition	859	106	3.3	1.4
Difficult Task				
Non-Trial transition	684	61	1.2	5.4
Trial transition	1108	110	8.0	5.2
Unpredictable				
Easy Task				
Non-Trial transition	710	53	7.4	4.7
Trial transition	890	72	2.3	5.1
Difficult Task				
Non-Trial transition	793	48	2.7	5.6
Trial transition	1195	67	9.4	2.2

Appendix 39: Reaction times ANOVA for Training Session, Experiment 8.

	F	df	Significance
Main effect of group	0.602	2, 21	p = .557
Main effect of difficulty	5.369	1, 21	p < .05
Difficulty x group	0.945	2, 21	p = .083

Appendix 40: Errors ANOVA for Training Session, Experiment 8.

	F	df	Significance
Main effect of group	0.064	2, 21	p = .938
Main effect of difficulty	3.642	1, 21	p = .07
Difficulty x group	0.635	2, 21	p = .540

Appendix 41: Mean and standard error of reaction time, percentage error rates and outlier elimination for the Training Session, Experiment 8.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
		250 ms		
Easy Task	609	30	2.2	0.3
Difficult Task	627	23	2.9	0.3
		600 ms		
Easy Task	550	31	2.6	0.5
Difficult Task	605	23	3.7	0.4
		1200 ms		
Easy Task	607	38	3.3	0.1
Difficult Task	624	40	2.9	0.2

Appendix 42: Reaction times ANOVA for Experiment 8.

	F	df	Significance
Main effect of group	0.128	2, 21	p = .880
Main effect of predictability	60.652	1, 21	p < .001
Main effect of difficulty	0.001	1, 21	p = .977
Main effect of trial transition	122.293	1, 21	p < .001
Predictability x group	0.218	2, 21	p = .806
Difficulty x group	1.090	2, 21	p = .354
Trial transition x group	1.728	2, 21	p = .202
Predictability x difficulty	84.630	1, 21	p < .001
Predictability x difficulty x group	0.288	2, 21	p = .753
Predictability x trial transition	7.949	1, 21	p < .05
Predictability x trial transition x group	0.226	2, 21	p = .800
Difficulty x trial transition	1.274	1, 21	p = .272
Difficulty x trial transition x group	0.020	2, 21	p = .980
Predictability x difficulty x trial transition	15.841	1, 21	p < .01
Predictability x difficulty x trial transition x group	2.192	2, 21	p = .137

Appendix 43: Errors ANOVA for Experiment 8.

	F	df	Significance
Main effect of group	0.123	2, 21	p = .885
Main effect of predictability	19.722	1, 21	p < .001
Main effect of difficulty	0.359	1, 21	p = .555
Main effect of trial transitioning	8.074	1, 21	p = .05
Predictability x group	0.027	2, 21	p = .973
Difficulty x group	1.799	2, 21	p = .190
Trial transition x group	0.288	2, 21	p = .753
Predictability x difficulty	0.792	1, 21	P = .384
Predictability x difficulty x group	0.319	2, 21	p = .730
Predictability x trial transition	19.882	1, 21	p = .000
Predictability x trial transition x group	0.232	2, 21	p = .795
Difficulty x trial transition	1.745	1, 21	p = .201
Difficulty x trial transition x group	1.755	2, 21	p = .197
Predictability x difficulty x trial transition	6.399	1, 21	p < .05
Predictability x difficulty x trial transition x group	1.654	2, 21	p = .215

Appendix 44: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 250 ms group level of Experiment 8.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Easy Task				
Non-Trial transition	580	39	2.5	2.2
Trial transition	856	61	2.1	5.3
Difficult Task				
Non-Trial transition	623	35	1.6	5.7
Trial transition	980	101	2.9	2.5
Unpredictable				
Easy Task				
Non-Trial transition	794	53	2.3	7.0
Trial transition	1027	61	6.1	2.4
Difficult Task				
Non-Trial transition	744	36	2.2	7.1
Trial transition	965	73	4.7	2.4

Appendix 45: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 600 ms group level of Experiment 8.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Easy Task				
Non-Trial transition	609	48	2.1	3.1
Trial transition	798	78	1.8	4.9
Difficult Task				
Non-Trial transition	637	47	2.1	10.0
Trial transition	923	106	3.1	3.0
Unpredictable				
Easy Task				
Non-Trial transition	805	42	1.4	7.4
Trial transition	992	22	6.6	4.5
Difficult Task				
Non-Trial transition	780	31	3.0	11.9
Trial transition	932	48	5.1	1.6

Appendix 46: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 1200 ms group level of Experiment 8.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Easy Task				
Non-Trial transition	658	64	2.9	2.0
Trial transition	852	74	2.9	1.1
Difficult Task				
Non-Trial transition	667	58	2.2	4.3
Trial transition	895	47	2.5	2.1
Unpredictable				
Easy Task				
Non-Trial transition	886	48	3.9	5.4
Trial transition	1043	61	6.1	1.7
Difficult Task				
Non-Trial transition	792	36	2.0	4.3
Trial transition	957	49	3.9	1.6

Appendix 47: Reaction times ANOVA for Experiment 9.

	F	df	Significance
Main effect of RSI	1.689	1, 11	p = .220
Main effect of predictability	8.035	1, 11	p < .05
Main effect of difficulty	13.605	1, 11	p < .01
Main effect of trial transition	44.800	1, 11	p < .001
Predictability x RSI	0.002	1, 11	p = .969
Difficulty x RSI	0.175	1, 11	p = .684
Trial transition x RSI	50.908	1, 11	p < .001
Predictability x difficulty	2.625	1, 11	p = .133
Predictability x difficulty x RSI	0.363	1, 11	p = .559
Predictability x trial transition	5.845	1, 11	p < .05
Predictability x trial transition x RSI	0.458	1, 11	p = .512
Difficulty x trial transition	6.033	1, 11	p < .05
Difficulty x trial transition x RSI	0.006	1, 11	p = .939
Predictability x difficulty x trial transition	13.858	1, 11	p < .01
Predictability x difficulty x trial transition x RSI	0.037	1, 11	p = .851

Appendix 48: Errors ANOVA for Experiment 9.

	F	df	Significance
Main effect of RSI	1.344	1, 11	p = .271
Main effect of predictability	11.810	1, 11	p < .01
Main effect of difficulty	0.535	1, 11	p = .480
Main effect of trial transition	6.293	1, 11	p < .05
Predictability x RSI	0.084	1, 11	p = .777
Difficulty x RSI	0.311	1, 11	p = .588
Trial transition x RSI	5.155	1, 11	p < .05
Predictability x difficulty	10.482	1, 11	p < .01
Predictability x difficulty x RSI	0.877	1, 11	p = .369
Predictability x trial transition	0.454	1, 11	p = .512
Predictability x trial transition x RSI	0.406	1, 11	p = .537
Difficulty x trial transition	2.143	1, 11	p = .171
Difficulty x trial transition x RSI	3.602	1, 11	p = .084
Predictability x difficulty x trial transition	1.129	1, 11	p = .311
Predictability x difficulty x trial transition x RSI	0.075	1, 11	p = .789

<u>Appendix 49</u>: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 250 ms RSI level of Experiment 9.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Easy Task				
Non-Trial transition	690	43	1.4	3.1
Trial transition	979	65	1.4	3.5
Difficult Task				
Non-Trial transition	787	35	1.2	5.6
Trial transition	1169	73	3.5	5.4
Unpredictable				
Easy Task				
Non-Trial transition	787	43	1.3	5.4
Trial transition	1120	98	3.7	6.4
Difficult Task				
Non-Trial transition	859	65	1.3	4.9
Trial transition	1203	116	2.6	5.6

<u>Appendix 50</u>: Mean and standard error of reaction time, percentage error rates and outlier elimination for the 1200 ms RSI level of Experiment 9.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
Easy Task				
Non-Trial transition	760	52	2.6	4.2
Trial transition	970	67	1.2	3.8
Difficult Task				
Non-Trial transition	822	56	1.9	8.7
Trial transition	1175	94	5.6	8.1
Unpredictable				
Easy Task				
Non-Trial transition	903	53	3.3	8.9
Trial transition	1094	75	4.2	9.6
Difficult Task				
Non-Trial transition	970	65	2.6	6.1
Trial transition	1181	106	4.9	8.5

Appendix 51: Detailed RTs and error analysis for the consonant/vowel vs. high/low experimental trials of Experiment 10.

The analysis of the experimental trials resembled closely that of the training trials. Error responses, very fast responses (less than 100 ms) and in this case responses that followed an error response were excluded from the analysis of the RT data. As a result, an exclusion of 7.6% of scores has occurred prior to data analysis. For both data sets (RTs and percentage errors) a repeated measures analysis of variance (ANOVA) was carried out and the within participants factors were predictability (predictable vs. unpredictable trials), trial transition (switch vs. non-switch trials) and task (consonant/vowel vs. high/low task).

RTs

The analysis revealed statistically significant main effects for the trial transition, [$F(1, 23) = 76.782$, $MS_e = 36905$, $p < .001$] and predictability, [$F(1, 21) = 17.080$, $MS_e = 42977$, $p < .001$] factors. The main effect of task failed to reach statistical significance. In general terms, responses were slower on switch than non-switch trials, they were slower overall on unpredictable than predictable cases. A number of statistically significant interactions was revealed; namely, the predictability x task interaction, [$F(1, 23) = 7.210$, $MS_e = 7407$, $p < .05$] and predictability x trial transition, [$F(1, 23) = 4.680$, $MS_e = 8104$. $p < .05$]. In the first case, the interaction seems to be driven by the fact that the difference between the predictable and unpredictable RTs for the high/low task is larger relative to that of the consonant/vowel task. In the second case, the difference between the predictable and unpredictable RTs for the non-switch trials is larger relative to that of the switch trials.

Error Rates

Error rates were analysed in the same way as the RTs. The associated ANOVA revealed that only the main effect of trial transition, [$F(1, 23) = 31.579$, $MS_e = .021$, $p < .001$] was statistically significant. The main effects of task and predictability failed to reach statistically significance. Therefore, participants were less accurate on switch than on non-switch trials. In addition, one interaction, namely the predictability x trial transition x task, [$F(1, 23) = 8.664$, $MS_e = .021$, $p < .01$] was also found to be statistically significant. In order to examine these interactions in more detail the data for predictable and unpredictable cases were analysed separately.

Predictable trials

Data were entered into a two-way, repeated measures ANOVA in which trial transition and task were entered as fixed factors. The main effect of trial transition, [$F(1, 23) = 8.897$, $MS_e = .040$, $p < .01$] was found to be statistically significant. In addition, the trial transition x task interaction [$F(1, 23) = 7.209$, $MS_e = .027$, $p < .05$] was also found to be statistically reliable. A Tukey's HSD test indicated that performance on switch trials for the high/low task was significantly less accurate when relative to the other trials ($p < .05$).

Unpredictable trials

For the data from the unpredictable trials only the main effect of trial transition [$F(1, 23) = 23.311$, $MS_e = .013$, $p < .001$] was statistically significant revealing that performance was less accurate on switch than non-switch trials.

Appendix 52: Detailed RTs and error analysis for the consonant/vowel vs. odd/even experimental trials of Experiment 10.

An exclusion of 9.2% of scores has occurred prior to data analysis for this part of the experiment. The analysis was exactly the same with the previously described analysis. The two tasks that were used this time are the consonant/vowel vs. the odd/even task.

RTs

The analysis revealed statistically significant main effects of trial transition, [$F(1, 23) = 86.868$, $MS_e = 45112$, $p < .001$] task, [$F(1, 23) = 13.142$, $MS_e = 17480$, $p < .01$] and predictability, [$F(1, 23) = 24.933$, $MS_e = 47095$, $p < .001$]. In general terms, responses were slower on switch than non-switch trials, they were slower overall on unpredictable than predictable case and finally, they were slower overall on the odd/even than on the consonant/vowel classification trials. Nevertheless, these general patterns were modulated by several significant interactions. A number of statistically significant interactions was revealed; namely, the predictability x task interaction, [$F(1, 23) = 6.515$, $MS_e = 16282$, $p < .05$], predictability x trial transition, [$F(1, 23) = 14.501$, $MS_e = 13360$, $p < .01$] and task x trial transition, [$F(1, 23) = 7.834$, $MS_e = 10896$, $p < .05$]. For the predictability x task interaction data are showing that in unpredictable cases RTs were higher for the odd/even task relative to the consonant/vowel task. That was not true for predictable RTs which were very similar for both tasks. The predictability x trial transition interaction is driven by the fact that unpredictable non-switch trials were substantially slower relative to predictable non-switch trials. On the other hand switch trials RTs were very similar between predictable and unpredictable cases. Finally, for the task x trial transition interaction data are revealing that overall switch costs were larger for the odd/even task relative to the consonant/vowel task.

Error Rates

Error rates were analysed in the same way as the RTs. The associated ANOVA revealed that the main effects of trial transition, [$F(1, 23) = 26.710$, MS_e = .043, $p < .001$] task, [$F(1, 23) = 33.441$, $MS_e = .030$, $p < .001$] and predictability, [$F(1, 23) = 5.746$, $MS_e = .052$, $p < .05$]. No interaction was found to be statistically significant. In general terms, responses were less accurate on switch than non-switch trials, less accurate overall on unpredictable than predictable case and finally, they were less accurate on the odd/even than on the consonant/vowel classification trials.

Appendix 53: Detailed RTs and error analysis for the odd/even vs. high/low experimental trials of Experiment 10.

An exclusion of 10.2% of scores has occurred prior to data analysis for this part of the experiment. The analysis was the same as in the previous parts of the experiment. The two tasks that were used this time are the high/low vs. the odd/even task.

RTs

The analysis revealed statistically significant main effects of trial transition [$F(1, 23) = 74.333$, $MS_e = 55175$, $p < .001$] task, [$F(1, 23) = 7.961$, $MS_e = 23153$ $p < .05$] and predictability, [$F(1, 23) = 8.923$, $MS_e = 86618$, $p < .01$]. In general terms, responses were slower on switch than non-switch trials, they were slower overall on unpredictable than the predictable case and finally, they were slower overall on the odd/even than on the high/low classification trials. Only one statistically significant interaction was revealed namely, the predictability x trial transition, [$F(1, 23) = 5.417$, $MS_e = 17892$. $p < .05$]. Specifically, the difference between the predictable and unpredictable RTs for the non-switch trials is larger relative to that of the switch trials.

Error Rates

Error rates were analysed in the same way as the RTs. The associated ANOVA revealed that only the main effect of trial transition, [$F(1, 23) = 8.615$, $MS_e = .079$, $p < .01$] was statistically significant. The main effects of task and predictability failed to reach statistically significance. Overall, participants were less accurate on switch than on non-switch trials. In addition, two interactions, namely the trial transition x task interaction, [$F(1, 23) = 8.125$, $MS_e = .014$, $p < .01$] and the predictability x trial transition x task interaction, [$F(1, 23) = 8.125$, $MS_e = .014$, $p < .01$] was also found to be statistically significant. In order to examine these interactions in more detail the data for predictable and unpredictable cases were analysed separately.

Predictable trials

Data were entered into a two-way, repeated measures ANOVA in which trial transition and task were entered as fixed factors. Only the main effect of trial transition, [$F(1, 23) = 22.878$, $MS_e = .018$, $p < .001$] was statistically significant. The trial transition x task interaction [$F(1, 23) = 8.125$, $MS_e = .027$, $p < .01$] was also found to be statistically reliable. A Tukey's HSD test indicated that performance on switch trials for the high/low task was significantly less accurate when relative to the other trials ($p < .05$).

Unpredictable trials

For the data from the unpredictable cases no statistical effects were uncovered.

Appendix 54: Detailed RTs and error analysis for the consonant/vowel vs. first/second experimental trials of Experiment 11.

An exclusion of 11.3% of scores has occurred prior to data analysis for the first part of this experiment. The analysis was the same as in experiment 10. The two tasks that were used this time are the consonant/vowel vs. the first/second task.

RTs

The analysis revealed statistically significant main effects of trial transition, [$F(1, 23) = 66.487$, $MS_e = 47062$, $p < .001$] task, [$F(1, 23) = 6.279$, $MS_e = 23790$, $p < .05$] and predictability, [$F(1, 23) = 24.444$, $MS_e = 66503$, $p < .001$]. In general terms, responses were slower on switch than non-switch trials, they were slower overall on unpredictable than predictable case and finally, they were slower on first/second than on consonant/vowel classification trials. Moreover, one statistically significant interaction was revealed; namely, the predictability x trial transition, [$F(1, 23) = 7.115$, $MS_e = 1271$, $p < .05$]. Specifically, the difference between the predictable and unpredictable RTs for the non-switch trials was larger relative to that of the switch trials.

Error Rates

Error rates were analysed in the same way as the RTs. The associated ANOVA revealed that only the main effect of predictability, [$F(1, 23) = 15.066$, $MS_e = .044$, $p < .01$] and task, [$F(1, 23) = 23.030$, $MS_e = .033$, $p < .001$]. The main effect of trial transition failed to reach statistically significance. Overall, responses were slower on unpredictable than the predictable cases and finally, they were slower overall on first/second than on consonant/vowel classification trials. Moreover, the predictability x task interaction, [$F(1, 23) = 7.545$, $MS_e = .017$, $p < .05$] was found to be statistically significant. In particular, the difference between the predictable and unpredictable RTs for the first/second classification trials was larger relative to that of the consonant/vowel classification trials.

Appendix 55: Detailed RTs and error analysis for the consonant/vowel vs. odd/even experimental trials of Experiment 11.

An exclusion of 7.6% of scores has occurred prior to data analysis for this part of the experiment. The analysis was the same as in the previous part of the experiment. The two tasks that were used this time are the consonant/vowel vs. the odd/even task.

RTs

The analysis revealed statistically significant main effects of trial transition, [$F(1, 23) = 67.870$, $MS_e = 59626$, $p < .001$] and predictability, [$F(1, 23) = 35.479$, $MS_e = 75264$, $p < .001$]. In contrast to the previous experiment, the main effect of task failed to reach statistically significance. In general terms, responses were slower on switch than non-switch trials and they were slower overall on unpredictable than on predictable cases. Moreover, one statistically significant interaction was revealed namely, the predictability x trial transition, [$F(1, 23) = 9.367$, $MS_e = 13651$, $p < .01$]. Specifically, the difference between the predictable and unpredictable RTs for the non-switch trials was larger relative to that of the switch trials.

Error Rates

Error rates were analysed in the same way as the RTs. The associated ANOVA revealed that only the main effect of trial transition, [$F(1, 23) = 13.029$, $MS_e = .057$, $p < .01$]. The main effects of task and predictability failed to reach statistically significance. Overall, responses were less accurate on switch than non-switch trials.

Appendix 56: Detailed RTs and error analysis for the odd/even vs. first/second experimental trials of Experiment 11.

An exclusion of 9% of scores has occurred prior to data analysis for the final part of the experiment. The analysis was the same as in the previous parts of the experiment. The two tasks that were used this time are the first/second vs. the odd/even task.

RTs

The analysis revealed statistically significant main effects of trial transition, [$F(1, 23) = 63.713$, $MS_e = 66616$, $p < .001$] task, [$F(1, 23) = 6.066$, $MS_e = 11320$ $p < .05$] and predictability, [$F(1, 23) = 21.982$, $MS_e = 73198$, $p < .001$]. In general terms, responses were slower on switch than non-switch trials, they were slower overall on unpredictable than predictable case and finally, they were slower overall on first/second than on odd/even classification trials. Finally, one statistically significant interaction was revealed, the predictability x trial transition, [$F(1, 23) = 17.252$, $MS_e = 12128$, $p < .05$]. Specifically, the difference between the predictable and unpredictable RTs for the non-switch trials was larger relative to that of the switch trials.

Error Rates

Error rates were analysed in the same way as the RTs. The associated ANOVA revealed that the main effects of trial transition, [$F(1, 23) = 47.642$, $MS_e = .027$, $p < .001$] and task, [$F(1, 23) = 4.745$, $MS_e = .028$, $p < .05$]. The main effect of predictability failed to reach statistically significance. Overall, responses were less accurate on switch than non-switch trial and finally, they were less accurate overall on first/second than on odd/even classification trials. Finally, the predictability x trial transition interaction, [$F(1, 23) = 4.449$, $MS_e = .015$, $p < .05$] was found to be statistically significant. Specifically, the error rate for the predictable non-switch trials was smaller relative to that of the unpredictable non-switch trials. The opposite was true for the switch trials where the error rate was higher for the predictable cases relative to that of the unpredictable cases.

Appendix 57: Reaction times ANOVA for Training Session, Experiment 10.

	F	df	Significance
Main effect of task	46.054	2, 44	$p < .001$

Appendix 58: Errors ANOVA for Training Session, Experiment 10.

	F	df	Significance
Main effect of task	3.895	2, 44	$p < .05$

Appendix 59: Mean and standard error of reaction time, percentage error rates and outlier elimination for the Training Session, Experiment 10.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
HL Task	607	28	0	1.2
CV Task	627	27	3.3	0.8
OE Task	651	28	3.9	0.5

Appendix 60: Reaction times ANOVA for the H/L vs. C/V condition, Experiment 10.

	F	df	Significance
Main effect of predictability	19.360	1, 23	p < .001
Main effect of task	0.008	1, 23	p = .930
Main effect of trial transition	76.782	1, 23	p < .001
Predictability x task	7.210	1, 23	p < .05
Predictability x trial transition	4.680	1, 23	p < .05
Task x trial transition	0.597	1, 23	p = .448
Predictability x task x trial transition	0.540	1, 23	p = .819

Appendix 61: Error rate ANOVA for the H/L vs. C/V condition, Experiment 10.

	F	df	Significance
Main effect of predictability	3.726	1, 23	p = .066
Main effect of task	1.445	1, 23	p = .242
Main effect of trial transition	31.579	1, 23	p < .001
Predictability x task	0.065	1, 23	p = .800
Predictability x trial transition	0.033	1, 23	p = .858
Task x trial transition	1.494	2, 23	p = .234
Predictability x task x trial transition	8.664	2, 23	p < .01

Appendix 62: Mean and standard error of reaction time, percentage error rates and outlier elimination for the H/L vs. C/V condition, Experiment 10.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
H/L Task				
Non-Trial transition	747	50	1.8	6.3
Trial transition	975	68	5.6	2.6
C/V Task				
Non-Trial transition	766	54	1.9	3.5
Trial transition	1018	70	2.7	3.1
Unpredictable				
H/L Task				
Non-Trial transition	994	63	3.6	4.9
Trial transition	1171	71	4.1	4.8
C/V Task				
Non-Trial transition	952	50	2.6	4.1
Trial transition	1142	70	4.7	4.7

Appendix 63: Reaction times ANOVA for the O/E vs. C/V condition, Experiment 10.

	F	df	Significance
Main effect of predictability	24.933	1, 23	p < .001
Main effect of task	13.142	1, 23	p < .01
Main effect of trial transition	86.868	1, 23	p < .001
Predictability x task	6.515	1, 23	p < .05
Predictability x trial transition	14.501	1, 23	p < .01
Task x trial transition	7.834	1, 23	p < .05
Predictability x task x trial transition	0.610	1, 23	p = .443

Appendix 64: Error rate ANOVA for the O/E vs. C/V condition, Experiment 10.

	F	df	Significance
Main effect of predictability	5.746	1, 23	p < .05
Main effect of task	33.441	1, 23	p < .001
Main effect of trial transition	26.710	1, 23	p < .001
Predictability x task	2.814	1, 23	p = .107
Predictability x trial transition	0.390	1, 23	p = .538
Task x trial transition	3.899	2, 23	p = .060
Predictability x task x trial transition	0.286	2, 23	p = .598

Appendix 65: Mean and standard error of reaction time, percentage error rates and outlier elimination for the O/E vs. C/V condition, Experiment 10.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
O/E Task				
Non-Trial transition	724	36	3.1	7.9
Trial transition	1126	72	7.4	2.0
C/V Task				
Non-Trial transition	754	39	1.2	3.6
Trial transition	1051	66	3.0	4.4
Unpredictable				
O/E Task				
Non-Trial transition	1001	54	3.4	6.6
Trial transition	1255	64	8.1	3.9
C/V Task				
Non-Trial transition	917	39	2.5	4.9
Trial transition	1107	53	5.1	6.8

Appendix 66: Reaction times ANOVA for the O/E vs. H/L condition, Experiment 10.

	F	df	Significance
Main effect of predictability	8.923	1, 23	p < .01
Main effect of task	7.961	1, 23	p < .05
Main effect of trial transition	74.333	1, 23	p < .001
Predictability x task	0.295	1, 23	p = .592
Predictability x trial transition	5.417	1, 23	p < .05
Task x trial transition	1.818	1, 23	p = .191
Predictability x task x trial transition	0.930	1, 23	p < .05

Appendix 67: Reaction times ANOVA for the O/E vs. H/L condition, Experiment 10.

	F	df	Significance
Main effect of predictability	0.200	1, 23	p = .659
Main effect of task	0.194	1, 23	p = .664
Main effect of trial transition	13.707	1, 23	p < .01
Predictability x task	1.062	1, 23	p = .313
Predictability x trial transition	1.232	1, 23	p = .279
Task x trial transition	1.529	1, 23	p = .229
Predictability x task x trial transition	6.542	1, 23	p < .05

Appendix 68: Mean and standard error of reaction time, percentage error rates and outlier elimination for the O/E vs. H/L condition, Experiment 10.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
O/E Task				
Non-Trial transition	786	49	3.7	5.3
Trial transition	1159	80	4.6	3.5
H/L Task				
Non-Trial transition	752	42	2.3	7.1
Trial transition	1054	57	6.3	4.7
Unpredictable				
O/E Task				
Non-Trial transition	966	40	3.5	7.3
Trial transition	1218	48	6.7	5.6
H/L Task				
Non-Trial transition	916	40	3.6	6.1
Trial transition	1159	61	5.7	5.9

Appendix 69: Reaction times ANOVA for Training Session, Experiment 11.

	F	df	Significance
Main effect of task	4.517	2, 44	$p < .05$

Appendix 70: Errors ANOVA for Training Session, Experiment 11.

	F	df	Significance
Main effect of task	0.320	2, 44	$p = .728$

Appendix 71: Mean and standard error of reaction time, percentage error rates and outlier elimination for the Training Session, Experiment 11.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
OE Task	671	33	3.8	0.6
CV Task	709	40	6.8	1.9
FS Task	739	31	13.4	0.9

Appendix 72: Reaction times ANOVA for the C/V vs. F/S condition, Experiment 11.

	F	df	Significance
Main effect of predictability	24.444	1, 23	$p < .001$
Main effect of task	6.279	1, 23	$p < .05$
Main effect of trial transition	66.487	1, 23	$p < .001$
Predictability x task	0.992	1, 23	$p = .330$
Predictability x trial transition	7.115	1, 23	$p < .05$
Task x trial transition	0.588	1, 23	$p = .451$
Predictability x task x trial transition	0.093	1, 23	$p = .763$

Appendix 73: Error rate ANOVA for the C/V vs. F/S condition, Experiment 11.

	F	df	Significance
Main effect of predictability	15.066	1, 23	$p < .001$
Main effect of task	23.030	1, 23	$p < .001$
Main effect of trial transition	0.285	1, 23	$p = .598$
Predictability x task	7.545	1, 23	$p < .05$
Predictability x trial transition	1.182	1, 23	$p = .288$
Task x trial transition	0.003	1, 23	$p = .960$
Predictability x task x trial transition	2.977	1, 23	$p = .098$

Appendix 74: Mean and standard error of reaction time, percentage error rates and outlier elimination for the C/V vs. F/S condition, Experiment 11.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
C/V Task				
Non-Trial transition	828	39	4.1	4.4
Trial transition	1114	65	3.6	5.1
F/S Task				
Non-Trial transition	857	41	3.6	6.7
Trial transition	1169	70	5.0	5.1
Unpredictable				
C/V Task				
Non-Trial transition	1038	47	3.5	6.3
Trial transition	1244	58	5.4	9.5
F/S Task				
Non-Trial transition	1102	46	7.0	7.7
Trial transition	1320	66	7.7	5.3

Appendix 75: Reaction times ANOVA for the C/V vs. O/E condition, Experiment 11.

	F	df	Significance
Main effect of predictability	35.479	1, 23	$p < .001$
Main effect of task	1.548	1, 23	$p = .226$
Main effect of trial transition	67.870	1, 23	$p < .001$
Predictability x task	0.722	1, 23	$p = .404$
Predictability x trial transition	9.367	1, 23	$p < .01$
Task x trial transition	0.034	1, 23	$p = .856$
Predictability x task x trial transition	1.575	1, 23	$p = .222$

Appendix 76: Error rate ANOVA for the C/V vs. O/E condition, Experiment 11.

	F	df	Significance
Main effect of predictability	1.271	1, 23	$p = .271$
Main effect of task	0.872	1, 23	$p = .360$
Main effect of trial transition	13.029	1, 23	$p < .01$
Predictability x task	2.197	1, 23	$p = .152$
Predictability x trial transition	0.268	1, 23	$p = .609$
Task x trial transition	0.888	1, 23	$p = .356$
Predictability x task x trial transition	0.126	1, 23	$p = .726$

Appendix 77: Mean and standard error of reaction time, percentage error rates and outlier elimination for the C/V vs. O/E condition, Experiment 11.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
C/V Task				
Non-Trial transition	814	45	3.1	4.9
Trial transition	1145	64	4.8	2.0
O/E Task				
Non-Trial transition	759	31	1.7	4.0
Trial transition	1111	65	3.6	4.5
Unpredictable				
C/V Task				
Non-Trial transition	1077	67	2.3	4.8
Trial transition	1334	82	4.6	5.0
O/E Task				
Non-Trial transition	1071	51	2.1	4.1
Trial transition	1292	86	5.6	4.0

Appendix 78: Reaction times ANOVA for the O/E vs. F/S condition, Experiment 11.

	F	df	Significance
Main effect of predictability	21.982	1, 23	$p < .001$
Main effect of task	6.066	1, 23	$p < .05$
Main effect of trial transition	63.713	1, 23	$p < .001$
Predictability x task	1.405	1, 23	$p = .248$
Predictability x trial transition	17.252	1, 23	$p < .001$
Task x trial transition	2.392	1, 23	$p = .136$
Predictability x task x trial transition	0.310	1, 23	$p = .583$

Appendix 79: Error rate ANOVA for the O/E vs. F/S condition, Experiment 11.

	F	df	Significance
Main effect of predictability	0.082	1, 23	$p = .777$
Main effect of task	4.745	1, 23	$p < .05$
Main effect of trial transition	47.642	1, 23	$p < .001$
Predictability x task	2.465	1, 23	$p = .130$
Predictability x trial transition	4.449	1, 23	$p < .05$
Task x trial transition	0.265	1, 23	$p = .611$
Predictability x task x trial transition	0.023	1, 23	$p = .880$

Appendix 80: Mean and standard error of reaction time, percentage error rates and outlier elimination for the O/E vs. F/S condition, Experiment 11.

Stimulus	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable				
O/E Task				
Non-Trial transition	784	41	1.7	5.7
Trial transition	1133	82	5.1	4.3
F/S Task				
Non-Trial transition	824	49	3.0	7.1
Trial transition	1202	80	6.6	2.1
Unpredictable				
O/E Task				
Non-Trial transition	1057	50	2.5	4.7
Trial transition	1259	66	5.2	5.1
F/S Task				
Non-Trial transition	1049	51	2.9	4.3
Trial transition	1309	65	5.9	5.8

Appendix 81: Reaction times ANOVA for Experiment 12.

	F	df	Significance
Main effect of block type	22.837	2, 30	p < .001

Appendix 82: Errors ANOVA for Experiment 12.

	F	df	Significance
Main effect of block type	1.386	2, 30	p = .266

Appendix 83: Mean and standard error of reaction time, percentage error rates and outlier elimination for Experiment 12.

Trial	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable Switch Block				
1	943	24	4.7	6.1
2	607	16	1.1	4.1
3	576	15	1.1	0.5
4	593	20	1.3	0.5
5	812	32	5.3	0.8
Unpredictable Switch Block				
1	982	20	5.8	3.4
2	620	21	1.3	2.8
3	592	17	1.9	0.8
4	599	20	2.3	0
5	834	27	6.3	0.9
Unpredictable Non-switch Block				
1	966	21	2.7	3.3
2	621	20	1.3	2.8
3	603	17	1.9	0.5
4	610	18	2.3	0.2
5	711	22	3.1	0.3

Appendix 84: Reaction times ANOVA for Experiment 13.

	F	df	Significance
Main effect of block type	121.629	2, 30	$p < .001$

Appendix 85: Errors ANOVA for Experiment 13.

	F	df	Significance
Main effect of block type	3.302	2, 30	$p = .051$

Appendix 86: Mean and standard error of reaction time, percentage error rates and outlier elimination for Experiment 13.

Trial	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable Non-switch Block				
1	940	15	5.6	8.6
2	601	15	2.7	5.8
3	572	13	2.7	1.1
4	577	15	1.9	0.5
5	601	12	4.7	2.2
Unpredictable Switch Block				
1	945	21	6.3	7.7
2	629	20	2.2	5.2
3	594	18	3.2	0.8
4	588	16	2.0	0.3
5	920	24	9.4	1.9
Unpredictable Non-switch Block				
1	948	20	3.8	6.1
2	614	17	2.7	4.4
3	581	14	3.1	0.6
4	588	15	2.0	0
5	634	16	3.9	0.5

Appendix 87: Reaction times ANOVA for Experiment 14.

	F	df	Significance
Main effect of block type	5.420	2, 20	$p < .05$

Appendix 88: Errors ANOVA for Experiment 14.

	F	df	Significance
Main effect of block type	2.896	2, 20	$p = .079$

Appendix 89: Mean and standard error of reaction time, percentage error rates and outlier elimination for Experiment 14.

Trial	Mean RT	*SE*	Errors (%)	Outliers (%)
Predictable Switch Block				
1	827	43	2.1	1.9
2	645	20	1.5	0
3	669	28	0.3	0
4	859	45	0.9	1.1
Unpredictable Switch Block				
1	860	41	1.5	2.8
2	664	20	2.4	0.3
3	681	23	0.6	0
4	904	36	1.2	1.4
Unpredictable Non-switch Block				
1	853	40	0.6	1.7
2	652	17	0.6	0.3
3	679	28	2.4	0
4	791	25	3.2	0.6

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