Executive Control – An Electrophysiological Investigation of Control Processes

Ian G. Mackenzie

Department of Psychology

University of Glasgow

Submitted for the degree of PhD to the Higher Degree Committee of the Faculty of Information and mathematical Sciences, University of Glasgow

Abstract

Everyday behaviour requires constant coordination and monitoring in order for our actions to be successful. Within cognitive science such coordination and monitoring of behaviour is termed 'control' and refers to a set of functions that serve to configure the mental system for performing specific acts. A system of cognitive control is thought to set high level goals and direct subordinate cognitive systems in order to accomplish those goals. This thesis utilises a cognitive electrophysiological approach to the study of executive control, addressing research questions concerning the mental processes that are modulated by executive control and the mechanisms underlying control-related processing adjustments.

The first experimental chapter investigates the process of task switching. More specifically, how demanding is a proposed stage of endogenous task-set reconfiguration in terms of information processing? It was previously reported that the process of task-set reconfiguration constitutes a hard bottleneck delaying even the earliest processing stages (e.g. perceptual) (Oriet & Jolicoeur, 2003). Three experiments investigated this claim by manipulating stimulus contrast and RSI within an alternating runs task switching paradigm. Both RT results and measurements of P1 and N1 ERP component peak latency did not offer support to the claim that task-set reconfiguration delays perceptual processing.

Experimental Chapters 3 and 4 used interference paradigms that are common within the study of executive control (e.g. Eriksen Flanker task and a Stroop task, respectively). Within such interference paradigms, separate stimulus dimensions (relevant and irrelevant) are manipulated, with RT being faster when both the relevant and irrelevant stimulus dimensions indicate the same response.

This is termed the 'congruency effect' and is often attributed to a failure of selective attention, namely, an inability to ignore the irrelevant stimulus dimension. It has been demonstrated that such congruency effects are dependent upon task sequence with the effect being reduced (or absent) after an incongruent trial (Gratton et al., 1992). Such conflict adaptation effects are a popular measure of cognitive control processes. An influential model of cognitive control is the conflict monitoring model of Botvinick et al. (2001), with much evidence for this model being based on the conflict adaptation effect. Specifically, the model proposes that the ACC measures for the occurrence of response conflict within two response channels, and when detected, signals its occurrence to other brain regions (e.g. DLPFC) that are involved in implementing control. Such control may be implemented via a top-down biasing mechanisms of attention toward the task-relevant stimulus feature.

Chapter 3 investigated the conflict adaptation effect within the Flanker task and examined, whether after the occurrence of conflict, attention is directed toward the task-relevant central target location. This was done by measuring P1 and N1 ERP component amplitudes. Although behavioural conflict adaptation effects were evident in overt behaviour, these were specific to response repetitions, consistent with a bottom-up priming account that excludes the necessity for a top-down control explanation (e.g. Mayr et al., 2003). In addition, P1 and N1 amplitude did not show any evidence of increased attentional focus toward the central target location after the occurrence of conflict.

Chapter 4 investigated the conflict adaptation effect within a modified Stroop task, and again, examined whether after the detection of conflict, attention is directed toward the task relevant stimulus feature. This was done by measuring

N170 amplitude - an ERP component proposed to index face processing - when a face stimulus served as the relevant and irrelevant stimulus dimension. Again, conflict adaptation effects were evident in overt behaviour, with this effect being driven by the occurrence of response conflict. Unlike the data from the Flanker task, the conflict adaptation effect within the Stroop task was specific to response alternations, and thus, a bottom-up priming account is not applicable in this instance. However, again the ERP results did not offer any evidence that the processing of the relevant stimulus dimension was enhanced after the occurrence of conflict.

Implications of the present results are discussed in the context of executive control and in particular, in relation to models of task switching and models of conflict control.

Declaration

This thesis has been composed by the undersigned. It has not been accepted in any previous application for a degree. The work, of which this thesis is a record, has been completed by myself, unless otherwise indicated in the text. I further state that no part of this thesis has already been, or is concurrently, submitted for any such degree or qualification at any other university.

Ian G. Mackenzie

Acknowledgements

I would like to thank my supervisor, Hartmut Leuthold, for all his guidance and patience during my time as a PhD student. Without his help, knowledge and encouragement, this thesis would not have been possible. Thank you.
I would like to thank my parents for their support in my academic pursuits.
This research was supported by a BBSRC studentship.

Table of Contents

List of Figures

complete (or at least partially complete) and thus, there will be no period of cognitive slack in which the effect of the contrast manipulation can be absorbed into. The parallel model predicts an underadditive effect of stimulus contrast with decreasing RSI. If perceptual processing is not possible during reconfiguration, every process will be delayed until reconfiguration is complete thus not allowing for any period of cognitive slack. As a result the effect of the contrast manipulation will be evident at both long and short RSIs. It is important to note that both models make the same predictions of additive effects of stimulus contrast on RT for repetition trials as no reconfiguration stage is assumed for repetition trials.

Figure 2.2: Spatial cuing of task where M indicates magnitude task and P indicates parity task. Left hand side indicates task mapping used in Experiment 1 with repetition trials occurring in the horizontal direction and switch trials in the vertical direction. Right hand side indicates the additional task mapping used in Experiment 2 in order to balance for task switch direction (horizontal vs. vertical).

Figure 2.3: Mean RT per condition as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 200, 400, 800 vs. 1200 ms).

Figure 2.4: Mean error rate per condition as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 200, 400, 800 vs. 1200 ms).

Figure 2.5: P1 and N1 components as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 200, 400, 800 vs. 1200 ms).

Figure 2.6: P1 and N1 components as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 200, 400, 800 vs. 1200 ms) for a subset (n=10) of participants.

Figure 2.7: P1 and N1 components as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 200, 400, 800 vs. 1200 ms) at PO7 with additional high-pass filter for amplitude analysis.

Figure 2.8: P1 and N1 components as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 200, 400, 800 vs. 1200 ms) at PO8 with additional high-pass filter for amplitude analysis.

Figure 2.9: Mean reaction time per condition as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 300 vs. 1000 ms).

Figure 2.10: Mean error rate per condition as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 300 vs. 1000 ms).

Figure 2.11: P1 and N1 components as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 300 vs. 1000 ms).

Figure 3.4: ERP waveforms of Scerif et al. (2006) as a function of previous compatibility (context) and No-Go flanker trial type. Also the electrode locations where the ERP waveforms were measured (adapted from Scerif et al. (2006)).

Figure 3.5: Schematic of proposed attentional focus toward central location after an incompatible trial.

Figure 3.6: Example of trial sequence for attention control task 1. In the upper trial sequence the cue indicates that attention should be paid to the left location. This is where the subsequent stimulus is presented in that location (valid trial). The bottom trial sequence is an invalid trial where the stimulus is presented at the uncued location.

Figure 3.7: Error rates to target trials as a function of cue validity.

Figure 3.8: P1 and N1 components for stimuli presented to the left visual field (left column) and stimuli presented to the right visual field (right column) as a function of cue validity at electrode site PO7 (top row) and PO8 (bottom row). NB. ERP analysis was conducted on standard trials only that required no response to the target.

Figure 3.9: Schematic of trial sequence. Probe trials were randomly intermixed within blocks of standard flanker trials.

Figure 3.10: Mean RT as a function of previous compatibility and current compatibility plotted separately for response alternation trials (left panel) and response alternation trials (right panel).

Figure 3.11: Mean error rate as a function of previous compatibility and current compatibility type plotted separately for response repetition trials (left panel) and response alternation trials (right panel).

Figure 3.12: P1 and N1 Components at electrode sites PO7 (left) and PO8 (right) for response repetition trials (top row) and response alternation trials (bottom row) as a function of previous compatibility and current compatibility.

Figure 3.13: Mean P1 amplitude as a function of previous trial type and response sequence plotted separately for electrode site PO7 (left panel) and PO8 (right panel).

Figure 3.14: Stimulus-locked LRP interval for the flanker trials.

Figure 3.15: Response locked LRP interval for the flanker trials.

Figure 3.16: P1 and N1 components at electrode sites PO7 (left) and PO8 (right) as a function of previous compatibility and probe location.

Figure 4.5: Face stimuli. Top row - male actors, second row – male pop stars, third row – female actresses, bottom row – female pop stars (N.B. For the profession classification task (Experiment 2) it can be argued that some stimuli (e.g. Madonna) may belong to both categories. In this case, participants were informed to respond according to the most well known category (e.g. Madonna is better known as a pop star than she is as an actress).

Figure 4.6: Stimulus examples. Left = compatible, middle = category compatible, right = incompatible.

Figure 4.7: Mean RT as a function of previous trial type and current trial type for the FACE task plotted separately for response alternation trials (left panel) and response alternation trials (right panel).

Figure 4.8: Mean RT as a function of previous trial type and current trial type for the TEXT task plotted separately for response alternation trials (left panel) and response alternation trials (right panel).

Figure 4.9: Mean error rate as a function of previous trial type and current trial type for the FACE task plotted separately for response alternation trials (left panel) and response alternation trials (right panel).

Figure 4.10: Mean error rate as a function of previous trial type and current trial type for the TEXT task plotted separately for response alternation trials (left panel) and response alternation trials (right panel).

Figure 4.11: Grand average waveforms at electrode sites PO7, PO8, O1 and O2 as a function of current compatibility (top, middle and bottom rows of each electrode figure) and previous compatibility when responding to the FACE as the relevant stimulus dimension.

Figure 4.12: Grand average waveforms at electrode sites PO7, PO8, O1 and O2 as a function of current compatibility (top, middle and bottom rows of each electrode figure) and previous compatibility when responding to the TEXT as the relevant stimulus dimension.

Figure 4.13: Mean RT as a function of previous trial type and current trial type for the FACE task plotted separately for response alteration trials (left panel) and response alternation trials (right panel).

Figure 4.14: Mean RT as a function of previous trial type and current trial type for the TEXT task plotted separately for response alteration trials (left panel) and response alternation trials (right panel).

Figure 4.15: Mean error rate as a function of previous trial type and current trial type for the FACE task plotted separately for response alternation trials (left panel) and response alternation trials (right panel).

Figure 4.16: Mean error rate as a function of previous trial type and current trial type for the TEXT task plotted separately for response alternation trials (left panel) and response alternation trials (right panel).

Figure 4.17: Grand average waveforms at electrode sites PO7, PO8, O1 and O2 as a function of current compatibility (top, middle and bottom rows of each electrode figure) and previous compatibility when responding to the FACE as the relevant stimulus dimension.

Figure 4.18: Grand average waveforms at electrode sites PO7, PO8, O1 and O2 as a function of current compatibility (top, middle and bottom rows of each electrode figure) and previous compatibility when responding to the TEXT as the relevant stimulus dimension.

List of tables

Abbreviations

ACC	anterior cingulate cortex
ADC	asynchronous discrete coding
AFM	additive factor method
ANOVA	analysis of variance
BOLD	blood oxygen level dependent
DLPFC	dorsolateral prefrontal cortex
EEG	electroencephalogram
EOG	electrooculogram
ERN	error-related negativity
ERP	event-related potential
FFA	fusiform face area
fMRI	functional magnetic resonance imaging
Hz	hertz
LRP	lateralised readiness potential
MEG	magnetoencephalography
MRI	magnetic resonance imaging
ms	millisecond
MSE	mean square error
μV	microvolt
PET	positron emission tomography
PFC	prefrontal cortex
PPA	parahippocampal place area
PRP	psychological refractory period
R	response
RSI	response stimulus interval
RT	reaction time
S	stimulus
SAT	speed-accuracy trade-off
SOA	stimulus onset asynchrony
T	target
TSI	task-set inertia

Chapter 1. Introduction

1.1 Executive Control

As humans we afford an almost limitless array of behaviour, both in terms of variety and complexity. Indeed, what defines behaviour can range from a simple low level act of perceiving a stimulus to higher order goals and intentions. In order to accomplish such higher order goals, behaviour requires constant coordination and monitoring. However, we are usually unaware of such coordination and monitoring processes. A popular example often used within the literature concerns the skill of driving. Driving requires the combination of many skills, for example, changing gear, monitoring one's speed, waiting for and paying attention to the green light at traffic lights etc. These skills are accomplished so efficiently and with no perceived tax on processing resources that the experienced driver can often engage in additional and disparate activities like conversation. All of these simple tasks are assumed to require control processes in order for the behaviour to be coordinated and successful. It is only when behaviour is unsuccessful or deviates from the intended, for example, driving straight home and forgetting to stop at the shop for some groceries, that one becomes aware of the control needed.

Within cognitive science the term 'control' refers to a set of functions serving to configure the mental system for performing specific tasks. A system of cognitive control is thought to set high level goals and planning of behaviour and direct other cognitive systems in accomplishing those goals. Without some concept of control, it would be necessary to explain seemingly voluntary behaviour using mechanistic explanations used to explain reflexive behaviour (Monsell & Driver, 2000). Thus, control processes offer an insight into classical

problems of volition and intention (Logan, 2003). Without voluntary control, the concept of free will is an illusion.

The consideration of control as a psychological process can be traced to the writings of William James (James, 1890) who contrasted two dominating faculties: attention and the will. He conceptualised attention as the selective processing of goal-related events and argued for the necessity of such a system in order for meaningful experience.

> *"Millions of items of the outward order are present to my senses which never properly enter into my experience. Why? Because they have no interest for me. My experience is what I agree to attend to. Only those items which I notice shape my mind – without selective interest, experience is an utter chaos."* (p. 402)

For James, 'will' was the mechanism behind the production of voluntary movements which would bring about intended goals stating that *"voluntary movements must be secondary, not primary functions of our organism"* (p. 487). Thus, voluntary movements are willed from reflexive or instinctive movements that occurred first in a random or involuntary way.

The ideas of James and also those of Ach (1910, 1935), as highlighted by Hommel, Ridderinkhof and Theeuwes (2002), concerning a distinction between habits and intentional processes are evident in models of cognitive control introduced in the 1960s and 1970s. For example, Atkinson and Shiffrin (1968), as described by Shallice (1994), provided a model of the human memory system that distinguished between the functional architecture of the system and control processes. For Atkinson and Shiffrin, control processes were "*not permanent features of memory, but are transient phenomena under the control of the subject*" (p. 106). This idea of a separable system responsible for control was developed

and expanded upon and is evident in other models of cognition, for example, Baddeley and Hitch's (1974) central executive.

Although the above models emphasise the importance of control processes in determining behaviour, explanations regarding the nature of control, its implementation and workings were unsatisfactorily assigned to a singular controlled processing 'box'. Indeed, Newell (1980) stated that

> *"a major item on the agenda of cognitive psychology is to banish the homunculus [i.e. the assumption of an intelligent agent (little man) residing elsewhere in the system, usually off stage, who does all the marvellous things that need to be done actually to generate the total behaviour of the subject]."* (p. 715)

As a result of the inadequacies of assigning control to a homunculus-like controlling agent, research now focuses on specifying specifically the mechanisms involved in control processes and developing testable models of control. Questions of interest include:

- How is voluntary control asserted?
- How flexible is the control process?
- What are the limits of control?
- Do control processes affect the processing of relevant and irrelevant stimuli?
- Which brain area(s) contribute to control processes?
- What distinguishes controlled from automatic processes?
- How are controlled processes monitored and corrected if erroneous?
- Is control a unitary process?

While being far from exhaustive, the range and depth of questions within the domain of executive control highlights the move away from homunculi-based explanations.

1.2 Organisation

This thesis utilises a cognitive electrophysiological approach to the study of executive control, addressing research questions concerning the mental processes that are modulated by executive control and the mechanisms underlying control-related processing adjustments. The first part of the introduction chapter will introduce the methods used; firstly, the basics of mental chronometry (1.3) and secondly, an overview of the ERP technique (1.4). This section is not intended to provide a full overview of all issues but instead provide enough details relevant for later chapters. This is especially true of the ERP technique where an in depth coverage would increase the length of the thesis substantially (for a comprehensive introduction, see Luck, 2005). As a result, I will discuss the basic principles behind the ERP technique, relevant ERP components and the advantages of combining the ERP technique with more traditional methods of cognitive science. Alongside the discussion of relevant ERP components, the topic of attention will be touched upon. The reason for this is two-fold: first, ERPs have added a great deal of understanding to the mechanisms of attention with this area highlighting the type of questions suitable for the ERP technique; and second, such attentional modulations of early visual ERP components are relevant for experimental chapters 3 and 4.

The second section of the introduction will provide an overview of the literature within the area of executive control. This will include discussion of seminal papers in the area and also issues relevant to the forthcoming experimental chapters. First, the area of task switching will be introduced and evaluated as a method for the study of executive control (1.6). That is, does the switch cost measure reflect control processes? The first experimental chapter

concerns task switching and examines the possible effect of task reconfiguration on perceptual processing. Next, further paradigms used in the study of executive control will be introduced. These include common and well established paradigms within cognitive psychology (e.g. Stroop task, Simon task, Eriksen Flanker task) and as a result, only a brief description of the paradigm will be presented with focus being on details relevant for executive control. This includes the conflict adaptation effect (Gratton, Coles, & Donchin, 1992) and resulting conflict monitoring model (Botvinick, Braver, Barch, Carter, & Cohen, 2001). The conflict adaptation effect and conflict monitoring model is discussed extensively and will concentrate on the validity of the conflict adaptation effect in terms of bottom-up versus top-down processing. This is relevant for the second and third experimental chapters. While these chapters assume top-down processing and examine resultant effects on perceptual processing of relevant and irrelevant stimulus dimensions, possible influences of bottom-up processing are not ignored in the analysis or discussion.

Details that are only relevant for specific experimental chapters will be introduced in the introduction of that specific chapter, for example, the locus of slack logic is introduced in Chapter 2. While each experimental chapter will be discussed separately, a final general discussion chapter will integrate and examine the most important findings.

1.3 Mental Chronometry

Mental chronometry is the study of human information processing via the use of reaction time (RT) measures (Posner, 1978). Two main distinctions are evident within the literature concerning information processing, the first being the serial-versus-parallel organisation of processing stages. In a serial stage model,

information processing proceeds sequentially with no stage overlap. In contrast, parallel models allow for two (or more) stages to be active simultaneously. The second distinction concerns the discrete-versus-continuous transmission of information. In discrete models information accumulation can take one of two states: either no information or full information. In contrast, continuous processing describes a situation where information is gradually accumulated. While such distinctions are important for models of reaction time and affect the conclusions that one can draw about the organisation of cognitive operations, description will be brief and related to mental chronometry as a tool rather than a full critique of its implementation.

First, the subtraction method of Donders ([1868] 1969) will be introduced. This will provide a historical perspective to the issues of mental chronometry and the methods first used to investigate the time course of specific mental operations hypothesised to occur between stimulus and response. Following this, Sternberg's (1969) Additive Factor Method (AFM) and the advantages of such a method over the subtraction technique will be described. The cascade model of McClelland (1979) is discussed. As this model involves continuous information transmission, it provides a contrast and theoretical alternative to discrete information transfer. To conclude, the asynchronous discrete coding (ADC) model of Miller (1982) is touched upon as this model allows for simultaneous active stages (parallel processing) while still allowing for discrete information transfer.

1.3.1 The Donders Subtraction Method

Within Experimental Psychology, it is popular to conceptualise simple cognitive tasks as a series of sub-processes or stages, a procedure that can be

traced to the work of F.C. Donders ([1868] 1969). As a simple example, consider a situation where a participant is presented with a stimulus, makes a decision about the stimulus based on a predefined dimension and also responds according to a predefined dimension. Here, the task can be divided into three stages: a perception stage, a decision stage and a motor response stage (see Figure 1.1).

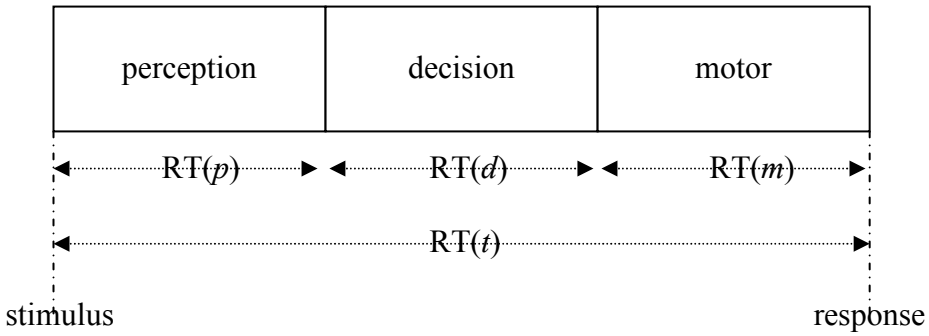


Figure 1.1: The division of a task into separate stages. Here the total reaction time is assumed to equal the sum of the reaction times for the separate stages.

Donders reasoned that the total RT would equal the total of the reaction times for the three stages such that

$$RT(t) = RT(p) + RT(d) + RT(m)$$

where t is the total, p is the time for the perceptual stage, d is the time for decision stage and m is the time for the response related stage. From this Donders proposed a subtraction method in order to infer the duration of a particular process via the use of three RT procedures. The RT procedures are the simple RT task, the choice RT task and the Go-NoGo RT task (see Figure 1.2). To estimate the duration of a discrimination stage, Donders subtracted the RT for the simple RT task from that of the Go-NoGo task while the duration of the response choice stage could be estimated by subtracting the RT for the Go-NoGo task from that of the choice RT task.

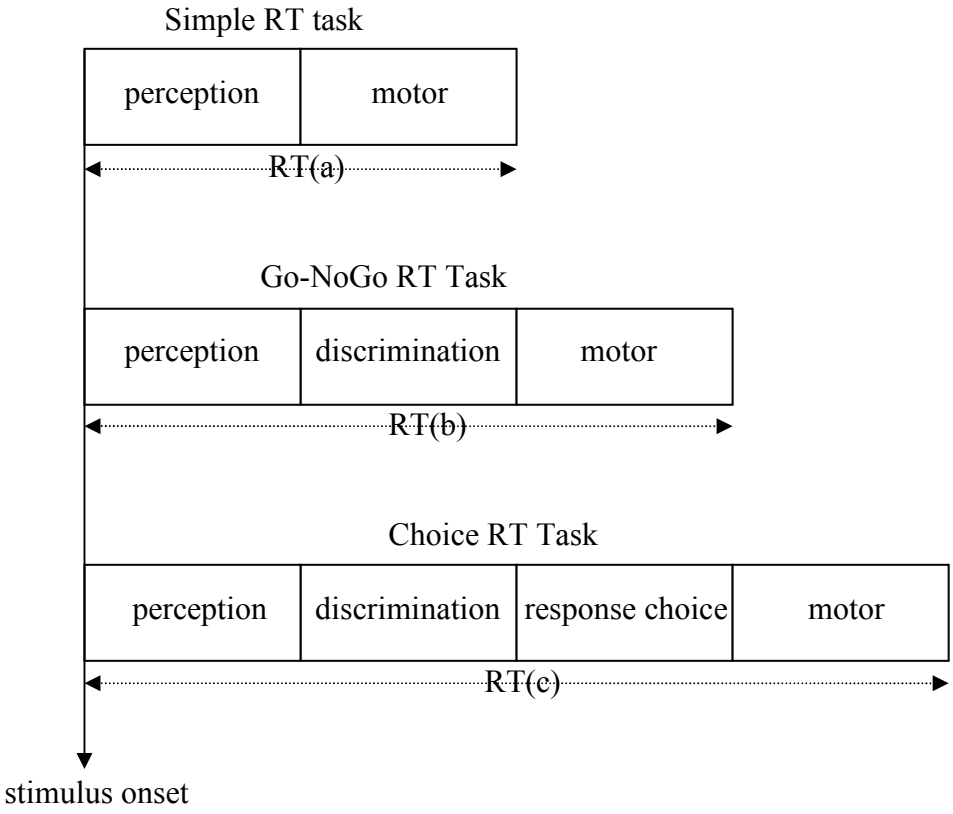


Figure 1.2: The three reaction time procedures and the processing stages involved in each. The time taken for the discrimination stage is the difference in reaction time between the simple RT task and the Go-NoGo RT task ($RT_{discrimination}$ = RT(b) – RT(a)). The time taken for the response choice stage is the difference in reaction time between the Go-NoGo RT task and the choice RT task ($RT_{response\ choice}$ = RT(c) – RT(b)).

Such subtraction logic requires strong assumptions. First, there is the assumption of additivity of stage durations. This simply requires that the durations of component mental processes combine to equal the total RT. Second, there is the assumption known as 'pure insertion'. Specifically, this requires that the insertion of an additional processing stage has no effect on the durations of the original stages. These assumptions have been strongly criticised and as a result of such concerns regarding the validity of the method, chronometric investigations were not widespread during the first half of the 20th Century.

1.3.2 The Sternberg Additive Factors Method (AFM)

The additive factors method (AFM) introduced by Sternberg (1969, 2001), like the subtraction method of Donders, assumes that cognitive stages are arranged sequentially with discrete information transmission between stimulus input and response output and thus, also assumes that total reaction time is the sum of the respective stage durations. However, the assumption of pure insertion is rejected within the AFM; instead, the AFM examines experimental factors that selectively influence the duration of a processing stage rather than the insertion or deletion of additional processing stages.

Sternberg demonstrated how the application of the analysis of variance (ANOVA) model could aid the understanding of processing stages and their organisation when two (or more) experimental factors are manipulated. He proposed that additive effects reveal influences on distinct stages whereas interactive effects are indicative of those factors having at least one stage in common. An additive effect on RT occurs if the two factors influence total processing time independently of each other; i.e. the change in processing time equals the sum of the changes induced by each factor (see Figure 1.3).

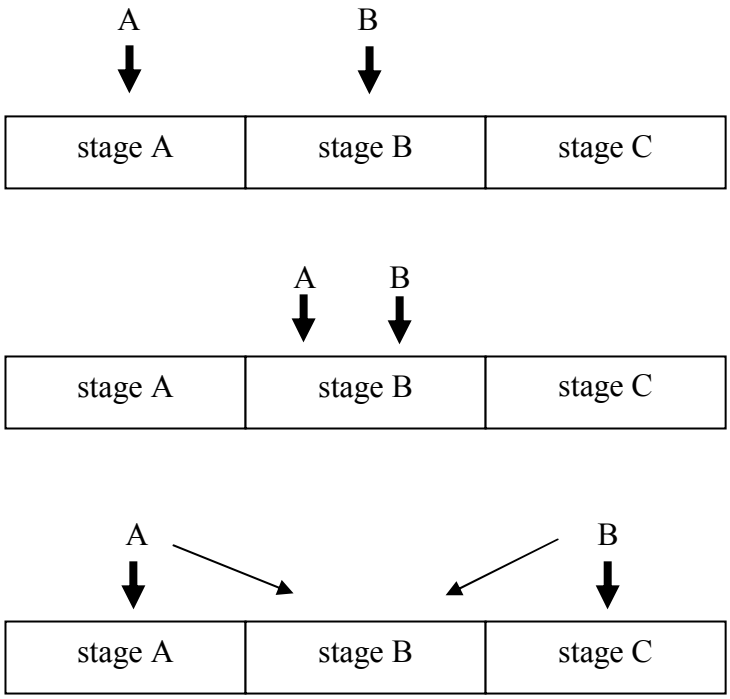


Figure 1.3: Examples of a hypothetical three-stage cognitive process. In the top example, Factors A and B influence different stages and will produce additive effects. Interactive effects can be observed when either two factors influence only one stage in common (middle) or two separate stages and one stage in common (bottom).

As an example of additive effects, consider the situation where stimulus quality is manipulated in conjunction with stimulus-response compatibility. Stimulus quality is assumed to affect the duration of the perceptual stage whereas stimulus-response compatibility is assumed to affect the duration of the response selection stage. In this case, within the ANOVA model, there should be main effects of both stimulus quality and stimulus-response compatibility. However, as these are assumed to affect different stages there should be no interaction.

Interactive effects should be observed when two (or more) factors influence the duration of the same processing stage. As an example of interactive effects, consider the situation where the number of response alternatives and stimulus-response compatibility - factors both likely to influence the response selection stage - are manipulated. Here, there should be an interaction between the number of response alternatives and stimulus-response compatibility revealing that both factors influence a common processing stage. Interactive effects can be distinguished in terms of whether the interaction is underadditive or overadditive. An overadditive interaction describes the situation where a factor has a greater influence on the other factors slower level. An underadditive interaction describes

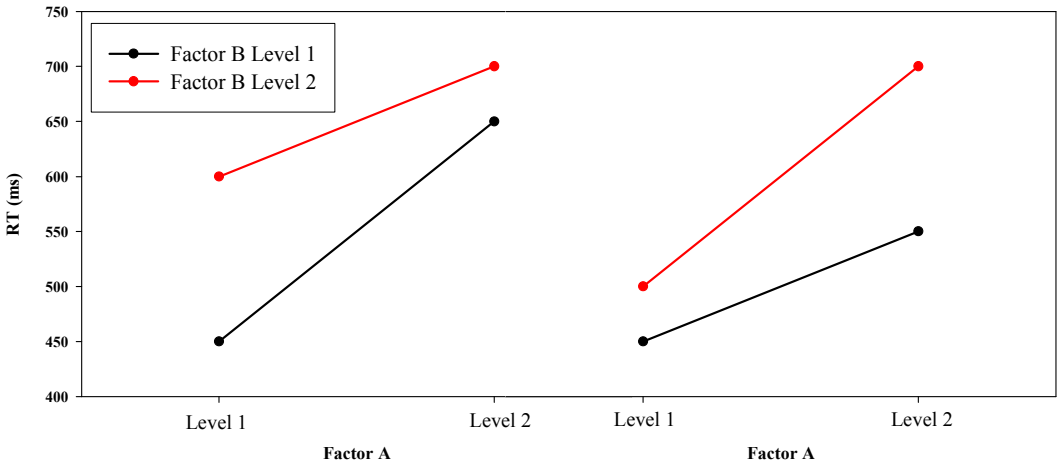


Figure 1.4: Hypothetical example of an underadditive interaction (left) and an overadditive interaction (right).

the reverse situation where a factor has a greater influence on the other factors faster level (see Figure 1.4). It is important to note that the interpretation of interactive effects within the AFM framework requires that both factors must influence reaction time (i.e. both main effects must be significant).

While the AFM allows powerful interpretation of reaction time effects, it is not unambiguous as it will only reveal the minimum number of stages involved.

For example, when two factors interact, they may influence one stage in common only or one stage in common in addition to separate effects of each factor on separate stages (see Figure 1.3).

Like the subtraction method of Donders, the AFM also rests on several assumptions, many originally noted by Sternberg (1969). First, the appropriate use of the method is dependent on processing operating in a serial and discrete manner with only one stage active at any given time. Second, the model assumes that the quality of the output is unaffected and as a result, the model can only account for accurate behaviour. Participants can trade-off accuracy for speed; a fact that can have implications for the AFM logic. For example, Pachella (1974) demonstrated that for low error rates (< 5 %), condition differences in reaction time may be due to condition differences in error rates. Thus, any RT effects should be considered alongside an analysis of error rates in order to exclude alternative speed-accuracy trade-off (SAT) explanations.

1.3.3 Cascade model

The cascade model of McClelland (1979) involves continuous information transmission and hence, stages that temporally overlap. While information transfer is still unidirectional between distinct processing levels (e.g. detection level, decision level), these different processing levels can be active at the same time, a property excluded in the discrete transfer mode of the AFM.

Several features of the model are important for interpreting the effects of factorial manipulations. First, information within a level is gradually accumulated at a particular rate up to an asymptotic activation level. Second, a change in activation level will depend on the difference between the current activation level

and the input level. Thus, a small difference between current activation level and input level will result in a slow change of activation. A final feature of the model concerns rate-limiting processes. These determine the slope of the activation function. Two parameters within the model vary and can account for response latency differences. These are the processing rate and the asymptotic level. Decreasing the processing rate or increasing the asymptotic level will both increase response time.

McClelland (1979) demonstrated that inferences about the locus of an experimental effect within the cascade model are consistent with those of a serial-discrete model when the experimental factors influence processing rates only. When the asymptotic activation level is affected, inferences from the models diverge. For example, when one factor influences the rate of a process and another the asymptotic activation level, an overadditive interaction is obtained. From AFM logic, this implies that the two factors influence at least one stage in common, whereas, from the perspective of the cascade model, the two factors may affect different stages.

1.3.4 Asynchronous discrete coding (ADC) model

Within the ADC model of Miller (1982) information transfer can still be assumed to be discrete, yet overlapping stages are possible due to parallel processing. For example, if a stimulus has two separately coded dimensions (e.g. shape and location), one of which determines response hand and the other response finger, the ADC model allows for partial information transfer of the stimulus attribute that was processed faster to the response selection stage. Here,

the perceptual analysis of the stimulus takes place in parallel while the information transfer remains discrete (see Figure 1.5).

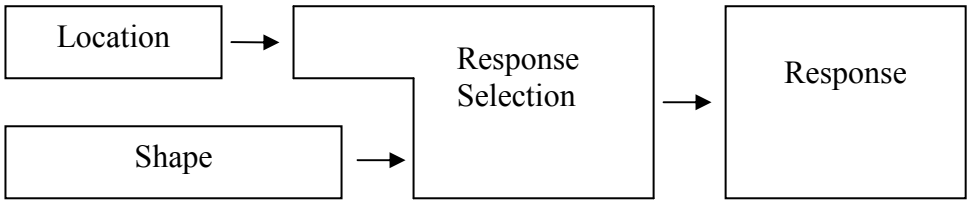


Figure 1.5: The asynchronous discrete coding (ADC) model of Miller (1982).

From the above descriptions of information processing models and the implications of discrete versus continuous transfer of information and the serial versus parallel organisation of processes, it is clear that data from factorial experiments may be, in certain circumstances, ambiguous and will clearly depend on the model adopted. For example, the existence of the SAT function suggests that information about a stimulus is accumulated gradually thus supporting a continuous view of information transmission, something that goes against the assumptions of discrete transfer of information in the AFM. However, the gradual SAT function can still be obtained in a model of discrete transmission. As argued by Meyer, Osman, Irwin, and Yantis (1988), with discrete transmission a decision about a stimulus is either based on no information or complete information. Performance would either be at chance level or completely accurate. If the point at which the transition to full information varies from trial to trial, the averaging procedure would result in a gradual function despite discrete information transfer (Meyer et al., 1988). Thus, it is clear to see that the interpretation of factor effects via the use of overt behavioural measures only is not straightforward.

In this situation additional information regarding the organisation of human information processing can be obtained from event-related potentials (ERPs). The ERP technique will be introduced in the next section.

1.4 Cognitive Electrophysiology

Reaction time studies alone can often support alternative models due to the fact that total RT reflects contributions from every stage of processing between stimulus and response. This makes it difficult to attribute a RT change or difference to one specific stage without the introduction of a number of assumptions (Luck, 1998). ERPs can be used to overcome aspects of this problem as they provide a continuous measure from stimulus to response and offer the possibility to infer the locus of the experimental effect more directly.

1.4.1 The EEG signal and Recording Issues

The EEG reflects the electrical changes in brain activity recorded from the scalp (for an introduction see Luck (2005a), or for an extensive overview see Picton, Lins & Scherg (1995)). The fluctuations in voltage are assumed to reflect the activity of large a number of simultaneously active neurons. There are two main types of electrical activity associated with neurons: action potentials and postsynaptic potentials. Action potentials are discrete voltage spikes that travel from the cell body to the axon terminals where neurotransmitters are released whereas postsynaptic potentials are the voltages arising when neurotransmitters bind to receptors on the membrane of the postsynaptic cell.

A number of points need to be noted regarding the type of electrical activity that can be recorded from the scalp. First, the activity of action potentials

is not detected via the use of scalp electrodes. Action potentials cause current to flow rapidly along the axon and as neurons do not fire simultaneously, action potentials in different axons will have a low probability of summation. In contrast, postsynaptic potentials are longer lasting and are more likely to be active synchronously, hence making summation of potentials more likely.

The configuration of neuronal populations also needs to be considered. One can distinguish between two types of configuration. The first, termed an open field, contains neurons that are arranged symmetrically in layers. This configuration allows for the activity to summate. In contrast, a closed field configuration involves neurons that are concentrically organised. This concentric organisation results in neuronal activity that is orientated in different directions and thus cancels out (see Figure 1.6).

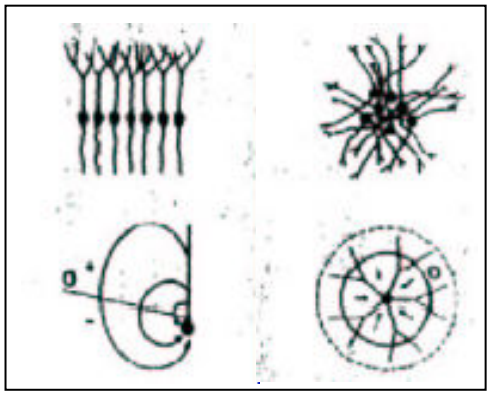


Figure 1.6: Open (left side) and closed (right side) spatial arrangements of neurons (adapted from Hillyard & Picton, 1987).

Thus, it is important to recognise that the neuronal activity that can be recorded at the scalp is only a fraction of the neuronal activity occurring within the brain. In order for electrical activity to be recorded from the scalp, the neurons must be

active synchronously and must be orientated in such a way that their effects at the scalp accumulate (Coles, Gratton, & Fabiani, 1990).

The EEG is recorded from the scalp using electrodes placed at desired locations generally according to the International 10-20 system (American Electroencephalography Society (1994)) (see Figure 1.7).

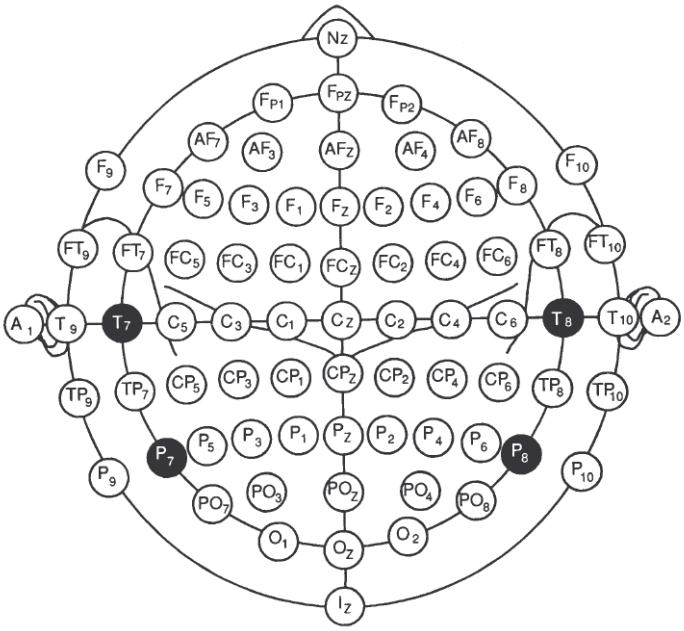


Figure 1.7: An extension of the International 10-20 System of Electrode Placement (from Picton, Lins & Scherg, 1995).

The 10-20 system locates the inion, nasion and preauricular points and places electrodes based on percentages of distance between locations. Location is specified with reference to proximity to regions of the brain (e.g. frontal, central, temporal and occipital) and the lateral plane with left sided electrodes labelled 'odd', right sided electrodes labelled 'even' and central electrodes labelled 'z'. Although electrode labels refer to brain locations, activity recorded at a certain site might not reflect activity generated from that area. This is because the brain

acts as a volume conductor and electrical activity generated within one area may be detected at more distant locations.

The EEG emphasises voltage changes that happen over time. In general, EEG recording systems use differential amplifiers utilising two types of electrodes: active electrodes and a reference electrode(s). The reference is placed on a convenient location on the participant's head (or body). A differential amplifier amplifies the difference between the active and the reference electrode. From this, it is clear that electrical activity recorded at an electrode reflects the difference between that site and the reference site.

Once the EEG signal has been amplified, it must be converted from a continuous analogue signal into a discrete digital form. These discrete time points are called samples with the sampling period being the time between consecutive samples. The sampling rate is determined by the Nyquist theorem which states that all information within an analogue signal can be converted into digital format with no loss of information as long as the sampling rate is greater than twice the highest frequency of the signal.

1.4.2 Event-Related Potentials (ERPs)

The signal of interest within the EEG is extremely small compared to background noise. As a result, several signal processing steps need to be taken in order to extract the signal. The most common technique is averaging the signal aligned to some event, for example, stimulus presentation or overt response execution. Typically, the averaging epoch will extend several hundred ms before the event of interest and will last approximately several seconds. Averaging of the signal is based on the assumption that activity not time-locked to the event will

vary randomly across the averaging epochs and will average to zero. On the other hand, any signal that is time-locked to the event of interest is assumed to be non-random and, hence, will not average to zero. It is this signal that is termed the event related potential (ERP) (see Figure 1.8). The remaining noise in the average decreases as a function of the square root of the number of trials, in that doubling the signal to noise ratio will require four times as many trials.

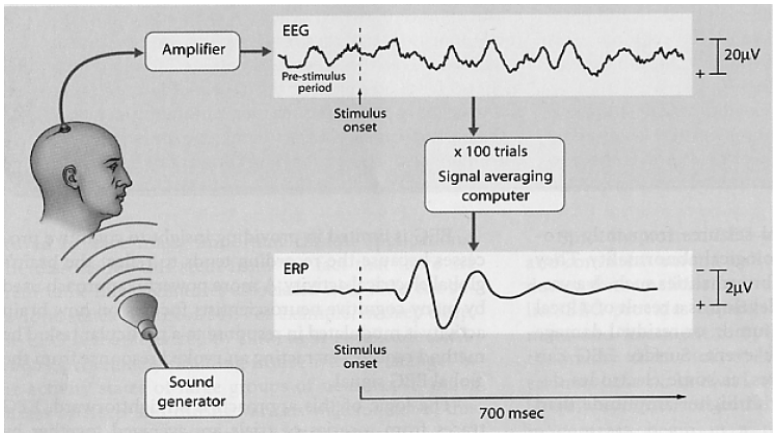


Figure 1.8: The raw EEG signal is averaged to cancel out the random noise present in the signal to give the ERP (from Gazzaniga, Ivry & Mangun, 2002).

1.4.2.1 Filtering the Signal

The use of filtering techniques allows for those frequencies in the EEG outside the interest of the researcher to be attenuated. Typically, the frequency range of interest for cognitive ERP studies lies within the range of 0.01 - 40 Hz. Thus, line noise (e.g. 50 Hz) from nearby electrical equipment that is picked up during recording is not within the frequency range of interest and can be eliminated via the appropriate use of a low-pass filter which attenuates high frequencies while allowing low frequencies to pass. In contrast, high pass filters attenuate low frequencies while allowing high frequencies to pass. As the frequency of interest and source of noise become more similar, it is more difficult to selectively filter out the noise without affecting the signal of interest.

A full overview of all issues related to filtering is beyond the scope of this introduction. What is important is that filtering substantially influences the ERP waveform and an appreciation of this is needed for appropriate application of a filter to an ERP waveform and also for interpretation. For a detailed discussion of filtering techniques applied to ERP data, see Luck (2005).

1.4.2.2 EEG Artifacts

The EEG signal can contain signals unrelated to cognitive processes (artifacts) such as blinks and eye movements. These signals can be extremely large when compared to the signal of interest and also may be time-locked to stimulus presentation and thus will not average out.

Eye movement related artifacts arise because the eyeball functions like an electrical dipole with positive and negative charges on either side. Movements of the eyes produce fluctuating electrical fields which contaminate the recorded brain activity. A number of procedures are available for dealing with such contamination. The first procedure simply involves removing those trials that are contaminated with a blink or eye movement before the averaging procedure. However, the complete removal of contaminated trials may result in an insufficient number remaining for analysis. As a result, techniques that estimate and remove the contribution of blinks and movements of the eyes from the recorded EEG signal are often utilised in order to retain a higher number of trials. For example, within BESA a dipole approach is used to estimate and remove the contribution of eye movements and blinks (Berg & Scherg, 1994). This is the approach utilised within this thesis for dealing with eye movement related artifacts.

1.4.3 ERP Components

An important question within ERP research concerns the nature of what is an ERP component. ERP waveforms are the combination of several summed underlying/hidden (or latent) components. There is no direct access to the latent components from the ERP waveform. From this it is also important to note that an ERP peak or trough and a component are not the same thing. Despite this, it is still common to classify an ERP component as a feature of the resulting waveform like a peak or trough. However, there is no direct correspondence between the timing of a distinctive feature such as a peak or trough and the temporal characteristics of the neural system. This is partly attributable to the fact that activity at a single electrode may be due to activity of a variety of different generators and spatial locations.

A topic of consideration when describing ERP components concerns the nomenclature. Early classification of ERP components centred on the exogenous-endogenous distinction. Components whose characteristic latency, amplitude and distribution depend on stimulus properties while being cognitively impenetrable are considered to be exogenous. In contrast, components whose characteristics depend on the cognitive processing of the participant are considered to be endogenous. However, this early distinction has proven to be an over simplification. For example, most early components have been shown to be modifiable by cognitive operations like attention (see below).

Components within an ERP waveform can be described in several ways including polarity, latency, scalp topography, experimental manipulation affecting the component etc. In terms of polarity, ERP components are defined as either positive (P) or negative (N). For example, a negative deflection at approximately

100 ms might be termed the N100, or alternatively the N1, so as to indicate that it is the first major negative component. Such sequential naming is common for earlier, more consistent potentials (those originally termed exogenous). Other parts of the ERP signal do not have a specific peak and thus receive non-specific names, for example, the 'slow wave'. Other components may be named after their supposed function like the lateralised readiness component (LRP), a component thought to index selective response preparation (cf. Coles, 1989; Eimer & Coles, 2003).

Beyond issues related to naming components, difficulties exist regarding how components should be defined. For example, some have proposed a physiological approach (e.g. Näätänen & Picton, 1987) to component definition which emphasises anatomical sources, while others (e.g. Donchin, 1981) promote a functional approach emphasising the cognitive processes associated with the component. Luck's (2005) definition of a component states that a component is "*scalp-recorded neural activity that is generated in a given neuro-anatomical module when a specific computational operation is performed*" (*p*. 59). This definition combines both the physiological and functional approaches and accommodates the fact that component latency may vary as can the scalp distribution and polarity.

1.4.4 ERP Analysis

Analysis of ERP data can take place at many levels and requires specific assumptions about the relationship between ERPs, cognitive processes and brain activity. Common measures of ERP components include latency measures, amplitude measures, peak onset of a component etc. with the most appropriate

measure being dependent on the hypothesis. From these measurements, there are generally three kinds of inference that are made: inferences about the timing of a cognitive process, inferences about the degree of engagement of a cognitive process and inferences about the functional equivalence of an ERP component. At the most basic of levels, for example, one may be interested in whether the processing between two conditions differ and if so, when does the processing start to differ?

The research question is the most important factor determining which form the analysis takes. Does the hypothesis make predictions based on a specific component? For example, many ERP studies have attempted to associate waveforms with certain cognitive processes. From this, it has been possible to use these specific ERP features as a marker for the engagement of cognitive processes, for example, P1 and N1 amplitude as markers of attention (see below). Here, the analysis can be restricted to electrode sites where the component is largest. This strategy will be adopted for the analysis of data in the forthcoming experimental chapters.

An effect-unspecific hypothesis predicts different neural processing between conditions but does not specify how this processing will differ. Analysis will be of an exploratory nature with a wide time range and number of electrodes. Care must be taken with any interpretation due to the post-hoc nature of the analysis.

1.4.4.1 Amplitude measures

All component measures must be made relative to a baseline. A commonly adopted baseline is the mean of the waveform computed across some pre-stimulus

interval, so that the waveform is scaled such that the mean across the baseline will be zero. A longer baseline is recommended (100 ms +) in order to reduce possible influences of different noise structures between different conditions.

It is generally assumed that an amplitude difference is evidence for a variation in the degree or intensity of engagement of common processes. There are a number of ways to measure amplitude. One method is to either determine the peak amplitude or the mean amplitude during some specified time window. This time window typically centres on the component peak and is usually narrow enough to avoid substantial component overlap. Both peak and mean amplitude measures have advantages and disadvantages. First, does the component have a well defined peak? If the answer is yes, then a peak measure can be taken with little ambiguity. However, some components will have a flatter morphology with no definitive peak making an area measure more appropriate. A mean amplitude measure can also be appropriate for components with a well defined peak. However, care should be taken when peak latency between experimental conditions differs, as this may produce an amplitude difference that is not evident in the peak. In addition, latency variability within a condition across individual trials, means that the measured peak amplitude of the average will be smaller than the peak amplitude of individual trials.

1.4.4.2 Latency measures

Measuring latency allows one to determine whether a component shows a temporal lag between conditions. The simplest measure of ERP latency is to determine the peak latency, that is, the point at which the waveform reaches maximum or minimum within a specified time window encompassing the

component of interest. For some hypotheses, it may be more important to determine the onset of a component, for example, the onset of hand-selective motor activation as indicated by the LRP.

1.4.4.3 Comparison of ERP Latencies to RT

As the ERP forms a continuous measure from stimulus to overt response and the latency of an ERP component can be determined (albeit with some difficulties – see above), it seems plausible that different ERP latencies across conditions can be compared to reaction time differences across conditions. However, this comparison is problematic. Reaction time is usually calculated as the mean over a large number of trials. The peak of an ERP waveform corresponds more closely to the mode of the distribution of single-trial latencies while an area measure of ERP latency corresponds more closely to the median of the distribution. Thus, the difficulties arise from directly comparing different measures of central tendency, namely, the mean, mode and median. If a difference in reaction time across conditions is heavily influenced by changes in the tail of the distribution, this will affect the mean more than either the mode or median. Thus, mean RT effects are generally larger than effects measured by ERP latency (for an example, see Luck, 2005).

1.4.5 ERP Components

1.4.5.1 C1 Component

The C1 component is the first major visual component with an onset latency of approximately 40 to 60 ms. The C1 component peaks approximately 80 to 100 ms after stimulus onset. It is largest at posterior midline electrode sites and

appears to be generated within area V1 (Jeffreys & Axford, 1972). The topographic organisation of V1 results in the component being positive for lower visual field stimuli and negative for upper visual field stimuli (Mangun, Hillyard & Luck, 1993). Thus, in order to isolate the C1 component, it is necessary to present upper-field stimuli in order to generate a negative C1 (see section 1.4.7 below). With lower-field stimulus presentation, the C1 component is positive and thus summates with the P1 component and becomes obscured.

1.4.5.2 P1 and N1 Components

The P1 component is largest at lateral occipital electrode sites and has a typical onset between 60 and 90 ms. The P1 component peaks approximately 100 to 130 ms after stimulus onset. The P1 is sensitive to variations in stimulus parameters, for example, P1 peak latency will be delayed for stimuli presented in lower contrast. Dipole modelling of the P1 component has demonstrated that its scalp distribution is consistent with a neural generator source within lateral extrastriate cortex (Clark & Hillyard, 1996).

The N1 component is a negativity that follows the P1 component. Again it is largest at lateral occipital electrode sites. The N1 component peaks approximately 140 to 200 ms after stimulus onset (see figure 1.9). It is important to note that components with the same name, for example a visual P1 and an auditory P1 might bear no relationship to each other. Such components are modality-dependent, whereas others (e.g. P300) are modality-independent.

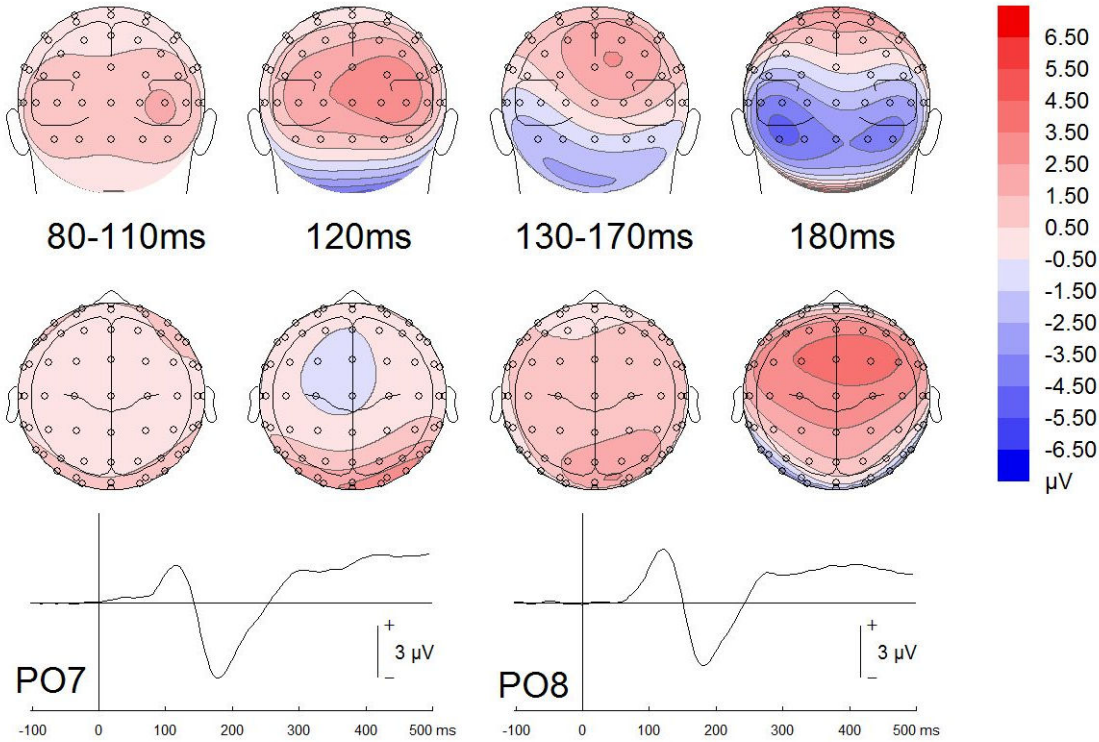


Figure 1.9: Diagram of the development of the P1 and N1 components. The top row shows back of the head while the bottom rows shows the top of the head. Time represents time from stimulus presentation.

1.4.6 Early Visual Components and Attention

Behavioural and physiological evidence exists for the role of attention in modulating the degree to which attended stimuli and unattended stimuli are processed. Behaviourally, attention can affect overt performance. For example, in an early RT study, Posner, Nissen, and Ogden (1978) demonstrated that reaction times to stimuli presented at expected, and thus, attended locations were faster than when the stimulus was presented elsewhere. Within this study, attentional focus was manipulated by the use of a precue that is presented prior to the stimulus.

The above advantage in terms of RTs to stimuli presented at attended locations suggests that these benefits are located at a perceptual stage. However, the requirement to respond to the stimulus at both attended and unattended

locations is problematic for a conclusive interpretation. For example, it remains a possibility that a higher decision or response criterion was set for those stimuli presented at the unattended location (Müller & Findlay, 1987; Shaw, 1984; Sperling, 1984; Sperling & Dosher, 1986). Such a hypothesis is consistent with late selection models of attention (e.g. Deutsch & Deutsch, 1963). ERP methodology has been used effectively to rule out this possibility. Based on the rationale of enhanced perceptual processing of stimuli presented at attended locations, it was proposed that such effects would result in observable differences in the visual evoked ERPs to stimuli presented at attended and unattended locations.

ERP studies using a similar, sustained attention paradigm have investigated effects of attention on visual processing (e.g. Gonzalez, Clark, Fan, Luck & Hillyard, 1994). In the sustained attention paradigm, participants are required to fixate at a central location while attending to either the left or right of fixation. Direction of fixation is manipulated between blocks of trials. Stimuli are presented rapidly in both the attended location and unattended location with the participant's task being to respond to targets in the attended location only. Target and non-target stimuli differ subtly, for example, a small size difference. Such a paradigm has the advantage that more stimuli can be presented within the same amount of time when compared to the cued paradigm as there is no need to present time consuming cues (Luck, 2005).

It has been demonstrated that the P1 and N1 components are larger for stimuli presented at the attended location (see Figure 1.10).

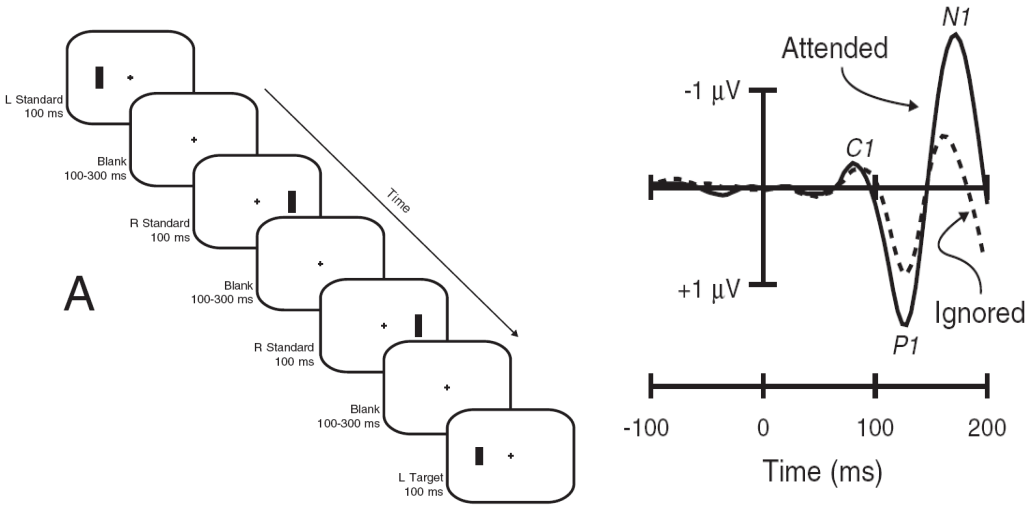


Figure 1.10: In the left column is an example of the sustained attention paradigm (see text for an explanation). The right column demonstrates the difference between the amplitude of the P1 and N1 components for attended and ignored stimuli (note that negative is plotted upwards in this example). The early C1 component is unaffected by attentional manipulation(adapted from Luck (2005), original data presented in Gonzalez et al. (1994)).

Several experiments (e.g. Mangun, Hansen, & Hillyard, 1987; Mangun & Hillyard, 1991) have replicated the above general findings of amplitude differences in the P1 and N1 components using an endogenously cued paradigm. However, task requirements appear to be important for the effect. For example, in Experiment 1 of Mangun and Hillyard (1991), both a modulation of P1 and N1 was observed when participants were required to perform a two-choice discrimination task. This N1 effect was not evident in a second experiment where the participants task was simply a speeded detection response to targets (simple RT task). This suggests a dissociation of the visual processes reflected. Mangun (1995) suggests that this is due to the fact that a speeded detection response requires no detailed perceptual processing, and that perceptual discrimination/identification may be indexed by the N1 component.

In contrast to the endogenously cued attention paradigm above which requires a decoding of information before allocating attention, cue information can take the form of a sensory event, for example, a flash in a peripheral location.

The location of the flash can be valid or invalid with respect to the subsequent location of the presented stimulus. Such peripheral cues may capture attention in a more automatic fashion, for example, such cues do not require any predictive validity in order to demonstrate cue validity effects (Jonides, 1981). In addition, the time course of attentional modulation is different across the two cueing procedures. Peripheral cues facilitate RTs at valid locations with cue-target stimulus onset asynchronies (SOAs) as short as 50-100 ms (Posner & Cohen, 1984). As the time between the cue and the presentation of the stimulus increases, the RT benefit for stimuli presented at valid locations may become a performance cost and possibly reflects the phenomenon of inhibition-of-return (Posner & Cohen, 1984). Inhibition-of-return is a bias against revisiting a location that has been recently attended to.

The above differences between attentional cueing paradigms (cued and peripheral) were investigated by Hillyard, Luck and Mangun (1994). RT results in both types of cueing demonstrated faster RTs to valid compared to invalid cued locations with the difference between the two types of cueing being minimal. In terms of the ERP results, in the endogenously cued condition, cue validity resulted in amplitude differences in both P1 and N1 peaks with larger peaks for valid trials. In terms of peripheral cueing, there was no modulation of the P1 component.

1.4.7 Localisation of Visual Attention Effects

The above results indicate that attention can modulate visual processing within 70-90 ms after stimulus presentation supporting an early selection view. However, this does not answer questions relating to where in the visual system

such attention effects operate. In order to gain a fuller understanding, attempts have been made to localise attention effects.

The C1 component does not show significant changes depending on attentional focus (Clark & Hillyard, 1996; Gonzalez et al., 1994; Mangun, Hillyard, & Luck, 1993). Dipole modelling of the C1 component indicates a neural generator in the primary visual cortex, with the C1 component varying in polarity depending upon stimulus position. This is consistent with the retinotopic organisation of the striate cortex (Clark, Fan & Hillyard, 1995; Mangun et al., 1993). The lack of an attention effect on the C1 in ERP studies suggests that attention only modulates visual processing after area V1. Single cell recordings in monkeys using a standard attention paradigm also demonstrated a lack of attentional effects in area V1.

The observed polarity reversal of the C1 component for stimuli presented in the upper and lower visual fields does not occur for either the P1 or N1 component (Mangun et al., 1993). This suggests that attention only modulates visual processing once information reaches extrastriate areas of the visual system.

The above findings from ERP studies are consistent with regards to the lack of an attention effect on the early C1 component. However, data from functional Magnetic Resonance Imaging (fMRI) studies have shown an attention effect in area V1 (e.g. Gandhi, Heeger & Boynton, 1999; Somers, Dale, Seiffert, & Tootell, 1999). It is possible that the task used in such studies was more appropriate for engaging attentional mechanisms in area V1 (Luck, 2005). This was investigated by Martinez et al. (1999). Using a typical attention paradigm, fMRI and ERP data were recorded from the same group of participants. Again, the results indicated a discrepancy between the fMRI data and the ERP data with

the fMRI data showing an attention effect within the striate cortex while the ERP data showed a lack of an attention effect for the C1 component. As the task was constant across both fMRI and ERP data sets, task differences cannot explain the discrepancy. It has been suggested that the attention effect within area V1 from fMRI studies reflects some form of feedback signal rather than a modulation of feed-forward sensory activity (Luck, 2005). If this is the case, attention operates early in the anatomical sense but not in the temporal sense (Kanwisher & Wojciulik, 2000).

An alternative explanation proposes that attentional effects measured via fMRI are the result of increases in baseline neural activity that occur before stimulus presentation and that these effects are more difficult to detect with ERPs (Kanwisher & Wojciulik, 2000). For example, Kastner, Pinsk, De Weerd, Desimone and Ungerleider (1998) demonstrated increased attention-related activity in the absence of stimulus presentation in a condition where stimulation was expected. They hypothesized that such activity reflects a top-down bias of neural signals and that such biasing signals are generated within a fronto-parietal network.

1.4.8 N170

Faces are extremely important for human interaction and as a result, much research has concentrated on investigating the neural mechanisms involved in facial recognition. fMRI and positron emission tomography (PET) studies have identified regions within the ventral occipito-temporal pathway of the brain, such as a lateral part of the fusiform gyrus that respond more to faces than any other stimulus category type (e.g. Kanwisher, McDermott, & Chun, 1997). The area

that responds more with face stimuli than any other category has been termed the fusiform face area (FFA). Studies using such techniques can only provide information about possible brain locations associated with face processing due to poor temporal resolution. The use of ERPs allows investigation of the temporal characteristics involved in face processing. ERP studies have identified a negative component over temporal-parietal regions occurring approximately 170 ms after stimulus presentation (termed the N170) that responds maximally to face stimuli compared to other object categories (e.g. Allison et al., 1994; Jeffreys, 1996). An analogous response component has been identified using magnetic resonance imaging (MEG) and has been termed the M170 (Liu, Higuchi, Marantz & Kanwisher, 2000) (see Figure 1.11).

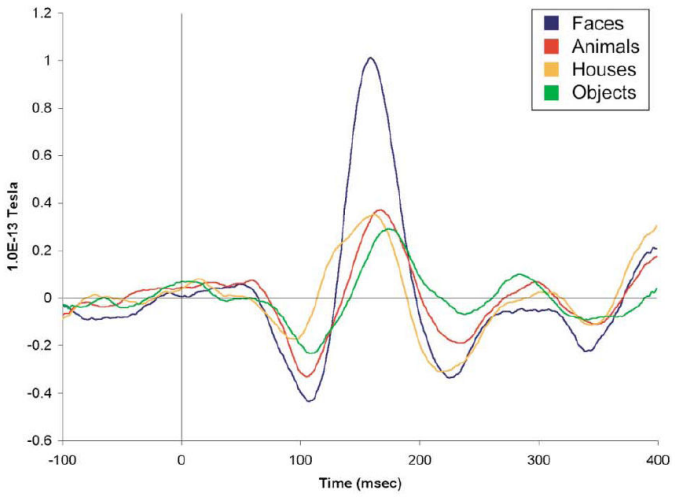


Figure 1.11: The M170 response to a variety of stimulus categories. The components amplitude is increased for face stimuli (adapted from Downing, Liu & Kanwisher, 2001).

1.4.8.1 Face Processing and Attention

The response of the FFA measured via fMRI and the N170 measured via ERPs may derive from the same neural source (Halgren, Raij, Marinkovic, Jousmaki & Hari, 2000). If this is true, the fMRI response is likely to reflect face

processing at all latencies while the ERP component reflects face processing at shorter latencies only (Downing et al., 2001). These measures (FFA activity and N170 amplitude) have been used as dependent measures in a series of studies that investigated mechanisms of attention and face processing (e.g. Wojciulik, Kanwisher, & Driver, 1998; O'Craven, Downing, & Kanwisher, 1999; Liu & Kanwisher, 2000).

Can face processing be affected by selective attention? It has been suggested that the processing of faces might form a special case of object processing and that a specialized face processing module might be engaged whenever a face is encountered, regardless of its relevance (e.g. Farah, Wilson, Drain, & Tanaka, 1995). Wojciulik et al. (1998) investigated the effect of selective attention on the processing of faces by comparing activity within the FFA in a task where a face stimulus was either task-relevant or task-irrelevant. Participants were presented with two face stimuli and two house stimuli at different spatial locations (see Figure 1.12). The participants task was to perform a matching task (same vs. different) on either the face stimuli or the house stimuli. This task was performed in separate blocks.

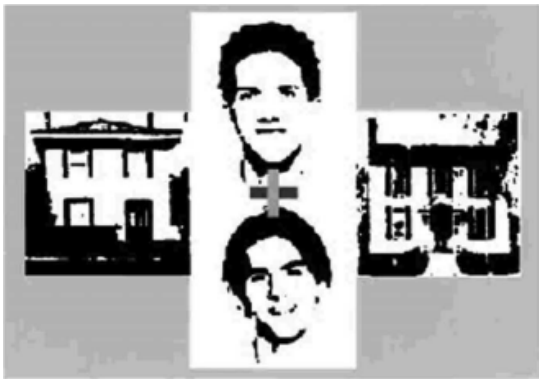


Figure 1.12: Example of stimuli used in the study of Wojciulik et al. (1998) (adapted from Downing et al. (2001)).

If face processing is unaffected by attention, then FFA activation should be similar across the attend-face and attend-house conditions. However, this was not the case. FFA activation depended on whether the face stimulus was task-relevant or task-irrelevant, with larger FFA activation when the face was task-relevant.

A similar result has been observed in ERP studies using the N170 as a dependent measure of face processing. Holmes, Vuilleumier and Eimer (2003) presented participants with displays like that used by Wojciulik et al. (1998) and required participants to perform the same matching task. The relevant stimulus dimension was cued trial-by-trial by the use of a cue that directed attention to either the vertical or horizontal dimensions. They compared the amplitude of the N170 when the face was presented at the cued location (task-relevant) and when the face was presented at the uncued location (task-irrelevant). Results indicated that the N170 component showed increased amplitude on trials where attention was focused toward the face stimuli relative to trials where attention was focused toward the house stimuli (see Figure 1.13).

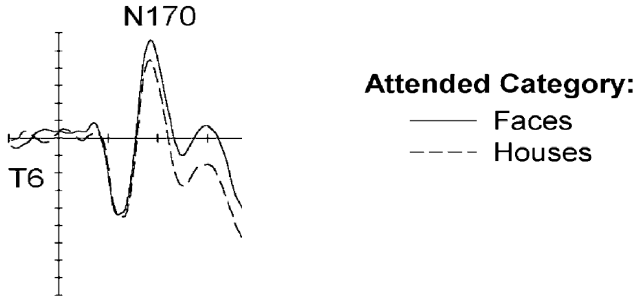


Figure 1.13: Grand-average ERP waveform showing increased N170 amplitude when faces were the attended category relative to when houses were the attended category (adapted from Holmes et al., 2003).

The above studies of Wojciulik et al. (1998) and Holmes et al. (2003) demonstrate attentional modulation of face processing when the different stimulus types occupy different locations in space. Attending to a location in space may restrict attention to encompass only information within that spatial location and

thus, does not determine the units of information attention can operate on (Downing et al., 2001).

Do attentional mechanisms operate in a location-based, feature-based or object-based fashion? A common distinction within the attention literature concerns location-based attention versus object-based attention. Location-based attentional selection predicts that both relevant and irrelevant stimuli will be selected at the attended location. Object-based attention allows selection of a relevant stimulus relative to an irrelevant stimulus despite them being presented at the same location.

O'Craven et al. (1999) tested the above distinction between object-based attention and location-based attention by using the activity within the FFA and the parahippocampal place area (PPA), an area proposed to respond selectively to places and houses (Epstein & Kanwisher, 1998; Epstein, Stanley, Harris, & Kanwisher, 1999), as dependent measures. Using a similar rationale to that of Wojciulik et al. (1998) (i.e. activity within an area that shows selectivity to a stimulus category will vary, dependent upon the degree to which that specific stimulus category is attended to), O'Craven et al. presented participants with stimuli consisting of two overlapping objects at the same location (see Figure 1.14).

Figure 1.14: Sample stimulus from O'Craven et al. (1999). (adapted from O'Craven et al., 1999).

In each display, one of the objects had a second visual attribute, namely, low-amplitude oscillating motion. Location-based attention predicts that attending to one object would also involve selection of the other object because they both appear in the same location whereas, for object-based attention, attending to one of the stimulus dimensions (e.g. motion) will also select that stimulus (e.g. face selected if the face stimulus was moving). The face and house stimuli were never task relevant, with the participants task being to direct attention to either the direction of the motion or the position of the static object (presented slightly off fixation in one of four directions).

The results demonstrated that when attending to the motion, increased activity within the FFA was observed when it was the face that was moving, while

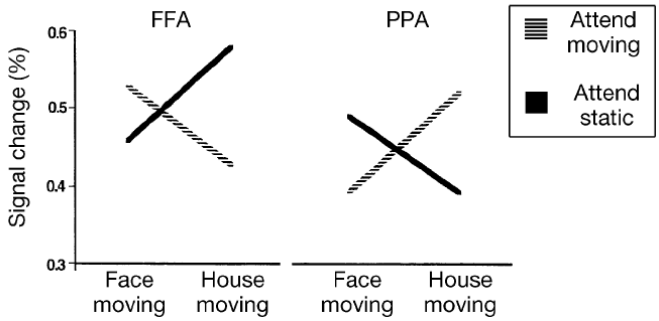


Figure 1.15: Results from O'Craven et al. (1999)

increased activity within the PPA was observed when the house was moving. This result reversed when attending to the direction of the static object (see Figure 1.15). From this it can be concluded that attention can be directed toward objects and select that object when several objects are presented at the same spatial location.

Liu and Kanwisher (2000), as described by Downing et al. (2001), investigated whether the modulation of object processing by attention when objects are presented at the same spatial location can be detected in the early

stages of face processing as indexed by the M170. Participants were required to view a single face or house stimulus. This stimulus served as the cue for the forthcoming target stimulus. The target stimulus consisted of a transparently overlapping face-house stimulus (see Figure 1.16).

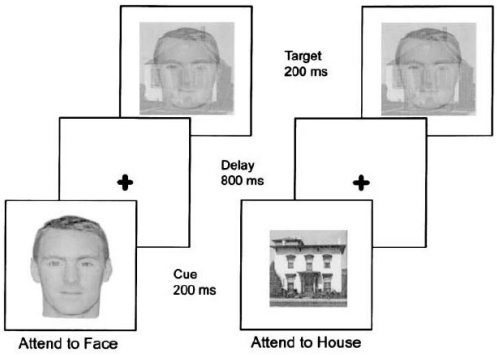


Figure 1.16: Experimental procedure of Liu and Kanwisher (2000) (from Downing et al., 2001).

The participants task was to indicate whether the cue (house or face) appeared in the subsequent compound stimulus. The results indicated a modulation of M170 amplitude with higher amplitude when attending to the face than when attending to the house (see Figure 1.17).

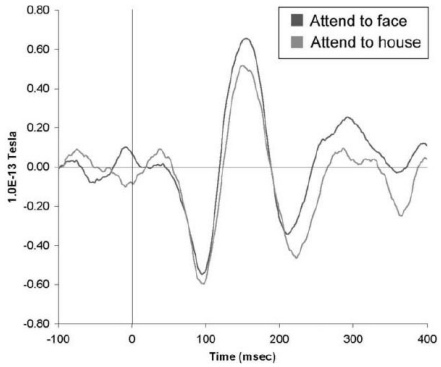


Figure 1.17: Results of Liu and Kanwisher (2000) showing amplitude difference in M170 as a function of attended stimulus category (from Downing et al., 2001).

The above findings of O'Craven et al. (1999) and Liu and Kanwisher (2000) demonstrate that attentional modulation effects of faces observed when stimuli are presented at different spatial locations (e.g. Wojciulik et al., 1999) can also be observed when the stimuli are presented at the same location.

1.4.9 The Lateralized Readiness Potential (LRP)

The LRP reflects the degree of hand-specific response preparation and is based on the readiness potential (RP) (cf. Coles, 1989). The RP is a negative-going ramp shaped potential that is maximal over central scalp sites. It develops approximately one second prior to the onset of a voluntary movement (Kornhuber & Deecke, 1965). The RP is more negative over the cortex contralateral to the responding hand and was proposed to offer a tool to infer an index of response preparation (Kutas & Donchin, 1980). Coles suggested a procedure for isolating the lateralization of the RP, the LRP. First, the potential recorded over the motor cortex ipsilateral to the correct hand is subtracted from the potential contralateral separately for left and right hand responses, a procedure that eliminates all symmetrically distributed activity. To eliminate asymmetric activity not specific to the response, the difference potentials are averaged over left and right hand responses,

$$LRP = \tfrac{1}{2}\,[\text{Mean}\,(C'_4 - C'_3) + \text{Mean}(C'_3 - C'_4)]$$

where C'_3 and C'_4 are electrode labels

Thus, it is proposed that the LRP indexes only hand-specific activity (Coles, 1989; Osman & Moore, 1993). Since the calculation subtracts with respect to the correct hand deviation, the negative direction reflects correct hand activation while

deviation in the positive direction reflects incorrect hand activation (see Figure 1.18).

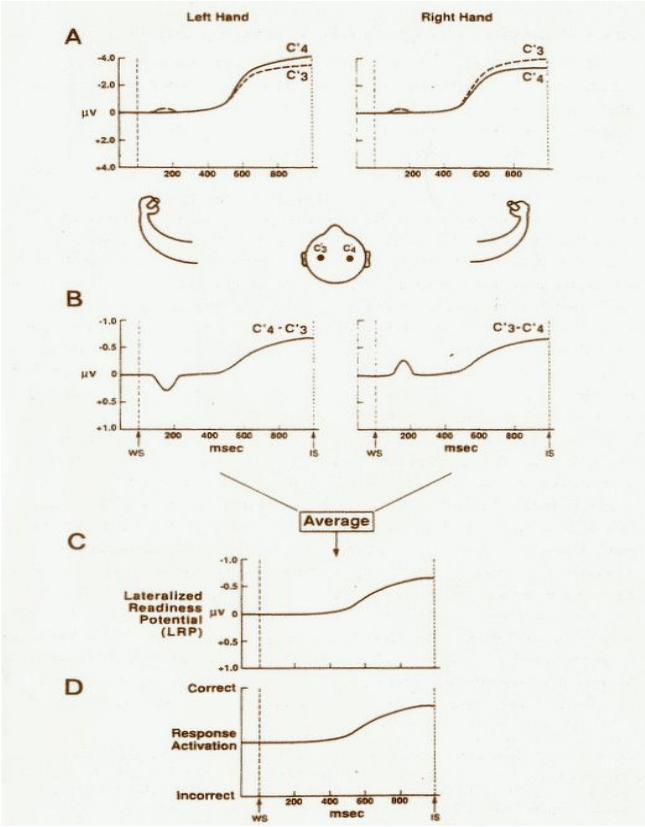


Figure 1.18: Derivation of the lateralized readiness potential (see text for an explanation) (from Coles, 1989).

The LRP can be calculated time-locked to either the stimulus or the response. The stimulus-locked LRP (S-LRP) is averaged aligned to stimulus onset with the interval between stimulus onset and the onset of the stimulus-locked LRP being called the stimulus-locked interval. The S-LRP interval is related to the duration of pre-motor processes, in particular, the point at which response selection terminates. For example, Miller, Ulrich and Rinkenauer (1999) demonstrated that manipulations of stimulus intensity influenced the S-LRP interval. High intensity stimuli results in a shorter S-LRP interval compared to low intensity stimuli. Stimulus intensity produced no effect on the LRP-R interval. In addition,

manipulations of stimulus-response compatibility, factors known to influence response selection stages within information processing, have been shown to influence the S-LRP interval selectively (Masaki, Wild-Wall, Sangals, & Sommer, 2004). Such findings support the proposal that the LRP begins after response selection. Alternatively, LRPs averaged time-locked to response onset are termed response-locked (LRP-R). The interval between LRP-R onset and overt response (LRP-R interval) is related to the duration of motor processes (Osman, Moore, & Ulrich, 1995). For example, the LRP-R interval is sensitive to factors affecting late processes, for example, response complexity (Smulders, Kok, Kenemans, & Bashore, 1995). Thus, the LRP can provide a time marker between stimulus and response and can determine whether the experimental manipulation influenced the duration of premotoric or motoric stages (see Figure 1.19).

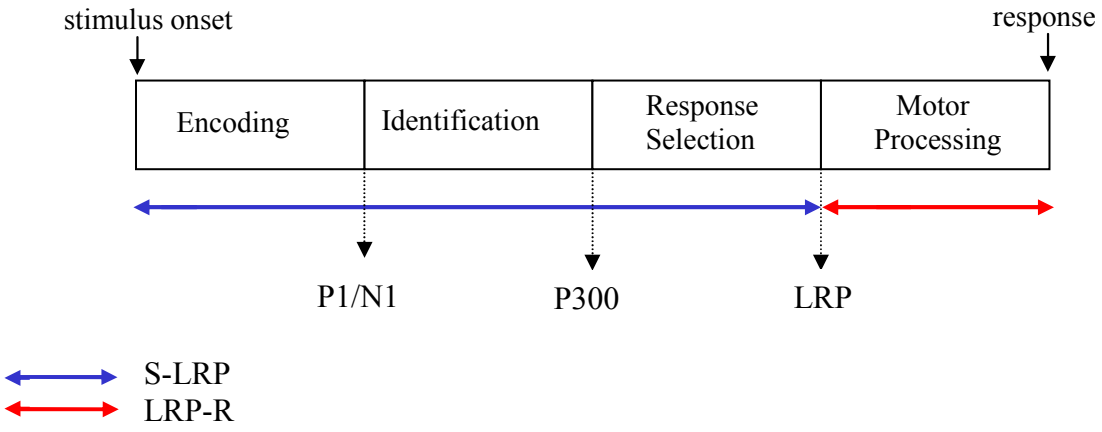


Figure 1.19: Stimulus-locked LRP (S-LRP) interval and Response-locked LRP (LRP-R) interval.

1.5 Organisation Revisited

The previous sections of this first chapter introduced the methods that will be used; namely, the overt behavioural measures of RT and error rate combined

with the measurement of ERPs. Issues related to these methods have been discussed. Alongside the methods related to the ERP technique and ERP components, the topic of attention was introduced with specific emphasis placed on the contributions made by ERP studies to this area. The following sections of this first chapter deal with the topic of the thesis – executive control. To recap, the area of task switching will be introduced and evaluated as a method for the study of executive control. Next, further paradigms (e.g. Stroop task, Simon task, Eriksen Flanker task) that have been used widely in the study of executive control will be discussed. This discussion will be based around the conflict adaptation effect (Gratton et al., 1992) and the resulting conflict control model of Botvinick et al. (2001). This section is intended to provide a general overview of the area and also a framework upon which the following experimental chapters and their rationale can build.

1.6 Executive Control and Task Switching

1.6.1 What is Task Switching?

Every task that we perform in our daily routine requires the appropriate configuration of mental resources. For example, typing requires that we coordinate attention between the keyboard and the screen, that we compose sentences and subsequently assess those sentences for correctness of grammar, syntax, word choice etc, all while trying to ignore distractions. Such a configuration of mental resources will allow the required task to be completed successfully. However, if our goals change, our mental resources will no longer be configured correctly. Thus, if we needed to answer the phone, we would need to reconfigure our mental resources so that they were appropriate to the task, by

paying attention to the speaker's voice rather than the keyboard or screen. Such appropriate configuration of mental resources has been termed adopting a 'task set' (Rogers & Monsell, 1995). From this it is clear that task switching simply refers to the process of changing from doing one thing to doing another thing, or in cognitive terms, changing from one 'task set' to another 'task set', a process known as task-set reconfiguration (Rogers & Monsell, 1995).

Task sets can also be triggered by external stimuli, for example, the presentation of a word can automatically trigger a 'reading task set'. This is referred to as exogenous control and contrasts with endogenous control (controlled activation of a task-set). Intentional or executive control is needed to select and implement task sets that are less automatic, for example, reading the colour of an incongruent stimulus in the Stroop task. It is this endogenous, intentional *reconfiguration* process that has been the focus of research as it may provide a window for the study of higher-order functions of executive control (Rogers & Monsell, 1995).

1.6.2 Task Switching Paradigms

The first experimental investigation of task switch processes was provided by Jersild (1927). As described by both Rogers and Monsell (1995) and Allport, Styles and Hsieh (1994), Jersild required participants to perform either a subtraction or an addition task individually within a block and compared this performance with the case where participants performed both the addition and subtraction tasks within the same block, alternating from one task to the other. Jersild reported longer RTs of several hundred milliseconds for each item when alternating between the two tasks within the same block compared to only

completing one task within a block. He termed this difference the 'shift cost' and associated it with the additional requirement to reconfigure task set within the two-task block.

Several methodological difficulties have been identified with the above paradigm (Rogers & Monsell, 1995). First, the alternating task requirement in the dual-task block requires that two tasks be kept in memory and that the participants reconfigure between these tasks on each trial. As only one task needs to be kept in memory for the single task block, it is not entirely clear whether the observed switch cost reflects the time needed to reconfigure, or alternatively, the increased processing demand of having two active task sets in memory. Second, a between-block design is susceptible to a confound of differences in arousal level, motivation etc.

A number of procedures have been developed to overcome the above problems with the most important methodological advance being the comparison of switch and non switch trials within the same block (Rogers & Monsell, 1995). A basic task-switching paradigm involves performing two (or more) tasks in a given sequence. A number of variations on the basic paradigm exist but generally fall into one of two classes: first, a paradigm where the task to be performed is cued by the spatial location of the stimulus (e.g. alternating runs paradigm of Rogers & Monsell, 1995); and second, a paradigm where the task to be performed is indicated by the use of a precue presented prior to the stimulus. In the alternating runs paradigm the task switch sequence is predictable while in the precuing paradigm, task sequence can be random (for a review see Monsell, 2003). Such paradigms allow the investigation of processes involved in the active preparation for an intentional task switch. For example, consider the alternating

runs paradigm of Rogers and Monsell (1995) (see Figure 1.20). This procedure involves a predictable AABBAABB… sequence. Thus, each task is performed for two consecutive trials before a switch is required. The benefit of such a sequence is that it allows for the direct comparison between switch and repetition trials, with a switch and a repetition trial alternating in perfect balance. In addition, spatial cueing has the advantage that it forgoes the necessity for the current task to be held in memory.

When the task switches, a change in task set is required. It has been found that switch trials take longer than repetition trials with the difference being termed the 'switch cost'. Switch trials are also more error prone giving an equivalent 'error cost'. By manipulating the time available between one trial and the next, the speed at which the switch is accomplished compared to a repetition is proposed to give a measure of executive control process involved in reconfiguration. Large switch costs are observed when the response stimulus interval (RSI) is short, with this cost being reduced as the time for reconfiguration (or RSI) is increased (Rogers & Monsell, 1995).

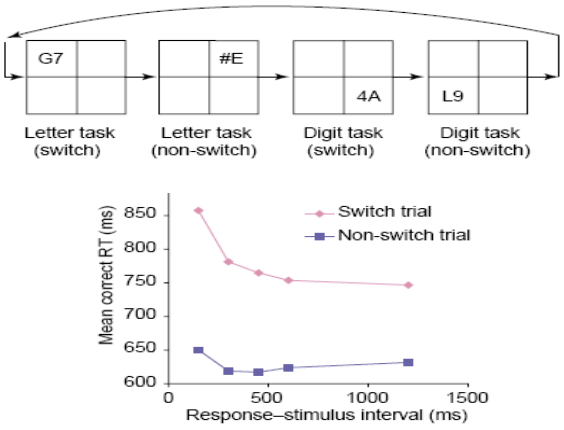


Figure 1.20: The top row demonstrates the alternating runs paradigm of Rogers & Monsell (1995). The task is cued by the spatial location within the 2*2 array. The task sequence is predictable due to the clockwise rotation of trials. Results (bottom) demonstrate the typical switch cost and the reduction of this switch cost

with increasing response-stimulus interval. Notice that a substantial part of the switch cost (so called 'residual cost') remains at the longest RSI (adapted from Monsell, 2003).

1.6.2 The Residual Switch Cost and Task Set Inertia

The finding that the switch cost is reduced with increased preparation time is robust. However, when the preparation is long enough to allow full reconfiguration, the switch cost is not entirely eliminated. This remaining portion of the switch cost with long preparation times is termed the 'residual cost' (Rogers & Monsell, 1995). As a result, proponents of an endogenous task-set reconfiguration process have postulated that such endogenous control needs the presentation of the stimulus in order to complete reconfiguration, a so-called exogenous component (Rogers & Monsell, 1995).

There are explanations regarding switch costs that do not posit any form of additional reconfiguration or endogenous control on switch trials. Here the switch cost is thought to reflect the suppression of the other task set rule (Allport, Styles, & Hsieh, 1994). This proposal is termed the 'task-set inertia' (TSI) hypothesis and experimental evidence exists to provide support for it, much of it surrounding the 'residual component' of the switch cost. Allport et al. reasoned that the switch cost reflects the competition between relevant and irrelevant task sets with the implementation of a new task set requiring the inhibition of the previous task set. Evidence for such a proposal includes findings of asymmetric patterns of switch costs with it being more difficult to switch to the easier of two tasks in a Stroop task (Exp. 5, Allport et al., 1994). Allport et al.'s TSI hypothesis explains such results by positing that in order to perform the colour naming, it is necessary to strongly inhibit the predominant word reading task, with this inhibition persisting when a change to word reading is required. It is proposed that this persisting

inhibition causes the switch cost. Conversely, one does not need to inhibit the colour naming in order to read the word, therefore, there is no inhibition of colour naming and as a result less of a switch cost (Allport et al., 1994) (although see Yeung & Monsell (2003) for boundary conditions). Alternatively, residual switch costs could also be due to an inability to complete task-set preparation in advance of the stimulus (e.g., Lien, Ruthruff, Remington, & Johnston, 2005) or to occasional failures to engage in preparation (e.g., De Jong, 2000). To conclude, although debates exist regarding the role each process has in contributing to the switch cost, it is generally accepted that a combination of endogenous reconfiguration and task-set inhibition provide the most convincing explanations of existing data (Monsell, 2003).

1.7 Cognitive Control

In order for our behaviour to be efficient and successful, we need to configure our cognitive system appropriately. The term cognitive control refers to such configuration (Botvinick, Cohen & Carter, 2004). Our environment contains an almost endless number of potential sources of information that can influence behaviour at any given moment in time. These sources of information, whether relevant or irrelevant for our current behavioural goals, compete for attention. Following from this, an important area of investigation concerns the control exerted upon attentional selection toward environmental information. This is especially important when one considers that different potential sources often convey conflicting information. Traditionally, the idea of implementing control has often been conceptualised as providing top-down cognitive control over task-relevant processes, for example, the biasing of attention toward the task-relevant

stimulus (Shallice, 1988). However, the relationship between such top-down factors and stimulus driven bottom-up influences cannot be ignored. Within the lab environment, congruency tasks have proved useful in the investigation of cognitive control mechanisms.

1.7.1 Behavioural Investigations of Cognitive Control

1.7.1.1 RT Interference Tasks

Within an interference task, the relationship between stimulus and response features is varied. The task is congruent (or compatible; terms used interchangeably within the literature) when both the relevant and irrelevant stimulus dimensions indicate the same response while being incongruent otherwise. Several congruency paradigms exist and include the Stroop paradigm, the Eriksen flanker task and the Simon task.

1.7.1.1.1 Stroop Task

The Stroop task (Stroop, 1935; for a review see MacCleod, 1991) requires participants to pronounce the colour of the font a word is written in while inhibiting the pronunciation of the word itself. Thus, when the word 'BLUE' is written in green ink rather than blue ink ('BLUE'), there are two conflicting pieces of information; first, the colour of the ink (the relevant dimension in this case) and second, the word itself (the irrelevant dimension). As a result of our automatic tendency to read words, this situation results in a processing conflict. This conflict needs to be overcome when the task is to name the font colour in order for behaviour to be successful.

1.7.1.1.2 Simon Task

Another example of a congruency task is the Simon task (Simon, 1969). In a Simon task, participants have to respond to a stimulus that is presented to left and right screen locations with left and right button responses. Although the screen location is irrelevant to the task, RT is decreased when the stimulus location and response correspond (i.e. left responses to left presented stimuli) and is increased with non-corresponding screen location and response (i.e. left responses to right side presented stimuli) (for an overview, see Hommel & Prinz, 1997). LRP evidence has indicated an effect at the level of motor activation (e.g. Stürmer, Leuthold, Soetens, Schröter & Sommer, 2002).

1.7.1.1.3 Eriksen Flanker Task

A final example of a congruency task is the Eriksen Flanker task (Eriksen & Eriksen, 1974). In the Eriksen Flanker task, task irrelevant flankers surround a central target stimulus. These flankers can convey either the same response as the target (congruent condition) or a different response (incongruent condition). Typically RTs are elevated for incongruent trials compared to congruent trials (for an overview see Eriksen, 1995). Although the flankers are task-irrelevant, there is evidence that they receive a high amount of processing. Indeed, irrelevant flanker stimuli may even influence information processing up to the level of the motor cortex (e.g. Mattler, 2003).

1.7.1.2 Interference effects

The congruency effect (faster RTs for congruent trials compared to incongruent trials) in such tasks is often described in the literature as a failure of

selective attention, namely, an inability to inhibit the irrelevant stimulus dimension. Thus, in the Simon task, participants fail to inhibit the irrelevant stimulus location information; in the Stroop task, participants fail to ignore the irrelevant word meaning; while in the Eriksen flanker task, participants fail to ignore the information conveyed by the irrelevant flankers. However, it must be noted that an inability to inhibit the relevant stimulus dimension may not be the only cause of interference effects. For example, many connectionist models of congruency effects do not include direct inhibition of irrelevant information but rather, rely solely on different activation levels of relevant information (e.g. Yeung, Botvinick, & Cohen, 2004).

1.7.2 Congruency Effects and Cognitive Control

Several studies have demonstrated that such congruency effects are subject to control. For example, Logan and Zbrodoff (1979) found reduced interference in a Stroop task when incongruent trials were presented more often. Similarly, the Simon effect diminishes as the frequency of non-corresponding trials increases (e.g. Stürmer et al., 2002). Recently, it has been demonstrated that such congruency effects are dependent upon the congruency sequence of trials within the task with the effect being reduced (or absent) after an incongruent or non-corresponding trial (e.g. Stroop task - Kerns, Cohen, MacDonald, Cho, Stenger & Carter, 2004; Simon task - Notebaert, Soetens, & Melis, 2001; Flanker task - Gratton et al., 1992). The finding that the congruency effect is reduced after conflict trials is termed the Gratton effect (or conflict adaptation effect) (Gratton et al., 1992) and is calculated as (RTci - RTcc) - (RTii - RTic) where ci is a congruent trial followed by an incongruent trial, cc is two consecutive congruent

trials, ii is two consecutive incongruent trials and ic is an incongruent trial followed by a congruent trial. The conflict adaptation effect has become a popular measure of cognitive control processes. Such sequential dependencies of congruency effects suggest on-line control mechanisms that operate quickly on a trial-by-trial basis.

1.7.3 Errors and Cognitive Control

Within cognitive studies, error trials are often discarded from the analysis. However, within the area of cognitive control, the analysis of error trials has formed the basis for model development. When we make an error, our behaviour needs to be adjusted so that we reduce the likelihood of committing a subsequent error. For example, Rabbitt (1966) demonstrated that participants are aware of their errors and that these errors result in frustration for the participant. The response time following an error is increased. This is termed post-error slowing and is indicative of a more cautious response strategy indicating that the participant has learnt something from the error and has adjusted behaviour accordingly. In addition, participants will often automatically correct erroneous responses (without explicit instruction to do so) (Rabbitt, 2002). Such automatic error correction is explained in terms of continued processing of the stimulus. For example, when stimulus presentation time is increased, so is the rate of error correction. Rabbit and Vyas (1981) propose that such increased error correction is due to increased opportunity for further processing of the stimulus with increased presentation time. Such further processing of the stimulus after response execution is important for models of conflict monitoring (see below).

1.7.4 Recruitment of Control

As mentioned previously, the above conflict adaptation effect suggests control mechanisms adjust our behaviour on-line in order that processing difficulties are reduced and that behaviour is successful. Such behavioural adjustments can be thought of as the consequences of any control mechanisms that are exerted. However, what triggers the control mechanisms that cause the behavioural adjustments? As highlighted by Botvinick et al. (2001), just knowing the consequences of control mechanisms without any knowledge regarding their recruitment is problematic for any model of cognitive control as it relies on homunculi-based arguments. More specifically, a full model of cognitive control requires that the mechanisms that trigger control processes be fully specified and not just assigned to a system that "just knows" when they are needed.

1.7.5 Neuroimaging Investigations of Cognitive Control

Although the above behavioural findings have implications for models of cognitive control, it has been the dramatic increase in neuroimaging techniques that has had the most impact on model development.

1.7.6 Conflict monitoring model

The anterior cingulate cortex (ACC) is located on the medial surface of the frontal lobes and is believed to play a role in cognitive control (e.g. Posner & Di Girolamo, 1998). However, activation within the ACC has been observed in a wide variety of task types using a range of research techniques (for a review, see Cabeza & Nyberg, 1997). Thus, it has been difficult to attribute a common factor of control processes to the ACC.

Botvinick et al. (2001) divide the wide variety of tasks that show ACC activation into three behavioural contexts: first, tasks that require the overriding of a pre-potent response; second, tasks that require a selection of a response from several permissible responses (termed under-determined responding); and third, tasks where errors are committed (for an overview, see Botvinick et al., 2001). A common example of a task that requires participants to override an automatic response is the Stroop task (see above). For example, Pardo, Pardo, Janer, and Rachle (1990) demonstrated, via the use of positron emission tomography (PET), increased activation within the ACC during performance of incongruent relative to congruent Stroop trials. This finding of increased ACC activation for incongruent trials has been observed in a number of other studies. For example, Botvinick et al. (1999) and Casey et al. (2000) observed increased ACC activation for incongruent relative to congruent trials in the flanker task.

Studies associated with the commission of errors have also implicated a role for the ACC in error detection. Here the use of ERPs has been especially important with the discovery of a component, the error-related negativity (ERN), which accompanies the commission of an error (Gehring, Coles, Meyer, & Donchin, 1990; Hohnsbein, Falkenstein, & Hoorman, 1989). Dipole localisation of the ERN has indicated a source within the ACC (Dahaene, Posner, & Tucker, 1994). Such findings have led to the proposal that the function of the ACC is that of error detection. However, an ERN-like component has also been observed on correct trials involving conflict i.e. incongruent trials (Vidal, Hasbroucq, Grapperon, & Bonnet, 2000). Similarly, data from fMRI studies have identified regions within the ACC that demonstrate increased activity for error trials (e.g. Botvinick et al., 1999; Carter, Braver, Barch, Botvinick, Noll & Cohen, 1998).

Again, activations have also been demonstrated in situations where the participant responded correctly; more specifically, increased ACC activity in conditions likely to produce an error despite correct performance (Carter et al., 1998).

Botvinick et al. (2001) argue that the ACC activation within all tasks can be explained via the implementation of one cognitive process – the detection of conflict. For example, errors in speeded response tasks are often associated with fast responses that are made before complete stimulus evaluation has taken place (Gratton, Coles, Sirevaag, Eriksen & Donchin, 1988). After the error is made, continued evaluation of the stimulus can lead to activation of the correct response (Rabbitt & Vyas, 1981). Thus, the ACC activity indexed by the ERN probably does not reflect the detection of errors per se, but rather a special case of conflict detection, with errors being most likely to occur when conflict is high. The proposal that the ACC serves to detect situations of conflict differs from previous accounts that, although also emphasizing the importance of conflict, viewed the role as being more regulative in terms of conflict resolution (e.g. Pardo et al., 1990). Such conflict resolution has been termed 'selection-for-action' and describes processes related to the selection of environmental objects as targets for action. Botvinick et al. (1999) investigated ACC activity in terms of selection-for-action and conflict detection within a flanker task using fMRI. Incompatible trials within a flanker task involve both conflict (response indicated by the central target and the surrounding flankers) and selection-for-action (attending to the target while ignoring the flankers). Based on the Gratton effect in behavioural data, Botvinick et al. reasoned that incompatible trials differ in terms of selection-for-action and conflict depending upon the previous trial type. Specifically, an incompatible trial preceded by another incompatible trial involves increased

selection-for-action and thus, reduced flanker interference. Alternatively, an incompatible trial that is preceded by a compatible trial involves weak selection-for-action and thus, increased flanker interference. From this, Botvinick et al. hypothesized that, according to a conflict monitoring view of the ACC, highest activity would be observed when conflict is high (i.e. for incompatible trials that are preceded by compatible trials). The selection-for-action view predicts that highest ACC activity will be observed when there is increased selection toward the central target (i.e. for incompatible trials that are preceded by incompatible trials).

The results demonstrated that peak ACC activation was greater for incompatible trials that were preceded by compatible trials (high conflict) (see Figure 1.21).

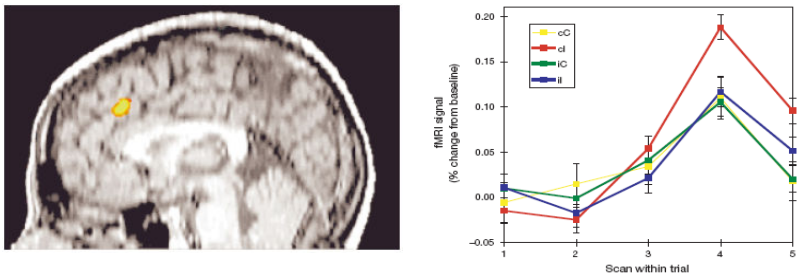


Figure 1.21: Above left shows location of greater activity for incompatible trials relative to compatible trials and also greater activity on ci than on ii trials. Above right shows the time course of ACC activation. ACC activation is greater on incompatible trials following compatible trials than on incompatible trials following incompatible trials (adapted from Botvinick et al., 1999).

From this it was proposed that the ACC is responsible for detecting conflict and relaying this information to brain areas responsible for implementing control rather than the ACC having any role in the resolution of conflict itself.

Botvinick et al. (2001) specified their conflict monitoring model

computationally via the use of a conflict monitoring unit which monitors the level of conflict among response units, effectively two such units if the choice task demands two different responses. To summarise, conflict is zero when only one unit is active while it rises when both units are active.

$$\text{Conflict} = -\sum_{i=1}^{N}\sum_{j=1}^{N} a_i a_j w_{ij},$$

Equation 1.1: Conflict is calculated as energy within the response layer. *a* is the activity within a unit, *w* is the weight between a pair of units with the subscripts *i* and *j* representing units of interest (Hopfield, 1982).

In addition to a unit measuring for the degree of conflict, a feedback-loop from the conflict monitoring unit to a group of context units was added (see Figure 1.22).

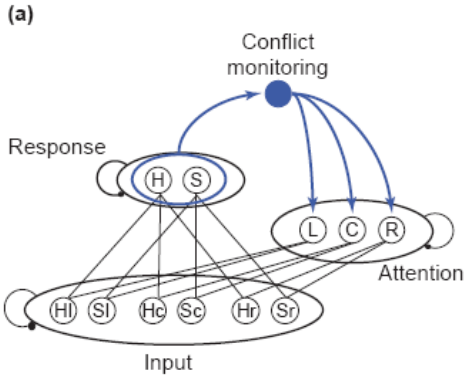


Figure 1.22: Conflict monitoring model of Botvinick et al. (2001) in relation to the flanker task.

The nature of these context units was determined by the task. For example, in the Stroop task, the units are task-related (colour vs. name) while in the flanker task, the units are related to spatial location (attention). This feedback-loop between the conflict monitoring unit and the context units determines the state of top-down control. The detection of conflict leads to strong control demands on the

subsequent trial while low conflict leads to a relaxation of control mechanisms. In a series of simulations, Botvinick et al. (2001) demonstrated the validity of the model by simulating effectively the Gratton effect in the flanker task (Simulation 2A), trial-type frequency effects in the Stroop task (Simulation 2B), and behaviour following the commission of an error (Simulation 2C).

A prediction of the conflict monitoring model is that conflict-related activity within the ACC should predict a subsequent increase in activity within the prefrontal cortex (PFC). This is based on the assumption that it is the PFC that is responsible for implementing control processes (Norman & Shallice, 1986). Also, anatomically, the ACC has extensive connections with areas within the PFC (Goldman-Rakic, 1987). This prediction was investigated, for example, by Kerns et al. (2004) using a variant of the Stroop task. As predicted by the conflict monitoring model, the fMRI data showed significantly less activity within the ACC for incompatible trials that were preceded by incompatible trials than for those preceded by compatible trials. In addition, greater ACC activity was associated with high adjustment trials and also increased activity within the prefrontal cortex in the subsequent trial (n + 1), findings all consistent with a conflict monitoring role for the ACC and not the allocation of control itself, a responsibility attributed to the PFC.

1.7.6.1 Source of Conflict

The above conflict control model is based mostly on studies that have concentrated on conflict in response selection. However, conflict can occur in a number of processing stages, for example, conflicts at the stage of stimulus encoding.

Stimulus conflict has been shown to have behavioural effects. Consider the case of a flanker task (letter stimuli) where, in addition to the standard compatible and incompatible trials, a third trial type where the distracters differ from the target but map to the same response (Eriksen & Schultz, 1979). Responses to this third type of trial are slower than responses to standard compatible trials, an effect that cannot be attributed to response conflict. Activation of the ACC in such trials would provide evidence that monitoring for conflict can occur prior to the response level.

Van Veen, Cohen, Botvinick, Stenger, and Carter (2001) using a version of the flanker task similar to that of Eriksen and Schultz (1979), observed ACC activity only in relation to response incongruent trials although stimulus incongruent trials reliably influenced RT leading to slower responses than fully compatible trials. This suggests that it is conflict at the response selection stage that drives the activity within the ACC. However, such a result may be task-dependent (van Veen & Carter, 2002) as ACC activity has been observed in tasks requiring no motor response, for example, in response to feedback about an error (e.g. Monchi, Petrides, Petre, Worsley, and Dagher, 2001).

Verbrugge, Notebaert, Liefooghe and Vandierendonck (2006) also investigated the effects of stimulus and response conflict. They demonstrated conflict adaptation after the removal of S-R repetitions. In terms of stimulus versus response conflict, the stimulus congruency effect was reduced after stimulus and response incongruent trials, whereas the response congruency effect did not depend on previous congruency.

The data regarding the contributions of stimulus and response conflict (and indeed, other sources of conflict) are inconclusive. This highlights an area of potential future development for the conflict monitoring model.

1.8 Complications for Conflict Adaptation: A bottom-up process?

Recently, the processes underlying the above behavioural conflict adaptation effects have been questioned. The debate involves alternative explanations that are not based on any form of top-down control (e.g. Hommel, Procter, & Vu, 2004; Mayr et al., 2003; Notebaert et al., 2001). Within such explanations, conflict adaptation effects are explained in terms of confounds related to certain sequence transitions being faster than others. For example, in a typical flanker task, a sequence analysis involves 16 possible trial transitions resulting from the factorial combination of the levels of current compatibility, previous compatibility and response sequence (see Table 1.1).

Table 1.1: Possible trial sequences within a typical flanker task (8 different sequences + a mirror reversal of each giving 16 in total).

Stimulus Array		**Sequence**	**Repetition vs. Change**	
n-1	n		Stimulus	Response
> > >	> > >	cc	YES	YES
> > >	< < <	cc	NO	NO
> > >	< > <	ci	NO	YES
> > >	> < >	ci	NO	NO
< > <	> > >	ic	NO	YES
< > <	< < <	ic	NO	NO
< > <	< > <	ii	YES	YES
< > <	> < >	ii	NO	NO

From these transitions, 50 % of cc and ii sequences involve stimulus-response (S-R) repetitions. In contrast, transitions from ic and ci sequences do not involve such S-R repetitions. It has been shown that trial sequences that involve exact S-R repetitions result in performance benefits (faster RTs). As a result, faster RTs for cc and ii may contribute to or explain the conflict adaptation effect (conflict adaptation effect = (RTci - RTcc) – (RTii – RTic)). Also, when considering the trial sequence ic or ci, 50 % involve response repetitions without a stimulus repetition. Such trial sequences are associated with increased RT compared to trials where both stimulus and response alternate. This effect can be explained with reference to Hommel's (1998) concept of event files in terms of a temporal binding process. On a given trial, a stimulus and response are temporarily associated with each other. If the next trial violates this association then the RT will be slowed. For example, consider a trial sequence where trial n-1 is congruent and trial n is also congruent. In this situation, fast RTs are expected as the trial sequence is either a complete repetition of both stimulus and response or a complete alternation with both stimulus and response changing. Alternatively, when trial n-1 is incongruent and trial n is congruent, either the stimulus changes or the response changes (not both), resulting in a breaking of the previously established association and as a result, increased RT. Thus, after congruent trials there is a large congruency effect. The increase in RT for such ic and ci trial sequences would further contribute to any conflict adaptation effect.

Mayr, Awh, and Laurey (2003) provide evidence for the above effect of bottom-up associate priming. Using a flanker task, it was demonstrated that when stimulus repetitions were removed from the analysis, there was no conflict adaptation effect after incongruent trials. Mayr et al. concluded that such conflict

adaptation effects can be explained without any reference to conflict-triggered regulation or a record of response conflict sequence but instead can be explained by stimulus-specific priming.

Nieuwenhuis, Stins, Posthums, Polderman, Boomsma and Geus (2006) argue that the task instructions emphasising accuracy in the Mayr et al. study may have resulted in low levels of processing conflict resulting in the reduced utilisation of control processes. In a series of experiments, Nieuwenhuis et al. explored the conflict adaptation effect under conditions of increased conflict (Exp 1. - flankers presented 100 ms before target; Exp 2. - emphasizing speed over accuracy), the generality of the effect (Exp 4. - letter stimuli replaced arrow stimuli) and in addition, an analysis of 892 previously collected data sets from a wide range of populations (Exp 5.). All effects were analysed separately for response change and repetition trials. Conflict adaptation effects were evident after response repetition trials; however, this was not the case for trials that involved a response change. This result supports the proposal by Mayr et al. (2003) that conflict adaptation effects can be explained in terms of associative priming. In addition, Nieuwenhuis et al. investigated the relative contributions to the conflict adaptation effect of exact S-R repetitions and impairments due to partial repetition trials across all 5 experiments. It was found that both contributed to the effect size. While there was a 13 ms benefit for cc trials and ii trial sequences, there was a 48 ms cost for ci and ic trial sequences.

Although the above studies of Mayr et al. (2003) and Nieuwenhuis et al. (2006) are consistent with an associative retrieval account of the conflict adaptation effect across a wide range of experimental task parameters, including differences in inter-trial interval, stimulus presentation duration, speed-accuracy

trade-off manipulations etc., other studies have still demonstrated conflict adaptation effects even when task repetition trials are removed (e.g. Kerns et al., 2004; Ullsperger, Bylsma, & Botvinick, 2005). Indeed, Ullsperger et al. even demonstrated such conflict adaptation effects after repetition trials were removed using a flanker task with the digits 1-9. The use of such a stimulus set increases the array size thus reducing the effect of trial-to-trial repetitions of stimulus attributes.

Kunde and Wühr (2006) examined the conflict adaptation effect within the prime-target paradigm. In the prime-target paradigm, task-relevant targets are preceded by task-irrelevant primes. The task irrelevant primes can either indicate the same response as the subsequent target or a different response. Compatible primes lead to superior performance while incompatible primes lead to performance costs. Using a four choice (left, right, up or down), combined with prime-target correspondence across both horizontal and vertical dimensions, Kunde and Wühr were able to investigate the conflict adaptation effect when neither stimulus nor response repeated (see Figure 1.23).

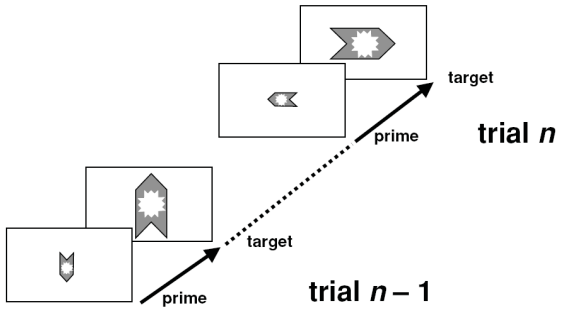


Figure 1.23: Prime-target paradigm across horizontal and vertical dimensions (from Kunde & Wühr, 2006).

An account based on bottom-up S-R repetitions predicts an absence of sequential effects while a general conflict detection mechanism still predicts sequential

effects across spatial dimensions. Additionally, it was investigated whether the size of the conflict effect resulted in changes in the conflict adaptation effect. This was done by varying the duration of the prime presentation. It was demonstrated that sequential effects were evident even when neither stimulus nor response repeated. Secondly, the size of the conflict adaptation effect was dependent upon the duration of the prime. With a longer prime duration the size of response conflict is increased resulting in greater conflict modulation. Such a result fits well with a conflict monitoring explanation while in contrast, explanations based solely upon bottom-up associative priming effects do not predict different modulations with differing degrees of conflict. Kunde and Wühr concluded, that at least for the prime-target paradigm, the conflict adaptation effect reflects an adaptation to conflict.

Conflict can occur in a number of situations. Thus, critical for a conflict monitoring account of sequential modulations is that it is the detection of conflict and not the actual event (e.g. stimulus location, prime compatibility, flanker compatibility) that determines the recruitment of control mechanisms. From this, it follows that if conflict triggers adjustment mechanisms independent of the source of conflict, then sequential effects might transfer between different types of interference tasks. To test this, Kunde and Wühr (2006) performed a second experiment where they compared sequential modulations across the prime-target paradigm when it was combined with a second source of interference. This was done by presenting the prime and targets at lateral locations to create Simon task interference (see Figure 1.24).

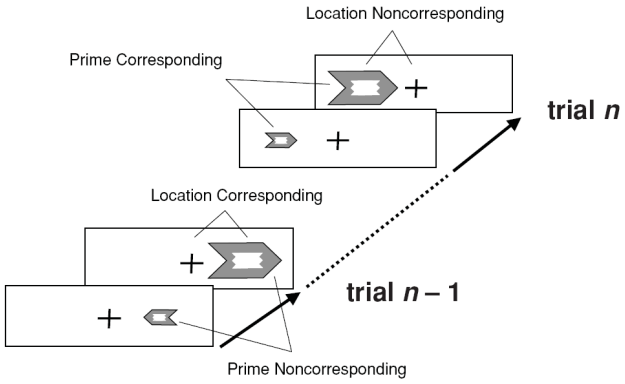


Figure 1.24: Prime-target paradigm combined with the Simon effect (from Kunde & Wühr, 2006).

The results showed that both types of interference affected performance and that each type also affected its equivalent correspondence effect sequentially. For example, a non-corresponding prime-target event reduced the prime-target correspondence effect in the subsequent trial while a spatially non-corresponding event (i.e. left stimulus location presentation requiring a right response) reduced the effect of spatial correspondence in the subsequent trial. In addition, such sequential modulations also occurred between correspondence effects. A spatially non-corresponding event reduced the prime-target correspondence effect on the subsequent trial while a non-corresponding prime-target event reduced the spatial correspondence effect (albeit in error rate only). Such results offer support to the idea that it is the general detection of conflict that leads to increased control (but see Notebaert & Verguts, 2008). In addition, such sequential modulation of correspondence effects between different types of correspondence is difficult to reconcile within a strict bottom-up view of S-R repetitions.

Notebaert, Gevers, Verbruggen, and Liefooghe (2006) examined the effects of S-R repetitions within a Stroop paradigm using three colours and three words. In addition, they introduced an RSI manipulation. It was hypothesised that

as top-down control requires time (Posner, 1980), time would be needed between the detection of conflict and the implementation of top-down control. Thus, the authors hypothesized that top-down attentional control would only be evident when a long enough time interval is available to allow such control to be implemented. The results showed that, for alternation trials, the conflict adaptation effect was only evident at the longer RSI level. However, for trials involving some form of repetition, the conflict adaptation effect was evident at both the short and long RSI levels.

The lack of conflict adaptation at the short RSI level fits well with the temporal aspects of top-down attentional control (e.g. Müller & Rabbitt, 1989). For example, in attentional cueing paradigms, the focus of attention cannot be altered when the interval between the cue and the to-be-attended-to stimulus is short (< 100 ms). The results of Notebaert et al. (2006) suggest the importance of both top-down configuration processes and bottom-up processes. Importantly, it is the time available to implement top-down control that determines its contribution.

The above findings regarding the conflict adaptation effect are inconclusive at best. While bottom-up S-R repetition appears to be important in explaining some aspects of the conflict adaptation effect (e.g. Mayr et al. (2003), such arguments cannot explain the effect entirely. There are two main reasons for this; the first being studies demonstrating the conflict adaptation effect in the absence of S-R repetitions (e.g. Kerns, 2004) and second, the vast quantity of neuroimaging data demonstrating increased activation to the conflict within the ACC across a number of tasks makes for a convincing argument. This is especially true in the case of Kerns et al. (2004) where ACC activity can predict subsequent behavioural adjustments and level of activity within the PFC.

Experiments reported in Chapters 3 and 4 examine aspects of the conflict adaptation effect. Although the rationale for the experiments adopts a top-down control view, the analysis will not ignore the issues of S-R repetitions discussed above. As a result, data analysis will consider the conflict adaptation effect separately for repetitions and alternations.

1.9 ERP Procedural details

The forthcoming experimental chapters involve the recording of ERPs. With this procedure, several technicalities need to be reported. In order to avoid repetition for each of the experiments reported, general details will be reported now. Any deviation from the standard details reported here will be highlighted where appropriate as will details only relevant for the experiment reported e.g. analysis epoch.

1.9.1 Electrophysiological Recordings

Electroencephalographic (EEG) activity was continuously recorded from 70 Ag/AgCl electrodes over midline electrodes Fpz, AFz, Fz, FCz, Cz, CPz, Pz, POz, Oz, and Iz, over the left hemisphere from electrodes IO1, Fp1, AF3, AF7, F1, F3, F5, F7, F9, FC1, FC3, FC5, FT7, C1, C3, C5, M1, T7, CP1, CP3, CP5, TP7, P1, P3, P5, P7, P9, PO3, PO7, O1, and from the homologue electrodes over the right hemisphere using a BIOSEMI Active-Two amplifier system. Two non-standard electrodes (PO9 and P10) were positioned at 33 % and 66 % of the M1-Iz distance (M2-Iz for the right hemisphere). EEG and EOG recordings were sampled at 256 Hz. Vertical electroocular (vEOG) and horizontal EOG (hEOG) waveforms were calculated offline as follows: vEOG(t) = Fp1(t) minus IO1(t) and hEOG(t) = F9(t) minus F10(t). Trials containing blinks were corrected using a

dipole approach (BESA, 2000) and EEG activity was re-referenced to average reference. EEG and EOG activity was filtered (band-pass 0.01-40 Hz, 6 db/oct), averaged time-locked to stimulus onset (S-locked data) or to response onset (R-locked data). In addition, trials with non-ocular artifacts (e.g. drifts, channel blockings, EEG activity exceeding ±75 μV) were discarded.

1.9.2 LRP

For each participant and each experimental condition, the ERP at recording sites ipsilateral to the response hand was subtracted from the ERP at homologous contralateral recording sites. For each homologous electrode site-pair (e.g., C3/C4) the resulting difference waveform was averaged across hands to eliminate any ERP activity unrelated to hand-specific motor activation (cf. Coles, 1989). The term LRP will be exclusively used to describe activity at the C3/C4 site. LRP onsets were measured and analysed by applying the jackknife-based procedure suggested by Miller, Patterson, and Ulrich (1998) and Ulrich and Miller (2001). Statistical analyses were performed by means of Huynh-Feldt corrected repeated measures analyses of variance (ANOVA). The *F*-values were corrected as follows: $F_C = F/(n-1)^2$, where F_C denotes the corrected *F*-value and n the number of participants (cf. Ulrich & Miller, 2001). For all post-hoc comparisons the level of significance was Bonferroni adjusted with the alpha level per measure set at $p = .05$.

Chapter 2. Task Switching and Perceptual Processing

2.1 Introduction

Task switching has become an important paradigm for the study of executive control (Monsell, 2003). Oriet and Jolicoeur (2003) sought to determine how demanding the process of switching between different tasks is. They assumed that the process of changing task set (task-set reconfiguration) occupies central resources and examined if such a process constituted a strict bottleneck in terms of early perceptual processing. Oriet and Jolicoeur (2003) proposed that even early stimulus processing is deferred until the completion of the controlled reconfiguration process. That is, reconfiguration acts as a *hard bottleneck* during which no other processing is possible.

The present experiments attempt to test the claim of Oriet and Jolicoeur (2003) by using measures of ERPs in addition to behavioural measures. However, it is first necessary to introduce the position of Oriet and Jolicoeur and the experimental logic adopted by them, namely, the use of *locus of slack logic*.

2.1.1 Locus of Slack Logic

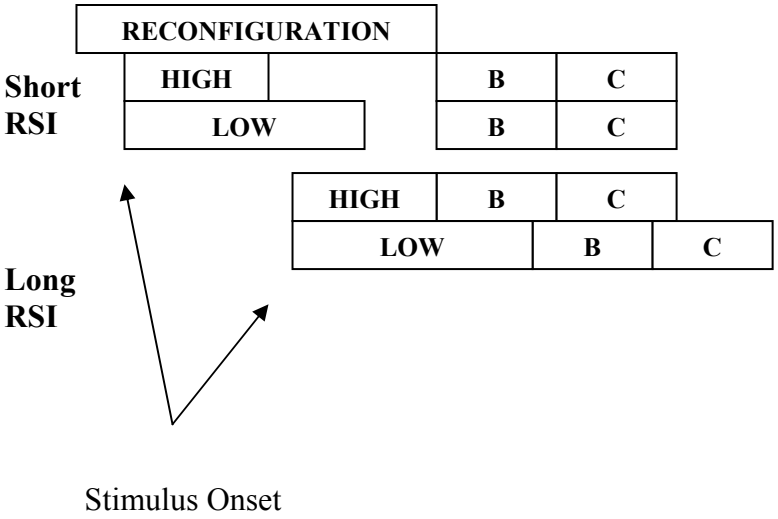
Oriet and Jolicoeur (2003) investigated whether any perceptual processing could take place in parallel with an assumed stage of task-set reconfiguration. In order to accomplish this, they adopted the locus of slack logic developed by Pashler and colleagues (1989, 1994). This method has frequently been used in relation to the psychological refractory period (PRP) paradigm. In the PRP paradigm, two targets (T1 and T2) are presented in succession at varying stimulus onset asynchronies (SOAs) with a speeded response required to both targets. Typically it is found that response time to T2 increases as the SOA between the

targets decrease. What is of most interest with regards to the present context in terms of serial/parallel models and processing bottlenecks is that increasing the perceptual processing difficulty of the second target produces less of a reaction time difference as SOA decreases (i.e. an underadditive interaction between the T2 manipulation and decreasing SOA) (Pashler, 1994; Pashler & Johnstone, 1989). Such a result is explained by proposing that while demanding central processing stages of T1 occupy central resources, central stages of T2 must wait for the central stages of T1 to be completed creating a period of 'cognitive slack'. This period of cognitive slack can absorb the effect of certain early manipulations, for example, effects of perceptual contrast, a manipulation that affects the duration of pre-bottleneck processes (Pashler, 1984; Pashler & Johnstone, 1989). As the SOA between T1 and T2 decrease, there is a greater period of cognitive slack and thus, differences in processing time of a pre-bottleneck process will have less of an effect on RT to T2.

The locus of slack logic was used by Oriet and Jolicoeur (2003) and was adapted to the task-switching paradigm. They reasoned that the process of task-set reconfiguration requires access to central resources and as a result, may constitute a hard bottleneck, creating a period of cognitive slack similar to the situation in the PRP paradigm. By postulating an additional stage of endogenous task-set reconfiguration on task switch trials compared to task repetition trials, Oriet and Jolicoeur (2003) investigated whether any additional processing could take place in parallel with such a task set reconfiguration stage. They compared a parallel and sequential model of task-set reconfiguration (see Figure 2.1). They expected that if parallel perceptual processing is possible during task set reconfiguration then there should be an underadditive effect of an early perceptual manipulation

(e.g. contrast) for switch trials but not for repetition trials. This underadditive effect results from the period of cognitive slack created by the postponement of stages requiring central resources due to task-set reconfiguration for switch trials at short RSIs. At long RSIs, no period of cognitive slack (or a reduced period of cognitive slack) exists because task-set reconfiguration is complete (or partially complete) before the next stimulus presentation. There is no hypothesised stage of endogenous reconfiguration for repetition trials and thus, no period of cognitive slack available to absorb the contrast manipulation. Alternatively, if task set reconfiguration imposes a hard bottleneck on perceptual processing, the effect of the contrast manipulation should be additive for both switch and repetition trials even for short RSIs. This result would support a sequential model of task set reconfiguration. Using a variation of the alternating runs paradigm of Rogers and Monsell (1995), Oriet and Jolicoeur (2003) compared two digit classification tasks (parity and magnitude). Stimuli were presented in either high or low contrast. The contrast manipulation was blocked as was the manipulation of response stimulus interval (RSI). In two experiments, Oriet and Jolicoeur (2003) found no underadditive effect of contrast with decreasing RSI and concluded that "reconfiguration of task set acts as a hard functional bottleneck, preventing even very early processes from being carried out" (p. 1048).

PARALLEL MODEL



SEQUENTIAL MODEL

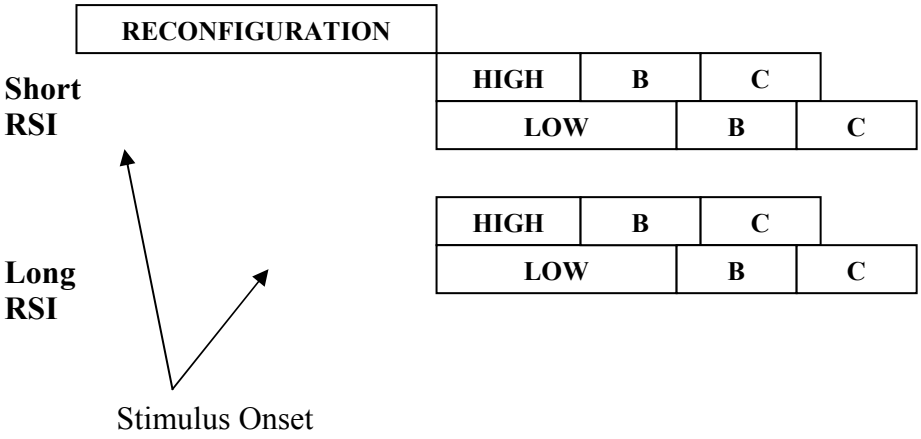


Figure 2.1: Predictions of parallel and serial models for switch trials. Hypothesised stage of task set reconfiguration proposed to create a bottleneck that delays stages requiring access to central resources (stages B+C). If perceptual processing is possible during this reconfiguration (parallel model), at short RSIs a period of "cognitive slack" is created that is able to absorb the extra processing required for the low contrast stimuli. At long RSIs reconfiguration will be complete (or at least partially complete) and thus, there will be no period of cognitive slack in which the effect of the contrast manipulation can be absorbed into. The parallel model predicts an underadditive effect of stimulus contrast with decreasing RSI. If perceptual processing is not possible during reconfiguration, every process will be delayed until reconfiguration is complete thus not allowing for any period of cognitive slack. As a result the effect of the contrast manipulation will be evident at both long and short RSIs. It is important to note that both models make the same predictions of additive effects of stimulus contrast on RT for repetition trials as no reconfiguration stage is assumed for repetition trials.

The claim of Oriet and Jolicoeur (2003) is strong, especially when such results are considered alongside those from other dual-task paradigms like the PRP paradigm. Within the PRP paradigm, such contrast manipulations demonstrate underadditivity with decreasing SOA (Oriet & Jolicoeur, 2003; Experiment 3, adapted PRP paradigm to match parameters of Task Switch Experiments 1-2). Such results suggest that parallel perceptual processing with central processing is not possible within a task-switching paradigm but is within a PRP paradigm. Why this should be is unclear. Oriet and Jolicoeur offer speculative explanations, for example, increased task difficulty can cause a deferment of early perceptual processing (Fera, Jolicoeur, & Besner, 1994) and a move from parallel to serial processing with a task-set change possibly being sufficient to cause this (Luria & Meiran, 2005). However, there is no explanation as to why this deferment does not occur within the PRP paradigm.

Previous ERP studies of task switching have identified task-switch specific ERP activity. For example, Wylie, Javitt and Foxe (2003) found that the first differential activity associated with task switching was found approximately 220 ms over posterior parietal areas, whereas the first differential activity over frontal areas was 200 ms later. No differential activity between switch and repetition trials was observed earlier than 220ms (i.e. P1/N1 components). Similarly, Karayanidis, Coltheart, Michie and Murphy (2003) observed differential activity (termed switch related negativity) that emerged after stimulus onset with this differential negativity peaking earlier as RSI increased. However, again such differential activity was not within the time range of the p1/N1 components and in addition, was focused over frontal electrode sites. The above studies suggest that the process of switching task affects processes after stimulus

identification with no difference evident for early visual components. However, the study of Wylie et. al. used a cueing paradigm where, in addition to the cue, the sequence was predictable with the interval between trials being 2 seconds. Although RSI was manipulated within the Karayanidis et. al study, the shortest RSI used was 150 ms. It is possible that if perceptual processes are delayed due to task-set reconfiguration, this will only be evident when using an extremely short RSI condition like that used by Oriet and Jolicoeur (2003). Thus, previous ERP studies of task-switch processes have not demonstrated differences in P1/N1 latency as a function of trial type.

2.1.2 Experimental Aims

The aim of the present set of experiments was to investigate the findings of Oriet and Jolicoeur (2003) and to provide a more thorough investigation of the locus of the processing bottleneck by using ERPs in addition to RT measures. As mentioned in the introduction, there are many advantages of using additional ERP measures to answer cognitive based questions, the biggest advantage being the continuous measure of processing from stimulus to response. The peak latency of early visual P1 and N1 components provides a measure of the time course of initial perceptual processing. Latencies of early visual potentials (P1, N1) have been demonstrated to sensitively reveal effects of the stimulus contrast (e.g. Jaskowski, Pruszewicz, & Swidzinski, 1990; Jentzsch, Leuthold, & Ulrich, 2007; Vaughan, Costa, & Gilden, 1966). Measuring peak P1 and N1 latency provides an additional measure that is specifically related to perceptual stages of information processing. It is predicted that if switching task delays perceptual processing, then there should be a delay in peak P1 and N1 latency depending upon whether the

trial involved a switch or a repetition. Thus, peak P1 and N1 latency offers an additional measure upon which a thorough test of the claim of Oriet and Jolicoeur can be made.

In addition, analysis of the LRP will offer insight into the locus of interference within a task-switching paradigm. For example, if task switching affects early pre-motor processes such as stimulus identification then there should be an effect within the stimulus-locked LRP interval. Alternatively, if task switching affects only relatively late motor processes there should be identical stimulus-locked LRP intervals but different response-locked intervals. Using identical LRP logic, Hsieh and Liu (2005) investigated the stage within information processing that is affected by task switching. They demonstrated that RT and the S-LRP interval were longer for switch relative to repetition trials. This finding suggests that task switching affects processing stages before response selection is completed.

The above measures, when compared across conditions identical to those used by Oriet and Jolicoeur (2003) and combined with RT measures, will offer additional insights into whether a sequential or parallel (or an alternative/combination) model is most appropriate for task-switch reconfiguration and perceptual processing. To summarise, it is hypothesised that if task-set reconfiguration does indeed delay perceptual processing, we should observe additive effects of contrast with decreasing RSI and delayed early visual components for task-switch trials relative to task repetition trials.

In addition, P1 and N1 peak amplitudes will also be analysed. This analysis is motivated by the possibility of an attention-related effect on task performance in the alternating runs paradigms (cf. Oriet & Jolicoeur, 2003). For

example, when the RSI is short, participants might not have shifted spatial attention to the location of the forthcoming stimulus, whereas this would not apply to long RSI conditions. P1 and N1 amplitude sensitively reflect such differential attentional effects (e.g., Mangun & Hillyard, 1991, see 1.4.6). Also, the possible modulation of the contrast effect on P1 and N1 amplitude could reveal further insights about modulations of perceptual processing as a function of the task sequence. For example, P1 and N1 are usually of larger amplitude for high than low contrast stimuli (e.g. Johannes, Münte, Heinze, & Mangun, 1995; Jentzsch et al., 2007).

2.2 Task Switch Experiment 1

2.2.1 Method Section

2.2.1.1 Participants

20 University of Glasgow students, ages 18 to 28 (mean 21.85, 10 Male) participated in exchange for pay (scale of £6 per hour). Ethical approval for the study was obtained from the University of Glasgow Ethics committee and all participants gave informed consent. All participants reported normal or corrected to normal vision. 18 of the participants were right handed as assessed by the Edinburgh handedness inventory (Oldfield, 1971) (Mean handedness score = 70.5).

2.2.1.2 Apparatus & Stimuli

Stimuli consisted of the digits 1 through to 9, excluding 5. All stimuli were presented in white on a black background using a standard computer monitor (15 inch). Stimuli were presented at random without replacement using Experimental Run Time System (BeriSoft Cooperation, 1987-2001). For half of

the trials the presented digit appeared in high contrast (white) while for the other half, low contrast (grey). Digits were presented in one of four locations in a quadrant defined by a 2x2 matrix centred at fixation. The distance between any two vertically or horizontally adjacent locations was 2.5 degrees of visual angle. A tone of 3000 Hz was presented in response to error trials. Participants sat approximately 80 cm from the screen with each digit subtending 0.6 degrees of visual angle in width and 0.7 degrees of visual angle in height.

2.2.1.3 Design

Contrast (high vs. low) was blocked with 4 blocks of high contrast trials and 4 blocks of low contrast trials for each of the 5 levels of RSI (50, 200, 400, 800 and 1200 ms). RSI was also blocked with each participant completing 8 blocks at each level of RSI. The order of blocks was balanced using a Latin square so that across 10 participants every level of RSI would follow every other level of RSI twice. Two practice blocks, one for high contrast and one for low contrast stimuli consisting of a sequence of 20 trials were completed before each level of RSI. Data from the practice blocks was not analysed. Following the practice blocks, participants completed 8 blocks of 68 trials for each level of RSI. Within each sequence of 68 trials, the first four trials were treated as a warm-up and thus, were discarded from the analysis. In total, 2740 trials were presented in one session.

2.2.1.4 Procedure

Participants were tested in a single session that lasted approximately 70 minutes experiment time and 20 minutes preparation/de-briefing time. Each sequence of trials began with an instruction screen informing participants of the

RSI and contrast level. This remained until the participant initiated the sequence by pressing the appropriate key. The quadrant appeared in the centre of the screen followed by the first digit at an interval equal to the block RSI.

The experimental task was to decide if the presented stimulus was odd or even (parity task - P) or greater or less than 5 (magnitude task - M). The experiment adopted the alternating runs paradigm of Rogers and Monsell (1995). In this paradigm the participant performs two tasks, task P and task M in the sequence PPMMPPMM. Thus, task repetitions and task switches occur alternately and equally allowing a direct comparison between the two types of trials. The task on the current trial was cued spatially. The parity task was to be completed when the digit was presented in one of the two upper row quadrants and the magnitude when the digit was presented in one of the two lower row quadrants (See Figure 2.2). The first digit was always presented in the upper left quadrant and as a result, the first trial was always a parity task followed by a task repetition. Digit location was always predictable with the next digit location being the quadrant clockwise to the current digit location.

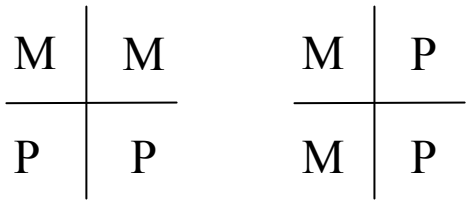


Figure 2.2: Spatial cuing of task where M indicates magnitude task and P indicates parity task. Left hand side indicates task mapping used in Experiment 1 with repetition trials occurring in the horizontal direction and switch trials in the vertical direction. Right hand side indicates the additional task mapping used in Experiment 2 in order to balance for task switch direction (horizontal vs. vertical).

For one half of participants the left response key represented odd and less than 5, while the right response key represented even and greater than 5. For the other

half the left response key represented odd and greater than 5, while the right response key represented even and less than 5. An error tone of 3000 Hz was sounded for a duration of 150 ms after making an error. This could either be an incorrect response or a response not occurring within the 2000 ms response interval. This was followed by an inter-stimulus interval not equal to that of the current block RSI but to a constant 1500 ms across all RSI blocks. This was done to allow full recovery from the error and thus, reduce the possibility of an error in the next trial. All error trials were removed from the analysis. Trials following an error were also removed, a necessary step resulting from the 1500 ms RSI for error trials. In addition to the longer RSI after error trials, it is unclear what task-set the participant had configured for the error trial and thus, it is unclear whether the current correct trial reflects a task switch or a task repetition (Oriet & Jolicoeur, 2003). In addition, trials following an error are thought to represent a special case where there is a reliable slowing of response speed. This is referred to as post-error slowing (e.g Rabbitt, 1966). Between blocks, feedback was given regarding accuracy and mean response time for that individual block.

2.2.2 Data Analysis

2.2.2.1 Behavioural Data

Trials with an incorrect response on either the preceding trial or the current trial, with RT < 150 ms (anticipation) or RT > 2,000 ms (miss) were excluded from the data analysis.[1] Overall this resulted in the exclusion of 9 % of trials. Practice trials and warm-up trials were also removed from the analysis resulting in 46107 observations remaining in the analysis. In addition, trials with EEG or EOG

[1] RTs greater than 2000 ms were infrequent (< 1 % of trials) and thus, their exclusion is unlikely to affect the reported results (c.f. Ulrich & Miller, 1994). Such a process is adopted for all subsequent RT analyses.

artifacts were excluded from the EEG data analysis. All signals were averaged separately for experimental conditions. Statistical analyses were performed by means of Huynh-Feldt corrected repeated measures analysis of variance (ANOVA). For the analysis of RT and error rate, the within-subject variables were RSI (50, 200, 400, 800 vs. 1200 ms), trial type (switch vs. repetition), and contrast (high vs. low) resulting in a 5x2x2 ANOVA.

Mirroring the analysis of Jolicoeur & Oriet (2003), a single value corresponding to the difference in underadditivity on task switch trials and task repetition trials was computed and tested against zero using a one-sample *t*-test. This single value was computed in one of three ways. For the first test, the average effect of contrast (low - high) over the two longest RSIs was subtracted from the average effect of contrast at the three shortest RSIs. This was done separately for task switch trials and task repetition trials resulting in two values. The final value was calculated by subtracting the value obtained for the switch trials from the value obtained from the repetition trials with a positive value indicating more underadditivity of the contrast effect on task switch trials than on task repetition trials. The second test repeated this procedure with the omission of the intermediate RSI level (400 ms). The third test considered only the longest and shortest RSI levels.

2.2.2.2 ERP data

A computerized peak-picking procedure was employed to measure the peak latency in the averaged ERP waveforms at a time point relative to stimulus onset of maximum positive or negative activity within specific time intervals and at specific electrode sites. In order to investigate the effect task switching has on

visual processing, the time of peak amplitude of waveforms within the time frame 110-180 ms for the P1 component and 150-250 ms for the N1 component at electrode site PO8 was calculated. PO8 was used as the P1 and N1 components were largest at this site. Peak P1 and N1 latency was calculated for all conditions and was analysed by means of a repeated measures ANOVA with the within participant factors RSI (50, 200, 400, 800 vs. 1200 ms), trial type (switch vs. repetition), and contrast (high vs. low).

2.2.3 Results

2.2.3.1 Behavioural Data

2.2.3.1.1 RT

Condition means for RT are displayed in Figure 2.3. The results replicate the main findings from the task switching literature. First, repetition trials were faster than switch trials resulting in a significant switch cost (622 vs. 806 ms); F (1, 19) = 130.6, MSE = 25949.0, $p < .0001$, producing average switch costs of approximately 185 ms. This switch cost was reduced from 240 ms to 154 ms as preparation time increased as indicated by the significant Trial Type x RSI interaction; F (4, 76) = 8.29, MSE = 3033.88, $p < .0001$. The contrast manipulation produced a significant main effect with responses to high contrast stimuli being faster than responses to low contrast stimuli (695 vs. 733 ms); F (1, 19) = 75.79, MSE = 1897.5, $p < .0001$. Importantly, no significant three-way interaction between RSI, trial type and contrast was found; F (4, 76) = 1.35, MSE = 345.82, $p > .05$. This indicates that the size of the contrast effect was not different across RSI depending upon whether the trial was a switch or repetition.

The two-way interaction between switch and contrast and the two-way interaction between RSI and contrast were also not significant (all *F*s ≤ 1).

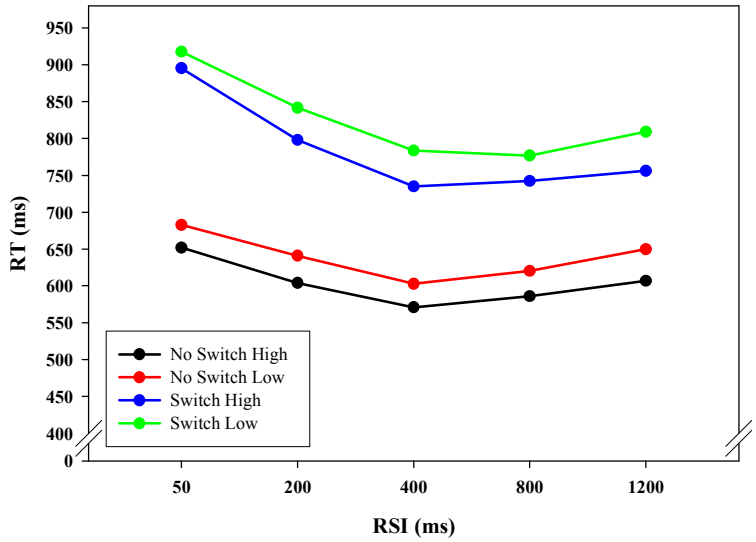


Figure 2.3: Mean RT per condition as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 200, 400, 800 vs. 1200 ms).

Table 2.1 shows the average difference in underadditivity of the contrast effect between task switch trials and task repetition trials for the three tests. Test 1 (three shortest vs. two longest RSI levels) yielded a difference of -1.5 ms, which was not significantly different from zero, $t(19) = -0.18$, $p > .05$. For Test 2 (two shortest vs. two longest RSI levels), 5.6 ms more underadditivity was observed on task switch trials than on task repetition trials. Again, this difference was not significant; $t(19) = 0.58$, $p > .05$. Finally, Test 3 (shortest vs. longest RSI level) revealed 17.7 ms more underadditivity on task switch trials than on task repetition trials, however, this difference was not reliably different from zero, $t(19) = 1.5$, $p = .15$.

Table 2.1: Positive values indicate more underadditivity on task switch trials than on task repetition trials. Test 1 compared the average effect at the two longest RSI levels (800 & 1200 ms) compared to the three shortest (0, 200, & 400 ms). Test 2 compared the two longest with the two shortest RSI levels. Test 3 compared only the longest and shortest RSI levels.

	Contrast Effect	*p* value
Test 1	-1.48	.86
Test 2	5.56	.57
Test 3	17.65	.15

2.2.3.1.2 Error Rate

Mean error rates are displayed in Figure 2.4. Error data were submitted to the same ANOVA procedure described above for the RT data. Error rates were generally low and ranged from 3 to 9 % across experimental conditions. Again, replicating previous results from the task switching literature, there was a main effect of trial type with more errors being made on task switch trials than on task repetition trials (6.6 vs. 3.7 %); F (1, 19) = 38.31, MSE = 41.82, $p < .0001$. There was a significant main effect of RSI with more errors being made at shorter RSI levels (6.4 % for the shortest RSI lowering to 4.7 % for the longest RSI); F (4, 76) = 3.2, MSE = 37.8, $p < .05$. The significant Trial Type × RSI interaction, F (4, 76)= 2.9, MSE = 14.6, $p < .05$, indicated a decrease of error rate with decreasing RSI for switch trials, whereas, for repetition trials, error rate remained relatively constant across all RSI levels. The main effect of contrast was not significant; F (1, 19) = 1.8, MSE = 10.66, $p > .05$, indicating that participants did not make more errors with low contrast stimuli than with high contrast stimuli. No other effects were significant (all Fs < 1.28, ps > .28).

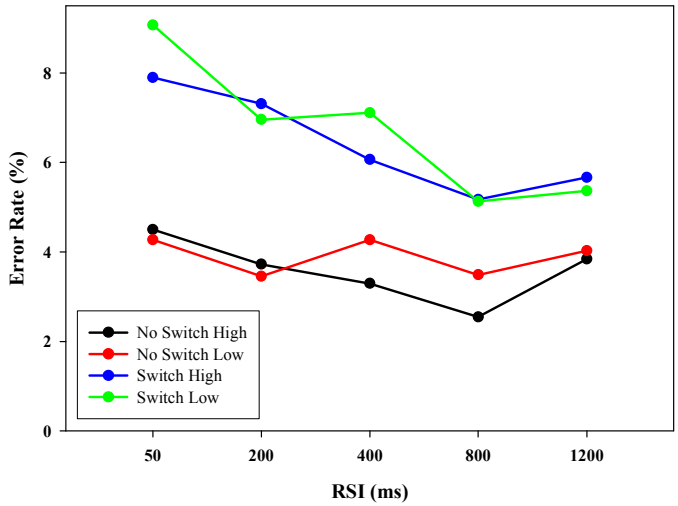


Figure 2.4: Mean error rate per condition as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 200, 400, 800 vs. 1200 ms).

2.2.3.2 ERP Results

Grand averaged waveforms for each condition over the right parieto-occipital scalp site (PO8) are displayed in Figure 2.5.

2.2.3.2.1. Latency measures

2.2.3.2.1.1 P1 Component

There was a significant main effect of contrast, with mean peak latency for high contrast stimuli being 127 ms compared to 160 ms for low contrast stimuli; $F(1, 19) = 283.08$, $MSE = 391.25$, $p < .0001$. There was a main effect of RSI with mean peak P1 latency for the five levels of RSI from the shortest to longest being 151 ms, 146 ms, 141 ms, 138 ms and 140 ms respectively; $F(4, 76) = 9.14$, $MSE = 237.80$, $p < .001$.

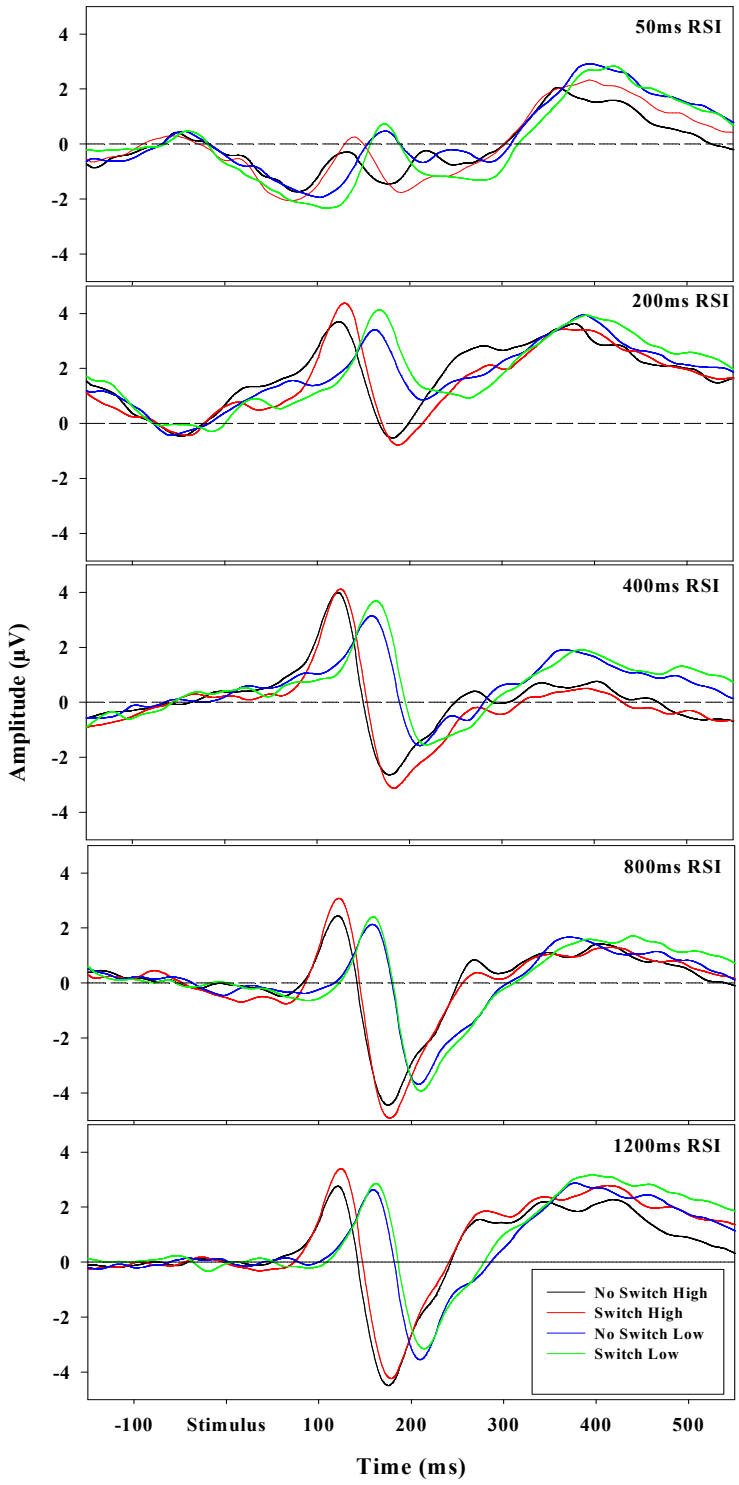


Figure 2.5: P1 and N1 components as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 200, 400, 800 vs. 1200 ms).

There was a main effect of trial type with mean peak P1 latency for task repetition trials being slightly shorter than mean peak P1 latency for task switch trials (142 vs. 145 ms); $F(1, 19) = 10.37$, $MSE = 116.8$, $p < .01$. A two-way interaction between RSI and contrast was observed indicating that the contrast effect increased with increasing RSI; $F(4, 76) = 3.57$, $MSE = 162.96$, $p < .05$. The contrast effect for the five levels of RSI from the shortest to longest was 24 ms, 37 ms, 36 ms, 34 ms and 36 ms, respectively. Importantly, like the RT data, the three-way interaction between RSI, contract and trial type was not significant indicating that the size of the contrast effect was not different across RSI depending upon whether the trial was a switch or repetition; (STAT VALUES). All other interactions did not reach significance.

2.2.3.2.1.2 N1 Component

There was a significant main effect of contrast with peak N1 latency being shorter for high than low contrast stimuli (187 vs. 211 ms); $F(1, 19) = 40.43$, $MSE = 1403.50$, $p < .0001$. There was a main effect of trial type with peak N1 latency being shorter for task repetition trials than task switch trials (196 vs. 201 ms); $F(1, 19) = 9.80$, $MSE = 273.86$, $p < .01$. There was a main effect of RSI with mean peak N1 latency for the five levels of RSI from the shortest to longest being 190 ms, 205 ms, 204 ms, 197 ms and 197 ms respectively; $F(4, 76) = 4.04$, $MSE = 725.8$, $p < .05$. There was a two-way interaction between RSI and contrast indicating that the contrast effect increased with increasing RSI; $F(4, 76) = 7.64$, $MSE = 519.66$, $p < .001$. The contrast effect for the five levels of RSI from the shortest to longest was 1 ms, 22 ms, 24 ms, 36 ms and 35 ms, respectively. Again the three-way interaction between RSI, contrast, and trial type was not significant; (STAT VALUES).

2.2.3.3 Participant Subset Analysis

Due to the short RSI levels (50 - 400 ms) there was strong component overlap between response processes of the previous trial and the early visual components of the current trial. As a result it was difficult to determine precisely the peak latency of the P1 and N1 components for a certain subset of participants whose P1 and N1 components were less well defined. Thus, in order to validate the results, an identical analysis to that performed above was performed on a subset (n=10) of participants whose averaged waveforms showed well defined P1 and N1 peaks determined by visual inspection. Grand average waveforms for each condition are displayed in Figure 2.6.

2.2.3.3.1 P1 component

As in the earlier analysis there was a main effect of contrast with peak P1 latency to high contrast stimuli being earlier compared to low contrast stimuli (124 vs. 154 ms); F (1, 9) = 278.48, MSE = 164.95, $p < .0001$. In addition to the main effect of contrast, both main effects of RSI and trial type were also significant. In terms of RSI, peak P1 latency for the shortest to longest RSI was 149 ms, 141 ms, 136 ms, 134 ms and 134 ms, respectively; F(1, 9) = 3.84, MSE = 418.36, $p <.05$. For the main effect of trial type, peak P1 latency for task repetition trials was shorter compared to task switch trials (137 vs. 141 ms); F(1, 9) = 10.22, MSE = 95.97, $p <.05$. More importantly, this analysis replicated the RSI × Contrast interaction, F (4, 36) = 4.48, MSE = 107.10, $p <.05$, which indicated a smaller contrast effect at the short RSI (18 ms) as compared to the other RSIs (33-34 ms). No other effects were significant (all Fs < 1).

2.2.3.3.2 N1 component

There was a significant main effect of contrast with peak N1 latency for high contrast trials being 188 ms compared to 210 ms for low contrast trials; $F(1, 9) = 15.65$, $MSE = 15.65$, $p < .01$. No other main effects or lower level interactions were significant. However, trial type did demonstrate a trend. Peak N1 latency for task repetition trials was 196 ms compared to 202 ms for task switch trials; $F(1, 19) = 4.35$, $MSE = 438.56$, $p = .07$.

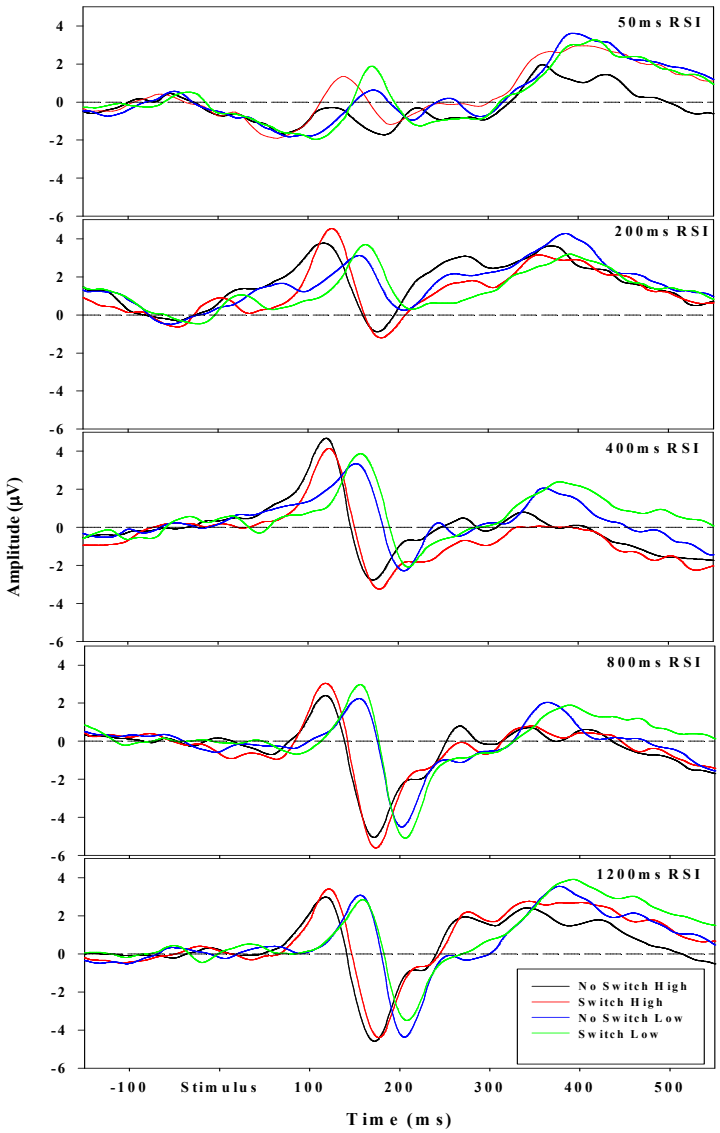


Figure 2.6: P1 and N1 components as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 200, 400, 800 vs. 1200 ms) for a subset (n=10) of participants.

2.2.3.4 Amplitude measures

Measurement of ERP peak amplitudes was complicated by the fact that particularly the ERP waveforms in the three shortest RSI conditions (50, 200, and 400 ms) were subject to overlapping brain activity related to the previous response and preparatory activity (cf. Figure 2.5). That is, in the 50-ms RSI there was a negative-going trend in the pre-stimulus interval, whereas in the 200-ms and 400-ms RSI a positive-going trend was evident. Therefore, ERP waveforms were high-pass filtered (2 Hz, 6 dB/oct) to reduce the influence of component overlap like in the study of Vogel and Luck (2000). The filtered ERP waveforms depicted in Figure 2.7 (PO7) and Figure 2.8 (PO8) indeed show a reduction of overlapping brain activity, although a residual negative trend is still apparent in the 50-ms RSI condition.

2.2.3.4.1 P1

P1 peak amplitude was larger over the right than the left parieto-occipital electrode (3.2 vs. 2.4 μV); F (1, 19) = 11.52, MSE = 12.07, $p < .01$, for high contrast than low contrast stimuli (3.0 vs. 2.6 μV); F (1, 19) = 14.16, MSE = 1.84, $p < .01$, and for task switch than task repetition trials (2.9 vs. 2.7 μV); F (1, 19) = 9.68, MSE = 1.09, $p < .01$. The switch effect was present only at the right but not the left parieto-occipital electrode (0.4 vs. 0.0 μV) as indicated by the significant Trial Type x Electrode interaction; F (1, 19) = 8.50, MSE = 1.32, $p < .01$. The main effect of RSI; F(4, 76) = 32.61, MSE = 6.71, $p < .001$, was due to a smaller P1 amplitude at the 50-ms RSI (0.7 μV) as compared to the other RSI conditions (about 3.3 μV). The RSI × Contrast interaction was significant; F(4, 76) = 6.50, MSE = 0.64, $p < .001$, due to the absence of the contrast effect at the shortest 50-

ms RSI (-0.13 μV) compared to the other RSIs (about 0.5 μV). All other interactions did not approach significance.

2.2.3.4.2 N1

The analogous analysis of N1 peak amplitude revealed a main effect of contrast; F (1, 19) = 5.31, MSE = 6.66, $p < .05$, indicating a larger N1 for high contrast than low contrast stimuli (-3.0 vs. -2.6 μV). The main effect of RSI was also significant; F(4, 76) = 11.22, MSE = 11.17, $p < .001$, due to a smaller N1 amplitude at the 50-ms and 200-ms RSI (about –2.3 μV) as compared to the other RSI conditions (about -3.3 μV). The RSI × Contrast interaction was significant; F(4, 76) = 6.50, MSE = 0.64, $p < .001$, due to the absence of the contrast effect at the shortest 50-ms RSI (-0.13 μV) compared to the other RSIs (about –3.8 μV). All other main effects or interactions did not approach significance.

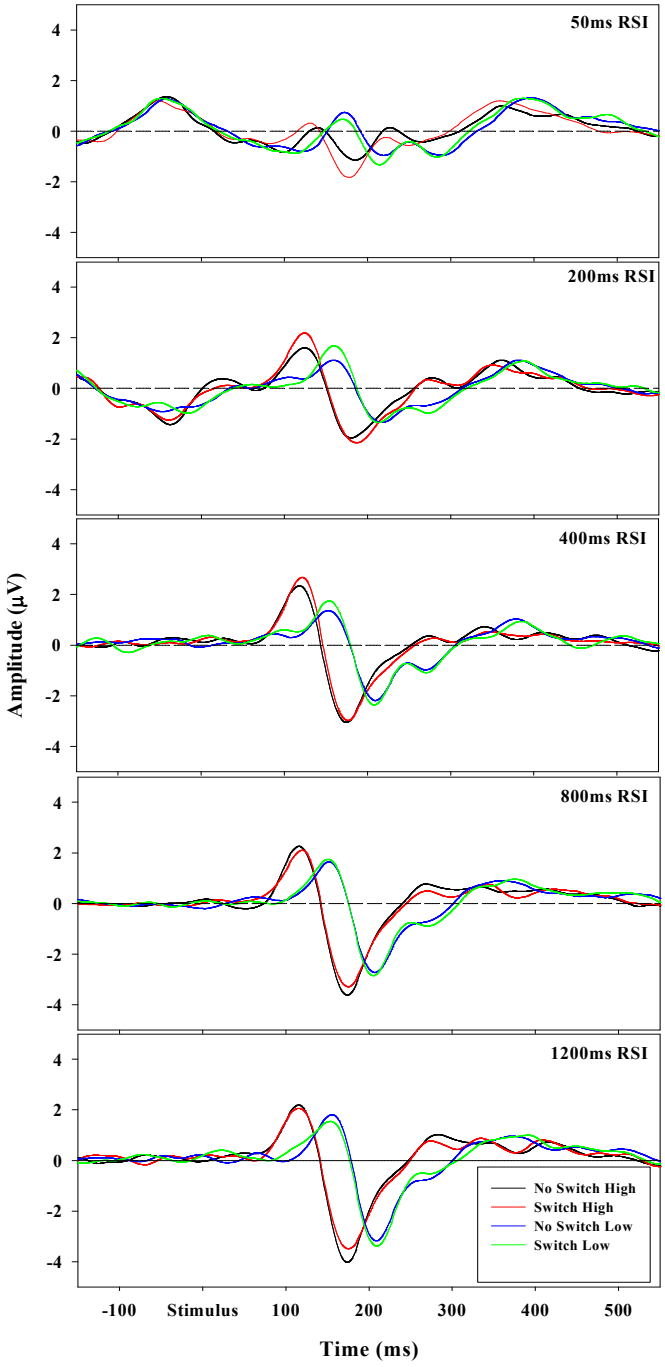


Figure 2.7: P1 and N1 components as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 200, 400, 800 vs. 1200 ms) at PO7 with additional high-pass filter for amplitude analysis.

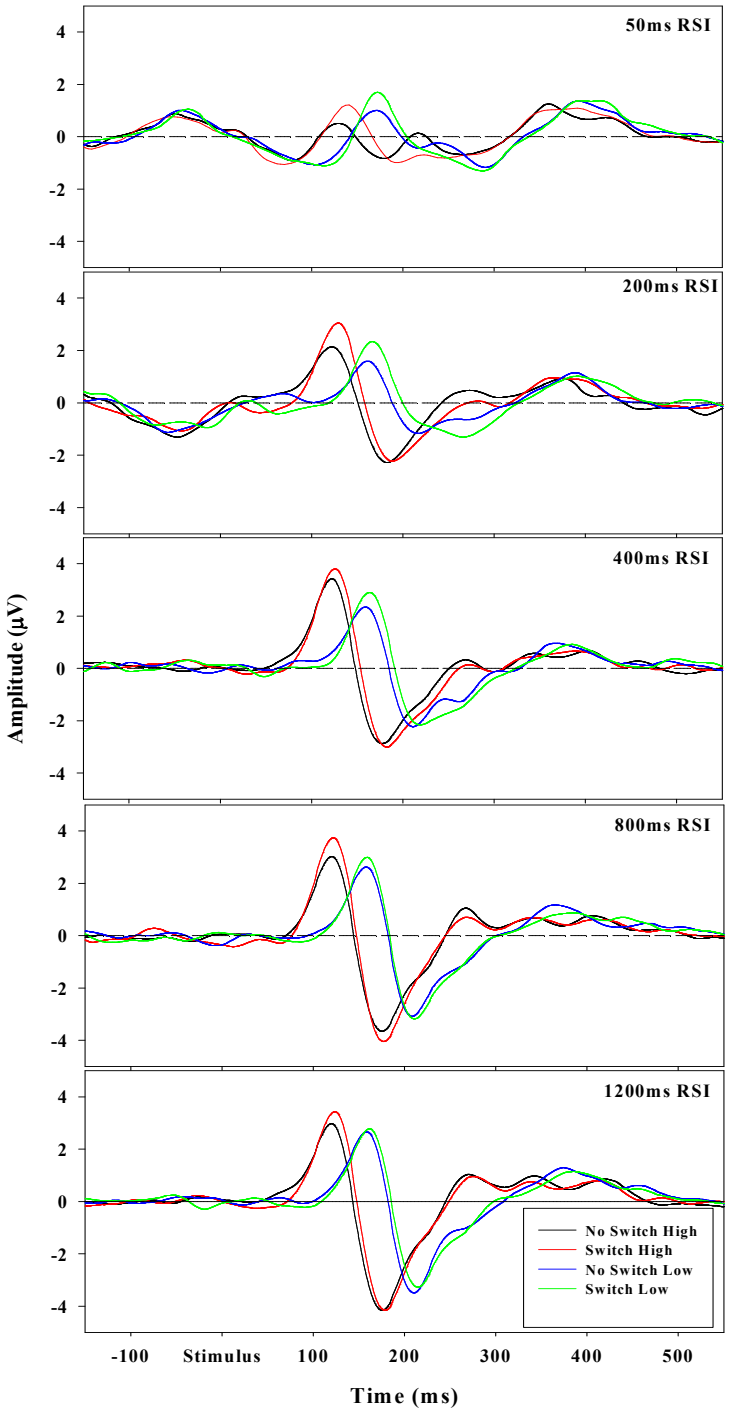


Figure 2.8: P1 and N1 components as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 200, 400, 800 vs. 1200 ms) at PO8 with additional high-pass filter for amplitude analysis.

2.2.4 Discussion

The present experiment investigated the process of task switching and whether a process of task-set reconfiguration constitutes a hard bottleneck delaying even the earliest stage(s) of processing (e.g. perceptual processing) as claimed by Oriet and Jolicoeur (2003). This claim was based on the findings of additive effects of a contrast manipulation and decreasing RSI. The present experiment adopted the same alternating runs paradigm of Rogers and Monsell (1995) while manipulating stimulus contrast and RSI interval. It was predicted that, if the reconfiguration process leads to a delay of perceptual processing, as proposed by Oriet and Jolicoeur, additive effects of the contrast manipulation would be observed with decreasing RSI. Such a result would add support to the claim of Oriet and Jolicoeur. Alternatively, if the process of task set reconfiguration does not constitute a hard bottleneck in terms of perceptual processing, then the effect of contrast should be underadditive with decreasing RSI for task switch trials only. This result would question the claim of Oriet and Jolicoeur and the sequential model of task set reconfiguration adopted. In addition, observing underadditive effects of contrast with decreasing RSI independent of whether the trial involved a switch or a repetition would question the need for an additional reconfiguration stage that is specific to task switch trials only. To extend the study of Oriet and Jolicoeur, ERPs were recorded in addition to overt measures of behaviour. Measuring peak P1 and N1 latency provides an additional measure that is specifically related to perceptual stages of information processing. It was predicted that if switching task delays perceptual processing, then there should be a delay in peak P1 and N1 latency depending upon whether the trial involved a switch or a repetition. Thus, peak P1 and N1 latency offers an

additional measure upon which a thorough test of the claim of Oriet and Jolicoeur can be made.

First, consideration will be given to the behavioural data. When considering the data in terms of basic task switching effects, the paradigm was effective. Participants demonstrated elevated RTs and error rate for switch trials relative to repetition trials. The average switch cost observed (~ 185 ms) is comparable to other studies that have used the alternating runs paradigm (e.g. Oriet & Jolicoeur, 2003; Rogers & Monsell, 1995). In addition, this 'switch cost' was reduced as RSI (or preparation time) increased, indicating that participants did use the RSI interval to prepare for the forthcoming task. However, the switch cost was still evident at the longest RSI (~ 154 ms). This portion of the switch cost is termed the 'residual switch' cost (see 1.6.2) and again, replicates previous findings (e.g. Oriet & Jolicoeur, 2003; Rogers & Monsell, 1995).

The contrast manipulation was also effective. Participants responded slower to low contrast stimuli than high contrast stimuli. In terms of the research question of interest, there was no three-way interaction between RSI, trial type, and contrast. Thus, the size of the contrast effect was not different across RSIs depending upon whether the trial was a switch or a repetition. In addition, the two-way interaction between trial type and contrast was not significant, indicating that the size of the contrast effect was not different across different RSI levels. This lack of a three-way interaction supports the conclusions of Oriet and Jolicoeur (2003) that the process of task set reconfiguration delays even early perceptual processing. However, numerically there was more underadditivity on task switch trials than on task repetition trials for the shortest RSI level. Although this difference was approximately 17 ms, it did not reach significance. Oriet and

Jolicoeur observed 11.8 ms more underadditivity on task switch trials when considering the two extreme RSIs, but similarly to the present experiment, this was not significant.

Regarding the ERP data, peak P1 latency was affected by the contrast manipulation, peaking approximately 33 ms earlier for high contrast than low contrast trials. This result was replicated for N1 latency with a contrast effect of approximately 24 ms. Peak P1 latency decreased as RSI increased and was also slightly shorter for task repetition trials than task switch trials. Again, this result was replicated for N1 latency. Importantly, RSI interacted with contrast with a larger effect of contrast at the longer compared to shorter RSI levels for both P1 and N1 latencies, albeit, to a larger extent for the N1 component. The RSI x Contrast interaction was not influenced by Trial Type, thus, the underadditivity observed for the contrast effect with decreasing RSI for both P1 and N1 latencies is independent of trial type.

An analysis on a subset of participants whose P1 and N1 components showed well defined peaks at the short RSIs was conducted in order to validate the above findings. Again, both P1 and N1 peaked earlier for high compared to low contrast stimuli. P1 analysis also replicated the main effect of trial type with peak P1 latency being shorter for task repetition trials than task switch trials, although this difference was extremely small (~ 4 ms). Importantly, the two-way interaction between RSI and contrast was replicated, again indicating a smaller effect of contrast on P1 latency with decreasing RSI.

The above behavioural and ERP data provide additional insights into the claim of Oriet and Jolicoeur (2003) that the process of switching task constitutes a hard bottleneck even for early perceptual processing. The behavioural data shows

a lack of a three-way interaction between trial type, contrast and RSI, indicating that the effect of contrast across RSI levels was similar for both task switch and task repetition trials. This replicates the finding of Oriet and Jolicoeur. As the amount of underadditivity appeared to be numerically larger on switch trials compared to repetition trials, an increased sample size may be appropriate to provide a statistically more powerful test. Although this is a possibility, Oriet and Jolicoeur's sample size was greater (n=80, Exp 1) and they also failed to observe a significant three-way interaction between trial type, contrast and RSI.

The ERP data showed that peak P1 and N1 latencies were earlier for task switch trials than task repetition trials suggesting some form of delay for perceptual processing depending upon trial type. However, this effect was relatively small (< ~ 5 ms) and was not influenced by RSI or contrast. Like the RT data, there was a lack of a three-way interaction between RSI, trial type and contrast. The two-way interaction between RSI and contrast was significant, in the analysis of P1 and N1 latencies. This underadditive effect of contrast with decreasing RSI independent of trial type provides additional data that cannot be reconciled within the sequential and parallel models of task switching considered by Oriet and Jolicoeur (2003), because task set reconfiguration is proposed to be specific to task switch trials and hence, underadditivity should not be observed across task repetition trials. As the P1 and N1 latency findings contrast with the RT results somewhat, one might wonder whether measurement problems of peak latencies at the short RSIs due to overlap with response-related components contributed to this discrepancy.

Additional analysis looking at the amplitude of the P1 and N1 components investigated possible effects of attention toward different spatial locations within

the 2x2 array. At the short RSI, participants may not have enough time to foveate or attend to the location of the next digit. If reconfiguration takes place before eye movements toward the target and if target processing requires that the target be foveated, this may be an explanation as to why there is a delay of perceptual processing at the short RSI. Although the influence of eye movements and target foveation was investigated by Oriet and Jolicoeur (2003, Exp 3) who concluded that target processing can begin even when the target is unlikely to be foveated to, an analysis of P1 and N1 amplitude will provide additional insights. For both P1 and N1 amplitude, there was a significant main effect of contrast with larger peak amplitudes for high contrast trials than low contrast trials. Again, for both P1 and N1 amplitude, there was a significant main effect of RSI with smaller peak amplitudes for the shorter compared to longer RSI levels. RSI and contrast interacted for both P1 and N1 amplitude and indicated an absence of any contrast effect at the short RSI compared to the longer RSI levels.

To summarise the above results, a lack of a three-way interaction between trial type, RSI and contrast in terms of RT replicated the results of Oriet and Jolicoeur (2003). Thus, the parallel model of task-set reconfiguration and perceptual processing considered is not supported from the behavioural results. Like the RT data, the ERP data for peak P1 and N1 latency did not demonstrate a significant Trial Type x RSI x Contrast interaction. However, the ERP data did show a significant interaction between RSI and contrast independent of trial type. This underadditivity of the contrast effect with decreasing RSI is difficult to reconcile with the conclusions of Oriet and Jolicoeur and also within the sequential and parallel models of task switch reconfiguration considered. As reconfiguration is proposed to be specific to task switch trials only, the

underadditivity observed for task repetition trials cannot be explained by parallel perceptual processing and task set reconfiguration.

2.3 Task Switch Experiment 2

The goal of the second experiment was to replicate the first while reducing the number of conditions (RSI levels) in order to improve data quality and also allow calculation of the LRP (see 1.4.9). In addition, Experiment 2 allows additional balancing considerations to be controlled for. For example, the switch direction (horizontal vs. vertical) and order of contrast conditions are considered and controlled for within Experiment 2.

2.3.1 Method Section

2.3.1.1 Participants

24 University of Glasgow students, aged 18 to 37 years (mean age 24.2 years, 10 male) participated in exchange for pay (scale of £6 per hour). Ethical approval for the study was obtained from the University of Glasgow Ethics committee and all participants gave informed consent. All participants reported normal or corrected to normal vision. 22 of the participants were right handed as assessed by the Edinburgh handedness inventory (Oldfield, 1971) (Mean handedness quotient = 77.9).

2.3.1.2 Apparatus & Stimuli

Stimuli and apparatus were identical to that described in Experiment 1.

2.3.1.3 Design

Contrast (high vs. low) was blocked with 6 blocks of high contrast trials

and 6 blocks of low contrast trials for each of the 3 levels of RSI (50 ms, 300 ms & 1000 ms). RSI was blocked with each participant completing 12 blocks at each level of RSI. The order of blocks was balanced using a Latin square in that across 12 participants every level of RSI would follow every other level of RSI twice. Two practice blocks (one for high contrast and one for low contrast stimuli) consisting of a sequence of 20 trials were completed before each level of RSI. Data from the practice blocks were not analysed. Following the practice blocks, participants completed 12 blocks of 68 trials for each level of RSI. Within each sequence of 64 trials, the first four trials were treated as a warm-up and thus, were discarded from the analysis. In total, this resulted in 2488 trials in one session.

2.3.1.4 Procedure

Participants were tested in a single session that lasted approximately 95 minutes (75 minutes experiment time and 20 minutes preparation/de-briefing time). The procedure was identical to that of Experiment 1 except for the following changes. Experiment 2 balanced for task switch direction (vertical vs. horizontal). For half of the participants, the odd/even task was to be completed when the digit was presented in one of the two upper row quadrants and the greater/less than task when the digit was presented in one of the two lower row quadrants. For the other half of the participants, the odd/even task was to be completed when the digit was presented in one of the two left column quadrants and the greater than/less than task when the digit was presented in one of the two right column quadrants. Thus, whether the task switch or task repetition occurred after a horizontal digit shift or a vertical digit shift was balanced. The first digit shift was always a repetition trial and as a result of the balanced location cueing

above, for half of the participants the first digit was presented in the upper left quadrant while for the other half, it was presented in the upper right (see Figure 2.2). Digit location was always predictable with the next digit location being the quadrant clockwise from the current digit location.

Four stimulus-response mappings were used in Experiment 2. For one quarter of participants the left response key represented odd and less than 5, while the right response key represented even and greater than 5. For one quarter the left response key represented odd and greater than 5, while the right response key represented even and less than 5. For one quarter the left response key represented even and less than 5, while the right response key represented odd and greater than 5. For one quarter the left response key represented even and greater than 5, while the right response key represented odd and less than 5. All other procedures were identical to Experiment 1.

2.3.2 Data Analysis

2.3.2.1 Behavioural Data

Data analysis mirrored that of Experiment 1 with the exception of the number of RSI levels. Error trials, trials following errors and outliers were removed from the analysis. Overall this resulted in the exclusion of 12.5 % trials. Practice trials were also removed from the analysis resulting in 55296 observations remaining in the analysis. The remaining RT data were averaged for each participant and condition with the means being submitted to a repeated measures analysis of variance (ANOVA). The within participant variables were RSI (50, 300, and 1000 ms), trial type (switch vs. repetition), and contrast (high vs. low) resulting in a 3x2x2 ANOVA.

2.3.2.2 ERP data

The ERP data were analysed in an identical way to that of Experiment 1. This involved a computerized peak-picking procedure to measure the peak latency of the early visual components. Specifically, the times of peak amplitude of the waveforms within the time frame 110-180 ms for the P1 component and 150-250 ms for the N1 component at electrode sites PO8 were calculated. This was computed for all conditions and was analysed by means of a repeated measures ANOVA with the within participant factors being RSI (50, 300 vs. 1000 ms), trial type (switch vs. repetition), and contrast (high vs. low).

LRP onsets were measured and analysed by applying the jackknife-based procedure suggested by Miller et al. (1998) and Ulrich and Miller (2001). That is, 24 different grand average LRPs for each of the experimental conditions were computed by omitting from each grand average the data of another participant. LRP onsets were determined in the waveform of each grand average. S-LRP onsets were measured in waveforms aligned to a 100-ms pre-stimulus baseline, at the point in time when LRP amplitude exceeded -0.5 μV. Onsets of LRP-R waveforms, which were aligned to a 100-ms baseline starting 500 ms before response onset, were obtained using a relative LRP amplitude criterion (50 %) (cf. Miller et al., 1998; see 1.9.2). Onsets were measured within a 300 ms wide time-span that preceded response execution.

2.3.3 Results

2.3.3.1 Behavioural Data

2.3.3.1.1 Reaction Time

Condition means for the RT data are displayed in Figure 2.9. In accordance with Experiment 1, the results replicate the main findings from the task switching literature. Repetition trials were faster than switch trials (637 vs.

847 ms); F (1, 23) = 119.48, MSE = 26580.73, p < .0001. This switch cost was reduced as preparation time increased, resulting in a significant two-way interaction between trial type and RSI; F (2, 46) = 13.88, MSE = 3907.16, p < .0001. The switch cost for the shortest RSI was 254 ms compared to a switch cost of 217 ms for the intermediate RSI and 159 ms for the longest RSI. The contrast manipulation produced a significant main effect of contrast, with responses to high contrast stimuli being faster than responses to low contrast stimuli (731 vs. 754 ms); F (1, 23) = 8.78, MSE = 4313.49, p < .01.

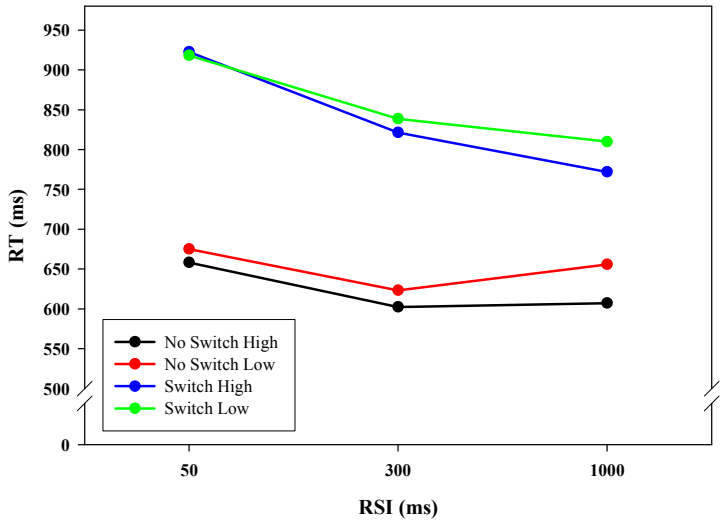


Figure 2.9: Mean reaction time per condition as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 300 vs. 1000 ms)

Importantly, no significant three-way interaction between RSI, trial type, and contrast was found; F (2, 46) = 1.66, MSE = 280.54, p > .05, indicating that the size of the contrast effect was not different across RSI depending upon whether the trial was a switch or repetition. However, the two-way interaction between RSI and contrast, independent of trial type, was significant; F (2, 46) = 8.0, MSE = 1061.86, p < .01. The size of the contrast effect was reduced for both switch and repetition trials as RSI decreased. For the longest RSI the contrast effect was 43

ms compared to 20 ms for the intermediate RSI and 6 ms for the shortest RSI. The two-way interaction between trial type and contrast was also significant; $F(1, 23) = 4.63$, $p < .05$. There was a 17 ms contrast effect for switch trials and a 29 ms contrast effect for repetition trials.

The average difference in the amount of underadditivity of the contrast effect between task switch trials and task repetition trials was compared between the shortest RSI level and the longest RSI level. There was approximately 10 ms more underadditivity on task switch trials than on task repetition trials, yet this difference was not significant; $t(23) = 1.07$, $p > .05$. When comparing the amount of underadditivity on task switch and task repetition trials between the shortest and intermediate RSI levels, there was 17.5 ms more underadditivity on task switch trials. Again this difference was not significant; $t(23) = 1.46$, $p > .05$.

2.3.3.1.2 Error Rate

Mean error rates are displayed in Figure 2.10. Error rates were generally low and ranged from 3 to 10 % across experimental conditions. As in Experiment 1, there was a main effect of trial type with more errors being made on task switch trials than on task repetition trials (8.84 vs. 4.6 %); F (1, 23) = 68.15, MSE = 37.94, $p < .05$. There was no significant main effect of RSI ($F < 1$) demonstrating that overall participant error rate was not affected by RSI level. The main effect of contrast was not significant; F (1, 23) = 1.74, MSE = 89.93, $p > .05$, indicating that participants did not make more errors with low contrast stimuli than with high contrast stimuli. There were no significant two-way or three-way interactions.

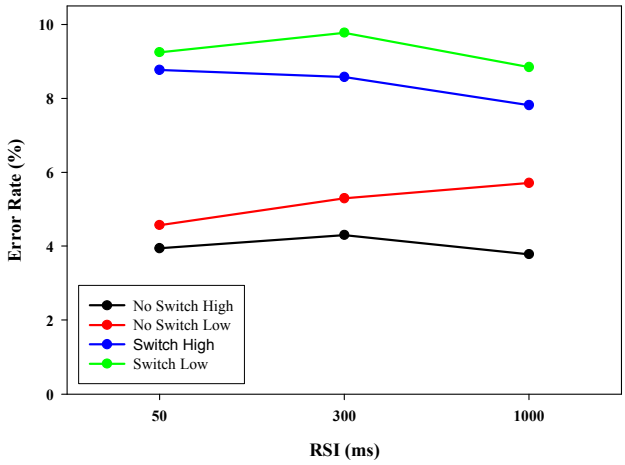


Figure 2.10: Mean error rate per condition as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 300 vs. 1000 ms).

2.3.3.2 ERP Results

2.3.3.2.1 P1 component

Grand averaged waveforms for each condition are displayed in Figure 2.11. There was a significant main effect of contrast with mean peak latency for high contrast stimuli being 130 ms compared to 162 ms for low contrast stimuli; $F(1, 23) = 261.66$, $MSE = 286.69$, $p < .0001$. The main effects of trial type and RSI did not reach significance. A two-way interaction between RSI and contrast was observed. The contrast effect increased from the shortest RSI (23 ms) to the intermediate RSI (34 ms) and the longest RSI (39 ms); $F(2, 46) = 6.37$, $MSE = 237.61$, $p < .01$. Importantly, the three-way interaction between RSI, contrast, and trial type was not significant indicating that the size of the contrast effect was not different across RSI depending upon whether the trial was a switch or repetition. All other interactions did not reach significance.

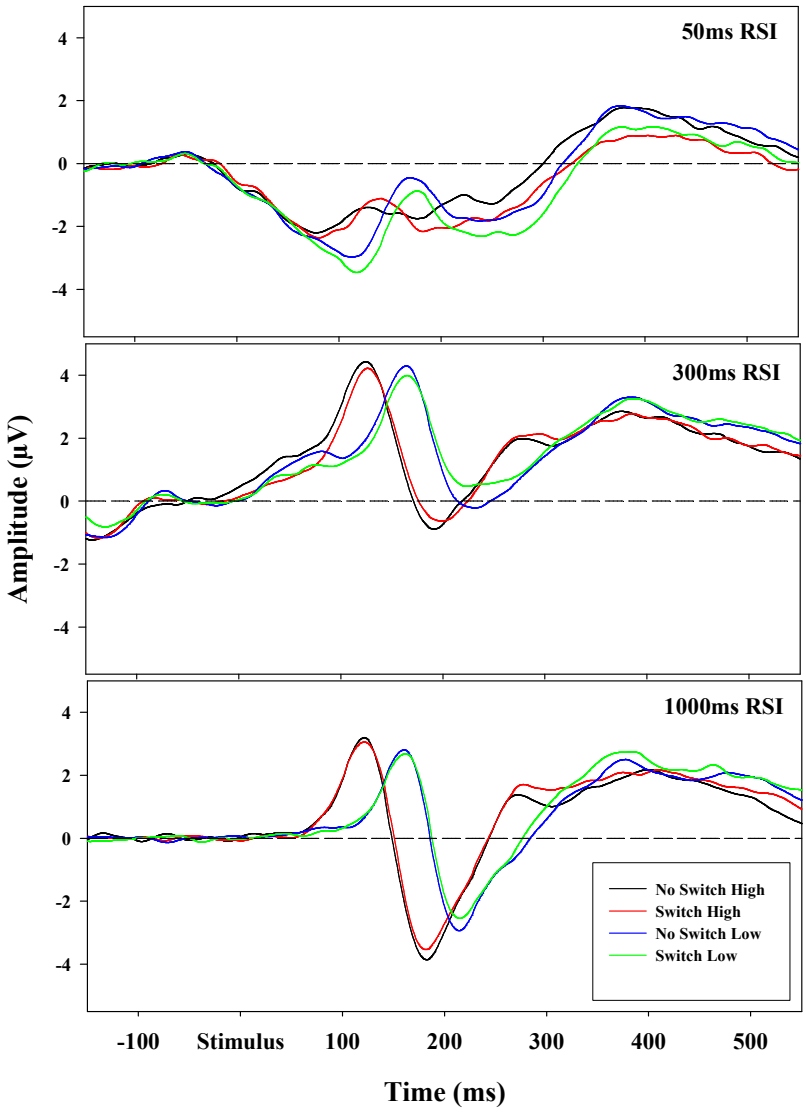


Figure 2.11: P1 and N1 components as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 300 vs. 1000 ms).

2.3.3.2.2 N1 component

There was a significant main effect of contrast with peak N1 latency for high contrast trials being 193 ms compared to 209 ms for low contrast trials; $F(1, 23) = 16.96$, $MSE = 1262.29$, $p < .001$. No other main effects were significant. There was a significant two-way interaction between RSI and contrast. The contrast effect was 0 ms at the shortest RSI, 18 ms at the intermediate RSI and 32 ms at the longest RSI; $F(2, 46) = 9.51$, $MSE = 646.04$, $p < .01$. The two-way interaction between contrast and trial type was significant. For repetition trials the

contrast effect was 22 ms compared to 12 ms for switch trials; $F(1, 23) = 6.15$, $MSE = 335$, $p < .05$.

2.3.3.3 Participant Subset Analysis

As with the analysis of Experiment 1, a subset analysis was performed on the ERP data from Experiment 2. The reasons for the subset analysis are identical to those used in Experiment 1. Here, the subset analysis was performed on 14 participants whose averaged waveforms showed well defined P1 and N1 peaks. Grand averaged waveforms for each condition are displayed in Figure 2.12.

2.3.3.3.1 P1 component

There was a significant main effect of contrast with mean peak latency for high contrast trials being 132 ms compared to 165 ms for low contrast trials, $F(1, 13) = 229.98$, $MSE = 196.16$, $p < .0001$. There was a significant main effect of RSI. Peak P1 latency for the shortest RSI was 156 ms compared to 148 ms for the intermediate RSI and 142 ms for the longest RSI; $F(2, 26) = 16.37$, $MSE = 180.87$, $p < 0001$. The main effect of trial type did not reach significance. However, a trend is evident with peak latency in repetition trials being shorter than for repetition trials (147 vs. 150 ms); $F(1, 13) = 3.66$, $MSE = 95.91$, $p = .08$. The two-way interaction between RSI and contrast demonstrated a trend. The contrast effect at the shortest RSI was 24 ms compared to 35 ms at the intermediate RSI and 40 ms at the longest RSI; $F(2, 26) = 3.12$, $MSE = 270.27$, $p = .09$.

2.3.3.3.2 N1 component

There was a significant main effect of contrast with peak latency for high

contrast trials being shorter than peak latency for low contrast trials (193 vs. 208 ms); $F(1, 13) = 9.07$, $MSE = 1017.31$, $p < .01$. The two-way interaction between RSI and contrast was significant. The contrast effect at the shortest RSI was -3 ms compared to 18 ms at the intermediate RSI and 30 ms at the longest RSI; $F(2, 26) = 4.76$, $MSE = 784.65$, $p < .05$. Again, the three-way interaction between RSI, contrast, and trial type was not significant. No other interaction was significant.

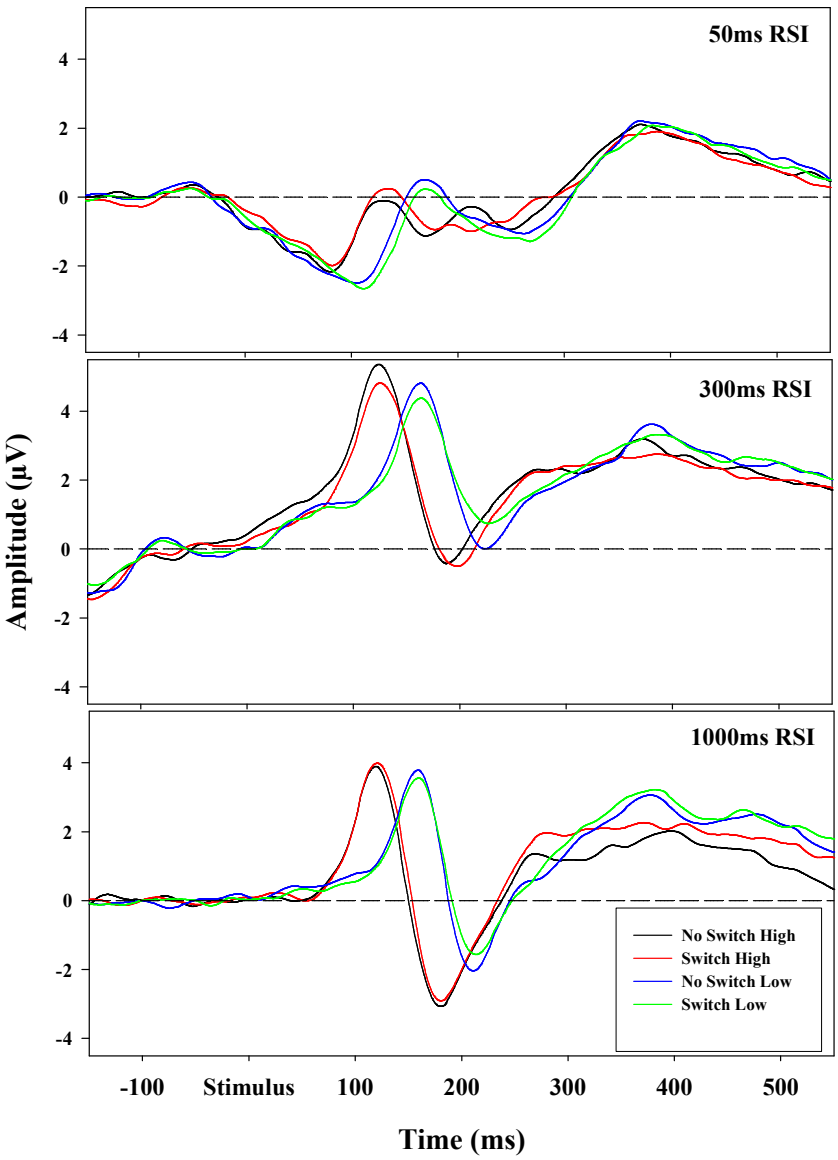


Figure 2.12: P1 and N1 components as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 300 vs. 1000 ms) for a subset (n=14) of participants.

2.3.3.4 Amplitude measures

Like in Experiment 1, the measurement of ERP peak amplitudes was complicated by the fact that particularly the ERP waveforms in the shortest RSI condition were subject to overlapping brain activity related to the previous response and preparatory activity (cf. Figure 2.10). That is, in the 50-ms RSI there was a negative-going trend in the pre-stimulus interval, whereas in the 300 RSI a positive-going trend was evident. Therefore, ERP waveforms were high-pass filtered (2 Hz, 6 dB/oct) to reduce the influence of component overlap like in the study of Vogel and Luck (2000). The filtered ERP waveforms depicted in Figure 2.13 (PO7) and Figure 2.14 (PO8) indeed show a reduction of overlapping brain activity, although a residual negative trend is still apparent in the 50-ms RSI condition.

2.3.3.4.1 P1

P1 peak amplitude was larger for high contrast than low contrast stimuli (3.0 vs. 2.6 μV), F (1, 23) = 5.32, MSE = 1.59, $p < .05$. The main effect of RSI, F(2, 46) = 151.63, MSE = 2.04, $p < .001$, indicated a smaller P1 amplitude at the 50-ms RSI (0.7 μV) as compared to the two longer RSI conditions (about 3.1 μV). In addition, the RSI × electrode interaction, F(2, 46) = 4.40, MSE = 1.42, $p < .05$, was due to a larger P1 over the right than the left parieto-occipital electrode only for the two longer RSIs but not the 50-ms RSI. The RSI × Contrast interaction was significant, F(2, 46) = 19.47, MSE = 0.38, $p < .001$. Like in Experiment 1, the contrast effect was absent and even numerically reversed at the shortest 50-ms RSI (-0.21 μV) compared to the other RSIs (about 0.45 μV). All other main effects or interactions did not approach significance.

2.3.3.4.2 N1

The analysis of N1 peak amplitude revealed a main effect of contrast, F (1, 23) = 21.65, MSE = 1.83, $p < .001$, indicating a larger N1 for high contrast than low contrast stimuli (-3.25 vs. -2.73 μV), and a main effect of RSI, $F(2, 46) = 43.72$, $MSE = 4.57$, $p < .001$, due to a smaller N1 amplitude at the 50-ms and 300-ms RSI (about –2.4 μV) as compared to the 1000-ms RSI (about -4.15 μV). The RSI × Contrast interaction was significant, $F(2, 46) = 5.23$, $MSE = 0.94$, $p < .05$, due to the absence of the contrast effect at the shortest 50-ms RSI (0.14 μV) compared to the longer RSI conditions (about 0.7 μV). This effect was further modulated by trial type as indicated by the significant RSI × Trial Type × Contrast interaction $F(2, 46) = 5.68$, $MSE = 0.15$, $p < .01$, as the RSI-related modulation of the contrast effect was stronger for task switch than task repetition trials. No other main effects or interactions approached significance.

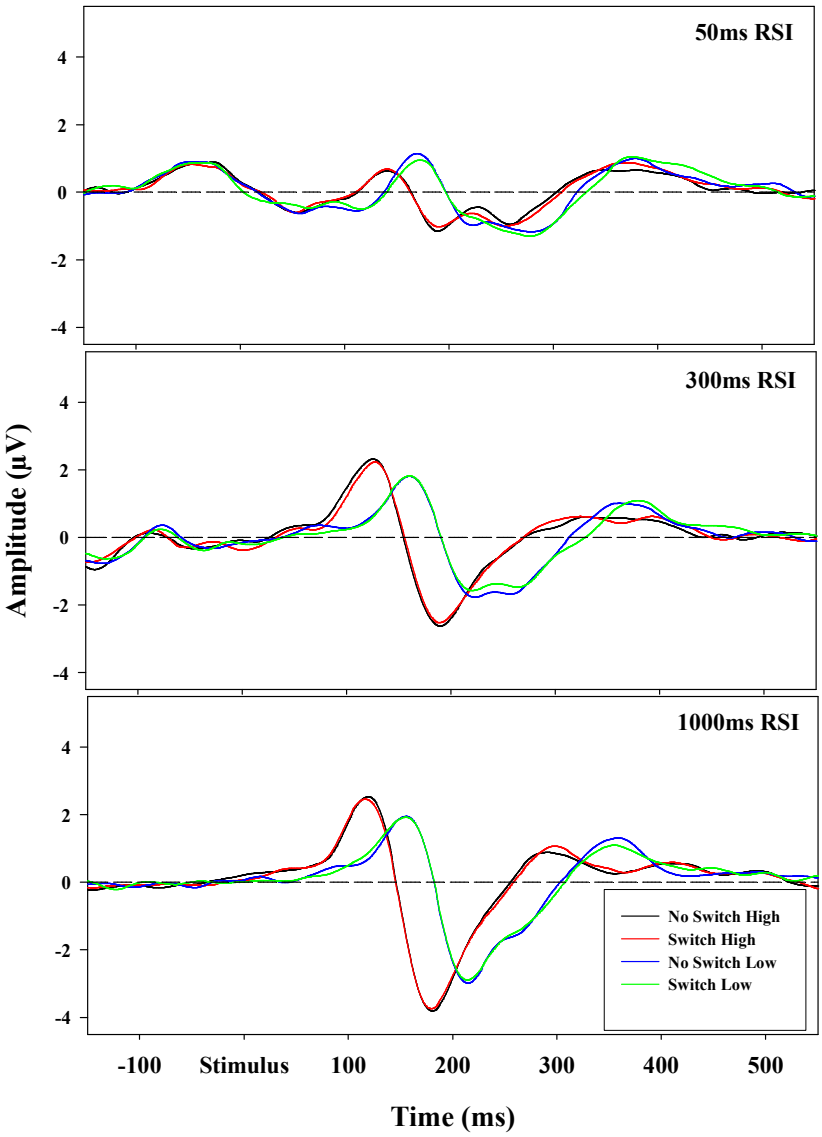


Figure 2.13: P1 and N1 components as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 300 vs. 1000 ms) at PO7 with additional high-pass filter for amplitude analysis.

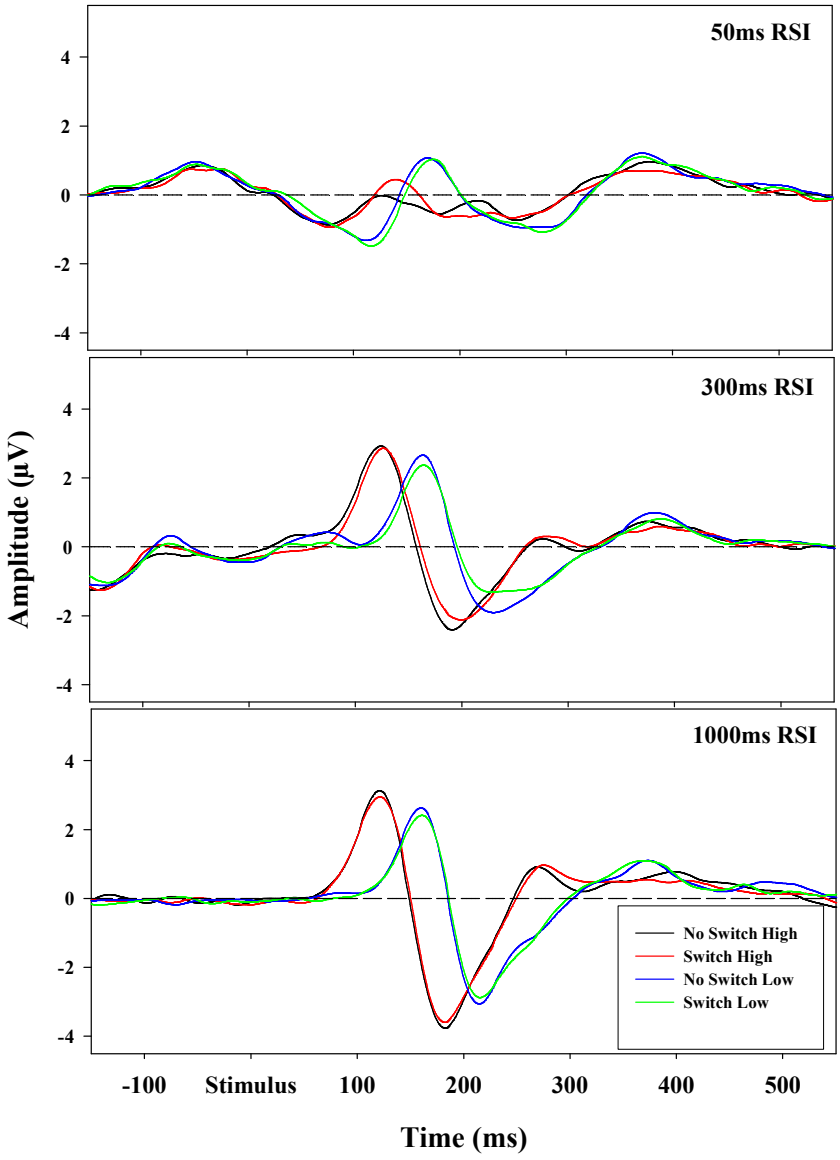


Figure 2.14: P1 and N1 components as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 300 vs. 1000 ms) at PO8 with additional high-pass filter for amplitude analysis.

2.3.3.3.5 LRP analysis

2.3.3.3.5.1 Stimulus-Locked LRP (S-LRP)

S-LRP waveforms are shown in Figure 2.15. There was a significant main effect of RSI with the S-LRP interval for the short RSI being 429 ms compared to 377 ms for the intermediate RSI and 336 ms for the long RSI; $F(2, 46) = 5.27$, $MSE = 75.18$, $p < .05$. There was a significant main effect of trial type with the S-LRP interval for task repetition trials being shorter than the S-LRP interval for

task switch trials (353 vs. 409 ms); $F(1, 23) = 7.11$, $MSE = 60.17$, $p < .05$. No other interactions reached significance.

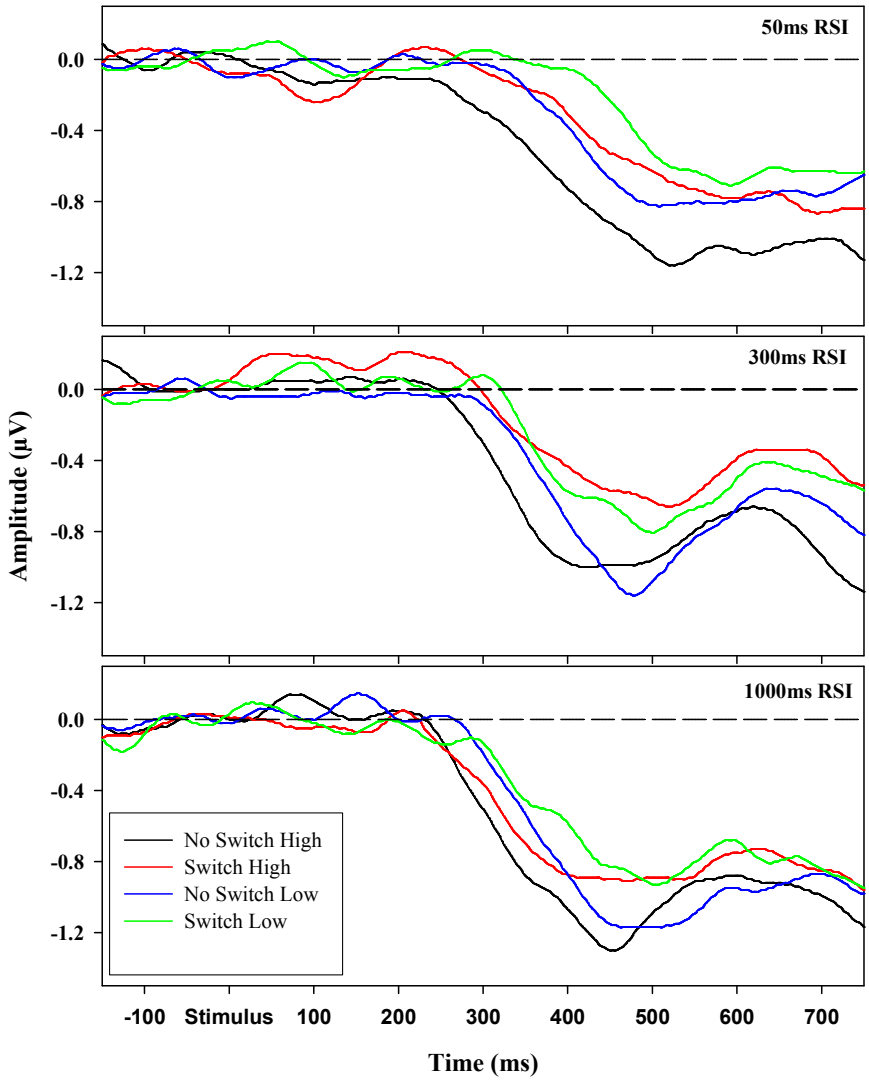


Figure 2.15: Stimulus-Locked LRP Waveforms as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 300 vs. 1000 ms).

2.3.3.3.5.2 Response-Locked LRP (LRP-R)

LRP-R waveforms are shown in Figure 2.16. None of the main effects and interactions reached significance (all Fs < 1).

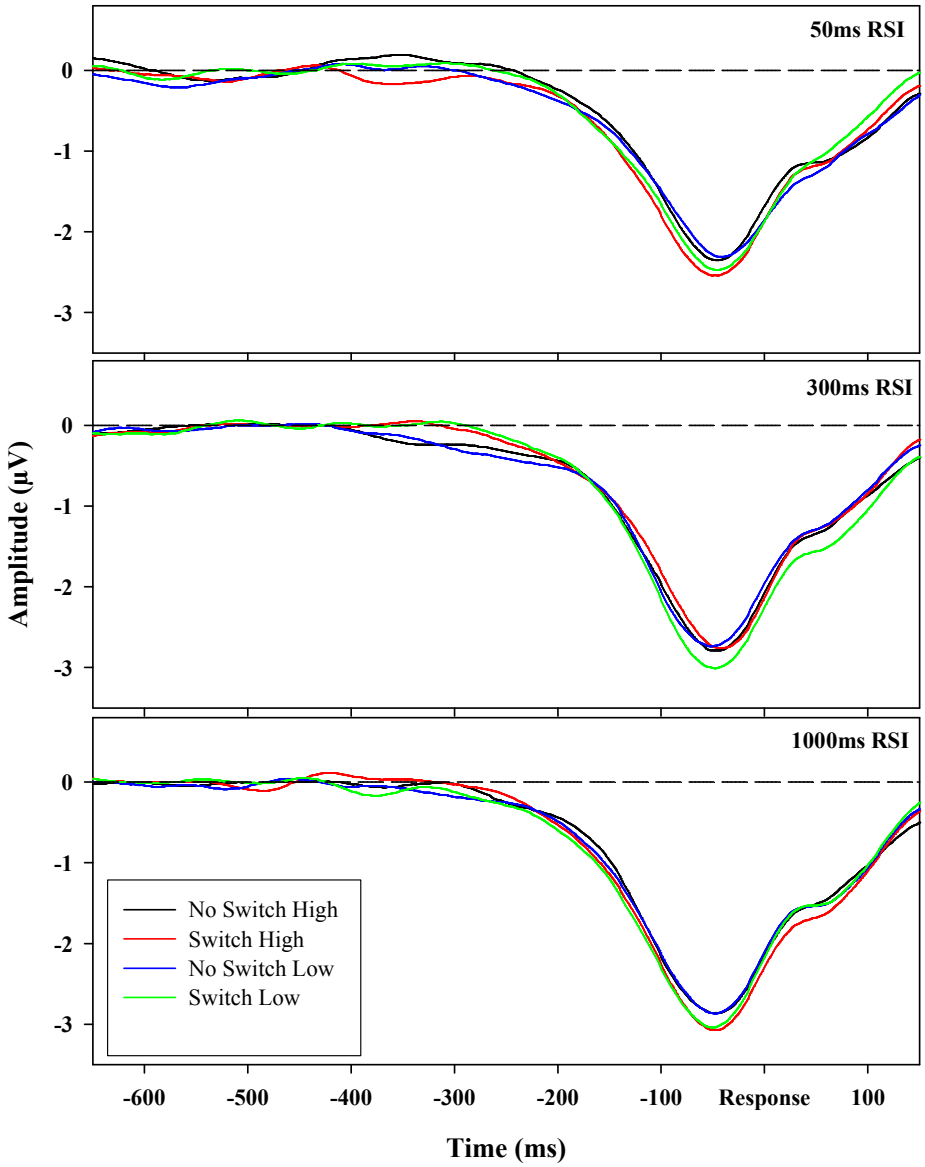


Figure 2.16: Response-Locked LRP Waveforms as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 300 vs. 1000 ms).

2.3.4 Discussion

The present experiment adopted the same experimental rationale and predictions of Experiment 1. The main findings from the task switching literature were replicated, namely, increased RT and error rates for switch trials compared to repetition trials. In Experiment 2, the average switch cost was 210 ms. Crucially, the three-way interaction between trial type, contrast and RSI was not significant indicating that there was no more underadditivity on switch trials than on repetition trials across all levels of RSI. However, unlike the RT data from

Experiment 1, there is evidence of underadditivity independent of trial type, indicated by the significant two-way interaction between RSI and contrast. This shows that the effect of contrast was reduced at the short RSI, consistent with the prediction of the parallel model. However, this reduced contrast effect with decreasing preparation time was consistent across trial type (i.e. it was not switch specific). This result questions whether a reconfiguration stage is specific to task switch trials only. The RSI x Contrast interaction observed in Experiment 2 is inconsistent with the data reported by Oriet and Jolicoeur (2003, Exps. 1 & 2). The present RT results demonstrated an underadditive effect of contrast with decreasing RSI independent of trial type. Although more underadditivity was observed on task switch trials than on task repetition trials (~ 11 ms) when considering the longest and shortest RSI, this difference was not significant.

Regarding the ERP data, peak P1 latency was affected by the contrast manipulation, peaking approximately 32 ms earlier for high contrast than low contrast trials. This result was replicated for N1 latency with a contrast effect of approximately 16 ms, and replicates the findings from Experiment 1 showing an effect of contrast on P1 and N1 peak latency. Importantly, RSI interacted with contrast with a larger effect of contrast at the longer compared to shorter RSI levels for the P1 and N1 components. The RSI x Contrast interaction was not influenced by Trial Type for either the P1 or N1, thus the underadditivity observed for the contrast effect with decreasing RSI is independent of trial type. Interestingly, trial type interacted with contrast for N1 latency and indicated a larger contrast effect for task repetitions compared to task switches. However, as this result was independent of RSI level, it is difficult to attribute this effect to differences in preparation time between trials.

Similarly to Experiment 1, an analysis on a subset of participants whose averaged waveforms showed well defined peaks was conducted in order to validate the above results. Again, both P1 and N1 peaked earlier for high compared to low contrast trials. For P1 latency, there was a main effect of RSI indicating that the P1 component peaked later at the shorter RSI. The significant RSI x Contrast interaction observed in the overall analysis was evident as a trend in the subset analysis for P1 and was significant for N1, and again, indicates that the effect of contrast increased with increasing RSI.

Increased signal to noise ratio resulting from an increased number of trials per condition in Experiment 2 compared to Experiment 1 allowed calculation of the LRP. To recap briefly, any effect on the S-LRP interval would localise the effect to processing stages before response selection. Alternatively, an effect on the LRP-R interval would localise the effect to processing stages that occur after response selection. There were no significant main effects or any lower level interactions within the LRP-R interval. This suggests that the process of task set reconfiguration does not affect any processes after the selection of response hand. The S-LRP interval demonstrated a significant main effect of RSI with a shorter S-LRP interval with increasing RSI. The main effect of trial type was also significant with the S-LRP interval being shorter for task repetitions that task switches. This suggests that any interference due to the requirement to switch tasks has its locus at a point before response selection terminates.

Again, like the analysis from Experiment 1, peak amplitude of the P1 and N1 components was analysed. P1 peak amplitude was higher for high contrast compared to low contrast trials and this result was replicated for N1 amplitude. For both P1 and N1 amplitude there was a main effect of RSI with a smaller P1

amplitude at the short compared to the longer RSI. The reduced P1 and N1 amplitudes observed at the short RSI suggests that participants do not have enough time to attend or focus toward the relevant location when the time interval between trials is short. Indeed, the results observed are consistent with results from the attention literature showing reduced P1 and N1 amplitudes for stimuli presented at unattended locations compared to attended locations (see 1.4.6).

2.4 Task Switch Experiment 3

2.4.1 Experimental Rationale

The finding of an underadditive effect of contrast and RSI suggests some kind of processing bottleneck that is evident on both task repetition and task switch trials. Experiments 1 and 2 used a trial sequence consisting of MMPPMMPP. This has the problem that the repeat trial is also the pre-switch trial. It is possible that while participants perform the currently relevant task, they also prepare for the forthcoming task-switch (Wylie, Javitt, & Foxe, 2004), which could explain the absence of task switch-specific effect on information processing (i.e. reconfiguration is involved on both task repetition and switch trials). To test this possibility, an alternating runs paradigm was used in which three subsequent repetition trials were followed by a switch trial (MMMMPPPPMMMM…). This allows assessment of the contrast effect on switch trials relative to pre-switch repeat trials (the last trial in the run of four demanding the same task). The first and second repeat trials should be uninfluenced by preparing for a forthcoming task switch, and thus, should provide a clearer baseline against which to compare switch trials because they are not contaminated (or contaminated less so) by preparing for a forthcoming task-switch.

2.4.2 Method Section

2.4.2.1 Participants

48 University of Glasgow students, aged 17 to 33 years (mean age 20 years, 12 male) participated in exchange for pay (scale of £6 per hour) or course credit. Ethical approval for the study was obtained from the University of Glasgow Ethics committee and all participants gave informed consent. All participants reported normal or corrected to normal vision. 43 of the participants were right handed as assessed by the Edinburgh handedness inventory (Oldfield, 1971) (Mean handedness quotient = 80.4).

2.4.2.2 Apparatus

Apparatus was identical to that used in Experiment 1 but ERP measurements were not made.

2.4.2.3 Design

Minor alterations were made to the number of blocks used, sequence length and the total number of trials. RSI (50, 300 and 1000 ms) and contrast (high vs. low) remained blocked with 4 blocks of high and 4 blocks of low contrast for each of the three levels of RSI. Again the order of RSI sequence was balanced by means of a Latin Square such that across 48 participants each level of RSI followed each other 4 times. A practice block consisting of a sequence of 64 (32 high followed by 32 low contrast) trials was completed before each level of RSI. Data from the practice blocks was not analysed. Following the practice

blocks, participants completed 8 blocks of 64 experimental trials for each level of RSI. In total, this resulted in 1728 trials in one session.

2.4.2.4 Procedure

Participants were tested in a single session that lasted approximately 45 minutes. Participants were informed of both the contrast manipulation and the RSI manipulation. These instructions were given to the participants verbally at the beginning of the experiment. In addition, each sequence of trials began with an instruction screen that informed participants of the forthcoming RSI and contrast level. This instruction screen remained until the participant initiated the trial sequence by pressing the appropriate key. A fixation cross appeared in the centre of the screen followed by the first digit at an interval equal to the block RSI.

The experimental task was identical to that of Experiments 1 and 2 except using the alternating run sequence PPPPMMMMPPPPMMMM… thus, a task switch trial occurred every fourth trial instead of every two. The same 2*2 grid used previously was adopted. Thus, participants performed one task for the full cycle of locations before switching task. The position of the switch was cued spatially, again balanced across participants so that half of the participants switched when the digit moved position horizontally and half when the digit moved position vertically. The first four trials were always repetition trials and as a result of the balancing of switch direction, the first digit presentation was either in the top left quadrant or the top right quadrant. Again digit location was predictable with the next digit location being the quadrant clockwise from the current digit location. Response mappings were balanced according to the procedure used in Experiment 1.

In addition to the error tone on error trials, a message appeared during the interval informing the participants of the task to be performed on the next trial and also the response mappings. This was considered necessary as a four sequence run within the quadrant does not specifically cue the task spatially, only the switch position. It is thus necessary to keep track of the current task internally. All other procedures were identical to those of Experiment 1.

2.4.3 Data analysis

RT and error data were averaged for each participant and condition with the means being submitted to a repeated measures ANOVA. The within participant variables were RSI (50, 300 and 1000 ms), trial sequence (switch, repetition 1, repetition 2 vs. repetition 3), and contrast (high vs. low). Both error trials and trials following an error were removed from the analysis as were outliers using the procedure described earlier. Overall this resulted in the exclusion of 22 % trials. Practice trials were also removed from the analysis resulting in 32,212 observations remaining in the main analysis.

2.4.4 Results

2.4.4.1 Behavioural Results

2.4.4.1.1 Reaction Time

Condition means for RT are displayed in Figure 2.17. In accordance with both Experiments 1 and 2, the results replicate the main findings from the task switching literature. All main effects were significant. The contrast manipulation produced a significant main effect with responses to high contrast stimuli being faster than response to low contrast stimuli (688 vs. 728 ms); F (1, 47) = 124.30, MSE = 3628, p < .0001. There was a significant main effect of trial type; F (3, 141) = 192.49, MSE = 24094.85, p < .0001, with responses to repetition trials being faster than those to switch trials. The mean RT for a switch trial was 898 ms compared to 635 ms for the first repetition, 651 ms for the second repetition and 649 ms for the third repetition. There was a significant main effect of RSI; F (2, 94) = 41.09, MSE = 29758.93, p < .0001, with responses being slowest for the shortest RSI (794 ms) compared to the intermediate RSI (721 ms) and longest RSI (711 ms).

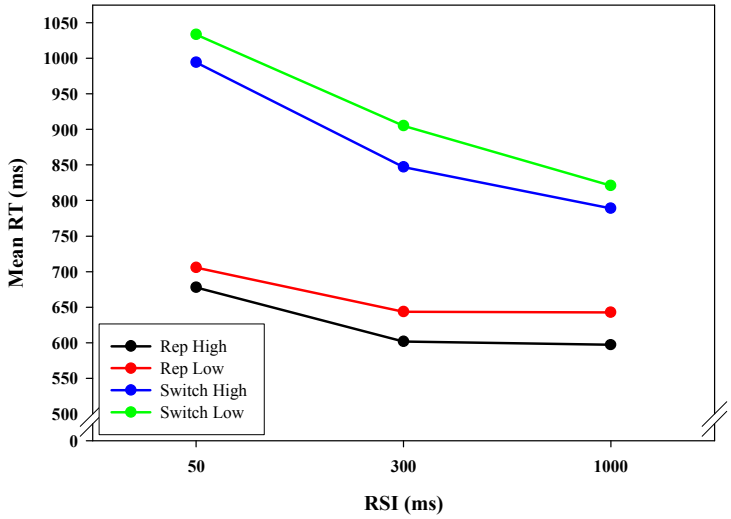


Figure 2.17: Mean reaction time per condition as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 300 vs. 1000 ms). Note that repetition trials 1, 2 and 3 are averaged together to create one repetition condition.

The switch cost was reduced as preparation time increased, resulting in a significant two-way interaction between trial type and RSI; F (6, 282) = 38.15, MSE = 2976.21, $p < .05$. For the shortest RSI the switch cost was 254 ms compared to 217 ms for the intermediate RSI and 159 ms for the longest RSI. Importantly, the three-way interaction between RSI, trial type, and contrast was not significant; F (6, 282) = 1.75, MSE = 963.15, $p > .05$. Replicating the finding from Experiment 2, the two-way interaction between RSI and contrast was significant; F (2, 94) = 3.84, MSE = 1599.68, $p < .05$. This two-way interaction reflects the fact that contrast had less of an effect at the short RSI (~ 30 ms) compared to the intermediate RSI (~ 46 ms) and the longest RSI (~ 42 ms) independent of whether the trial involved a task repetition or task switch.

A separate ANOVA was conducted on switch trials and the first repetition trial in the sequence, with condition means displayed in Figure 2.18.

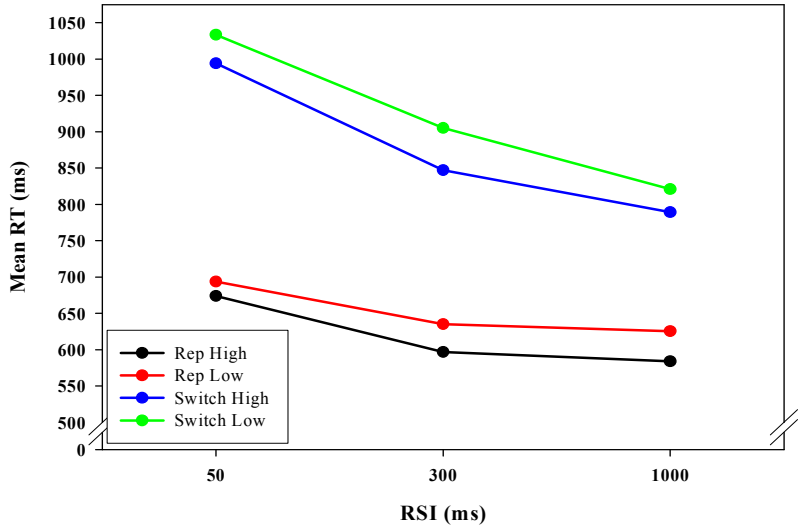


Figure 2.18: Mean reaction time per condition as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 300 vs. 1000 ms) for task repetition 1 only.

The first repetition trial within the present design was followed by another repetition trial and thus, the first repetition is uncontaminated by potential preparation for a forthcoming switch. There was a main effect of trial type, RSI and contrast with faster responses on task repetition trials than on switch trials (635 vs. 898 ms); $F(1, 47) = 217.88$, $MSE = 45918.12$, $p < .0001$; slower responses for the short RSI than the long RSI (50, 300, 1000 ms RSI = 849, 746, 705 ms, respectively); $F(2, 94) = 51.83$, $MSE = 20392.09$, $p < .0001$; and faster responses to high contrast trials than low contrast trials (748 vs. 786 ms); $F(1, 47) = 87.75$, $MSE = 2389.40$, $p < .0001$. A significant Trial Type x RSI interaction indicated that the switch cost decreased as preparation time increased; $F(2, 94) = 37.57$, $MSE = 5361.63$, $p < .0001$. For the shortest RSI the switch cost was 330 ms compared to 260 ms for the intermediate RSI and 201 ms for the longest RSI. There was a significant interaction between RSI and contrast; $F(2, 94) = 3.3$, $MSE = 1277.03$, $p < .05$, indicating that the contrast manipulation had less of an effect at the short RSI (~ 30 ms) compared to the intermediate RSI (~ 48 ms) and the longest RSI (~ 36.ms). However, a significant trend for the Trial Type x RSI x Contrast interaction; $F(2, 94) = 2.77$, $MSE = 1302.0$, $p = .068$, indicating that the reduction in the contrast effect with increasing RSI was different for switch and repeat trial 1. For switch trials the contrast effect for the short RSI was 39 ms compared to 57 ms for the intermediate RSI and 31 ms for the longest RSI. For repeat trials, the contrast effect for the short RSI was 20 ms compared to 39 ms for the intermediate RSI and 42 ms for the longest RSI.

In a similar fashion to Experiments 1 and 2, the average difference in the amount of underadditivity of the contrast effect between task switch trials and task repetition trials was compared. Here, the first repetitions and the second

repetitions are combined. The third repetition trial was not included as this trial may be different for reasons highlighted above (i.e. it is also a pre-switch trial). When comparing the amount of underadditivity between the shortest RSI level and the longest RSI level, there was approximately 26 ms more underadditivity on task repetition trials than on task switch trials. This difference was significant; $t(47) = -2.06$, $p < .05$.

2.4.4.1.2 Error Rate

Mean error rates are displayed in Figure 2.19. Error rates were generally low (although higher than in Experiments 1 and 2) and ranged from 4 to 12 % across experimental conditions. As in Experiment 1 and 2, there was a main effect of trial type with more errors being made on task switch trials than on task repetition trials (11 % compared to 4-6 % for repetition trials; F (3, 141) = 52.82, MSE = 53.70, $p < .0001$). There was a significant two-way interaction between trial sequence and RSI; F (6, 282) = 2.66, $p < .05$. For switch trials there was an increased error rate for the shortest RSI (12.3 %) compared to the intermediate (11.8 %) and longest RSI (9.7 %). This reduction in error rate with increasing RSI was not evident for repetition trials for either the first, second or third repetition trial. No other effects were significant (all Fs < 1.7, ps > .19).

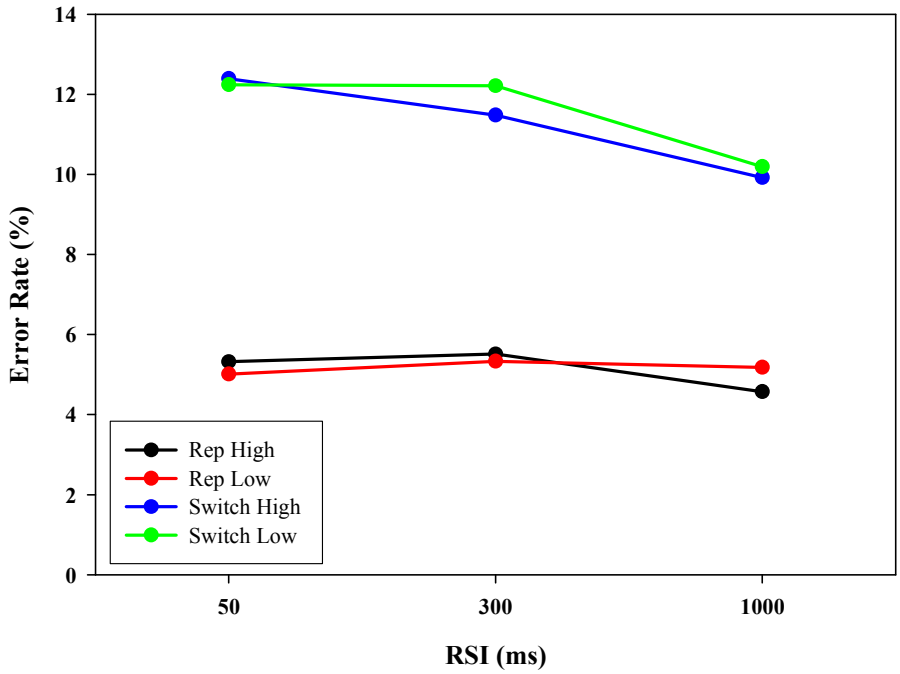


Figure 2.19: Mean error rate per condition as a function of trial type (switch vs. repetition), contrast (high vs. low) and RSI (50, 300 vs. 1000 ms). Note that repetition trials 1, 2 and 3 are averaged together to create one repetition condition.

2.4.5 Discussion

Experiment 3 was driven by the results of Experiments 1 and 2 indicating an underadditive effect of contrast with decreasing RSI for RT (Exp 2) and P1 and N1 peak latency (Exps. 1 & 2). Such results question the need for a reconfiguration stage that is specific to task switch trials only. However, when the task sequence consists of MMPPMMPP, the repetition trial is also a pre-switch trial. As mentioned previously, it is possible that while participants perform the currently relevant task during a task repetition, they are also preparing for the forthcoming task-switch (Wylie, Javitt, & Foxe, 2004). This could explain the absence of task switch-specific effect on information processing (i.e. as bottleneck reconfiguration is involved on both task repetition and switch trials). The present experiment tested this possibility that used an alternating runs paradigm that consisted of the trial sequence MMMMPPPPMMMM. This allows the assessment

of contrast effects on switch trials relative to pre-switch repeat trials and also switch trials relative to repeat trials that are followed by other repeat trials. The first and second repeat trials should be uninfluenced by preparing for a forthcoming task switch, and thus, should provide a clearer baseline against which to compare switch trials because they are not contaminated (or contaminated less) by potential preparation for forthcoming task-switch.

As in Experiments 1 and 2, the main task switching effects are replicated with increased RTs and error rates on switch trials compared to repetition trials. The average switch cost observed (263 ms) is larger than that observed in Experiment 1 (185 ms) and Experiment 2 (210 ms). Overall error rate was also higher in the present experiment than in Experiments 1 and 2. There are two possible explanations for the increased switch cost and error rate in the present experiment which both rely on differences between the task sequences. The present experiment used a four task sequence within the same 2 x 2 quadrant used in Experiments 1 and 2. Thus, in the present experiment the task that the participants were to perform was not cued by the spatial location of the stimulus but rather had to be remembered internally. It is possible that this additional need to keep track of the currently relevant task resulted in increased error rates. Indeed, as error rates were higher for switch compared to repetition trials and as error rate was highest at the shortest RSI, this explanation seems viable. In addition, repeating a task for 4 trials as opposed to 2 trials may result in participants becoming more settled into the current response set making it more difficult to switch to a different response set, thus producing increased switch costs. However, it must be noted that in a similar 4-run trial sequence, Monsell, Sumner and Waters observed no increase in switch costs with increased run-

length. They adopted an eight segment grid to cue task, thus it is likely that the use of a 2 * 2 quadrant in the present experiment resulted in the increased switch cost due to the additional constraint of needing to keep track of task sequence.

Again, like in Experiments 1 and 2, the observed switch cost was reduced as preparation time increased. The reduction in switch cost observed from the shortest RSI to the longest was approximately 95 ms. However, a significant portion of the switch cost was still evident at the longest RSI (~ 159 ms). This finding that the switch cost is not eliminated even when preparation is long replicates the results of Experiments 1 and 2 that also showed a substantial 'residual cost'.

Importantly, in terms of the experimental rationale, the three-way interaction between trial type, RSI and contrast was not significant replicating the results of Orient and Jolicoeur (2003) and those of Experiments 1 and 2. Similarly to the RT data of Experiment 2, there was a significant interaction between RSI and contrast reflecting the fact that the effect of contrast was reduced at the short compared to the longer RSI independent of trial type. Again, this result cannot be reconciled within the sequential and parallel models considered and questions whether reconfiguration is specific to task switch trials. An additional analysis was conducted on switch trials and the first repetition trial only. This was done to investigate task repeat trials that are not pre-switch trials and thus, are uncontaminated by potential preparation for a forthcoming switch. Again, a significant two-way interaction between trial type and RSI indicated that the switch cost was reduced as RSI increased. RSI interacted with contrast indicating less of an effect of contrast at the short RSI compared to the longer RSIs. Interestingly, there was a trend evident for the three-way interaction

between trial type, RSI and contrast. However, this interaction suggested that the reduction in the contrast effect with decreasing RSI was more evident for task repeat trials than task switch trials. Indeed, tests of underadditivity across task switch and task repetition trials (excluding the pre-switch trial) indicated approximately 26 ms more underadditivity on task repeat compared to task switch trials.

2.5 General Discussion

The present series of experiments was driven by the conclusion of Oriet and Jolicoeur (2003) that the process of switching task (task-set reconfiguration) constitutes a hardbottle neck delaying even perceptual processing. Three experiments were conducted in order to further test this claim. Experiment 1 replicated their design while introducing ERP measures of P1 and N1 latency to investigate perceptual processing more directly. Experiment 2 reduced the number of RSI conditions in order to increase the number of trials per condition which allowed interpretation of the LRP. Experiment 3 adopted a 4 trial sequence in order to investigate whether a repeat trial that occurred before a switch also involves some form of reconfiguration that creates a bottleneck. Experiment 3 was motivated by the RT results of Experiment 2.

Oriet and Jolicoeur's (2003) claim was based on their findings of additive effects of contrast with reduced RSI. From this they proposed a sequential model of task-switching where the process of task-set reconfiguration takes place before stimulus processing, response selection and response execution (see Figure 2.1). The results of the three present experiments do not add support to this claim. Instead, underadditivity was observed for a contrast manipulation and RSI in RT

(Exps. 2 & 3) and for P1 and N1 latencies (Exps. 1 & 2). This suggests that some processes must overlap in order for the effect of contrast to be absorbed at the shorter RSIs. However, as this observed underadditivity is independent of trial type, it cannot be attributed to a process of task-set reconfiguration that is specific to task switch trials only. Thus, the present data do not support the alternative parallel model considered. Experiment 3 showed that the effect of contrast was still underadditive with decreasing RSI when considering switch trials and repeat trials that preceded other repeat trials. Thus, any form of reconfiguration that may occur on pre-switch trials cannot provide an explanation for the underadditivity of contrast with decreasing RSI observed in Experiments 1 and 2.

The data from the present experiments seems to rule out both the sequential and parallel model of task-set reconfiguration considered. Gilbert (2005) questioned the basic central assumption necessary for the use of locus of slack logic and argued that, for the locus of slack logic to be applicable to a task-switching paradigm, one must first assume that task-set reconfiguration and other central resources occur in sequence. Without this assumption there is not any period of cognitive slack and thus, its logic cannot be applied (Gilbert, 2005). Indeed, when only factor (e.g. contrast) demonstrates an additive interaction with decreasing RSI, two possible explanations exist. First, the factor may affect a postbottleneck stage, or alternatively, there may be no bottleneck at all. Both of these explanations predict additive effects (Gilbert, 2005). Gilbert (2005) contrasted the serial and parallel models considered by Oriet and Jolicoeur (2003) with a model where all three processes (task-set reconfiguration, perceptual processing and response selection) take place in parallel. This 'interactive model' does not involve any period of cognitive slack because the initiation of the

response selection stage does not wait until the completion of the other stages. Using a computational simulation based on a variation of a model of the Stroop task (Gilbert & Shallice, 2002), Gilbert (2005) demonstrated that the pattern of data observed by Oriet and Jolicoeur (2003) could be observed without the necessity to assume successive stages for task-set reconfiguration and perceptual processing, or indeed, an additional stage of reconfiguration that is specific to task switch trials only.

To conclude, the present set of experiments offer no support for the conclusion of Oriet and Jolicoeur (2003) that the process of task-set reconfiguration delays perceptual processing. However, the data also do not support the alternative parallel model and thus, question whether response selection and task-set reconfiguration need to occur sequentially.

Chapter 3. Conflict Adjustment in the Eriksen Flanker Task: Influences of Top-Down Control of Attention

3.1 Introduction

The conflict monitoring model of Botvinick et al. (2001) predicts that after the detection of conflict, control mechanisms are recruited in order to reduce the effect of conflict in subsequent behaviour (see 1.7.6). In the case of the flanker task, it has been proposed that the control mechanisms involve selective attention toward the task relevant aspect of the stimulus (Casey et al., 2000; Botvinick et al., 2001). Specifically, after an incompatible trial, there will be increased attentional focus toward the central location within the flanker array. In contrast, a compatible trial does not produce conflict, and thus, increased attentional focus toward the central target location is of less importance. In this case, it is proposed that spatial attention is distributed more widely (see Figure 3.1).

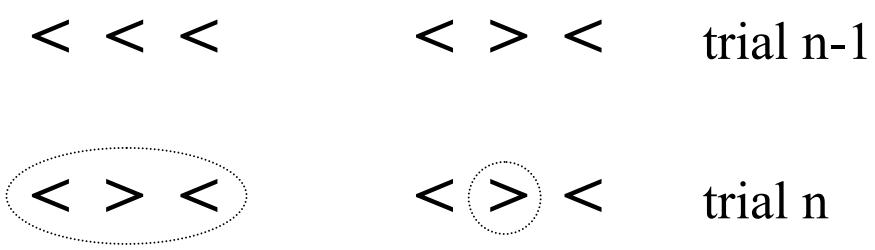


Figure 3.1: Schematic of proposed attentional focus after compatible and incompatible trials

The idea that conflict detection and resultant control mechanisms can vary attentional focus suggests that differences in early visual processing may be detectable via the use of ERPs (see 1.4.6). Scerif, Worden, Davidson, Seiger and Casey (2006) investigated this using an adapted version of the flanker task. In addition to the standard flanker trials, an additional stimulus array that omitted the central target was included (see Figure 3.2). This additional stimulus array type

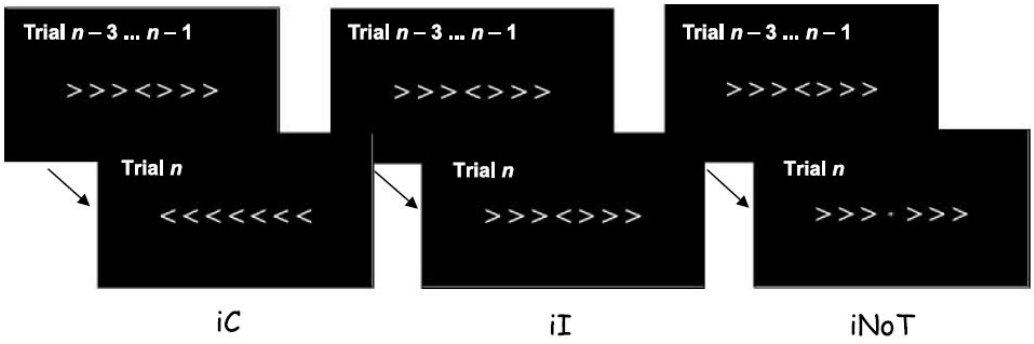


Figure 3.2: Stimuli examples from Scerif et al. (2006). iC describes the situation where incompatible trials precede a compatible trial. iI describes the situation where incompatible trials precede an incompatible trial. iNot describes the situation where incompatible trials precede a trial that does not contain a central target.

did not require a response. The conflict context of the preceding trials and the compatibility of the current trial were manipulated. Their analysis focused on the modulation of the P1 component, the first component that is robustly modulated by attention, as outlined in the introduction (see 1.4.6). The authors hypothesised that 1) the amplitude of the P1 component would be reduced for incompatible trials if such a context results in a more restricted focus of attention toward the target, as there would be less visual stimulation from the flankers and 2) trials that contained no target should show reduced or enlarged P1 amplitudes depending upon whether they were preceded by an incompatible or compatible trial. For example, when preceded by incompatible stimuli, there should be a reduced P1 amplitude resulting from focused attention toward the central target location, a location where there is no visual stimulation in non-target trials.

The behavioural results of Scerif et al. (2006) demonstrated the typical conflict adaptation effect with faster responses to incompatible trials following incompatible trials (512 ms) than after compatible trials (518 ms). However, responses to compatible trials were not reliable influenced by context. Response repetitions and alternations did not reliably modulate the two-way interaction

between previous context (compatible vs. incompatible) and conflict (current compatible vs. current incompatible).

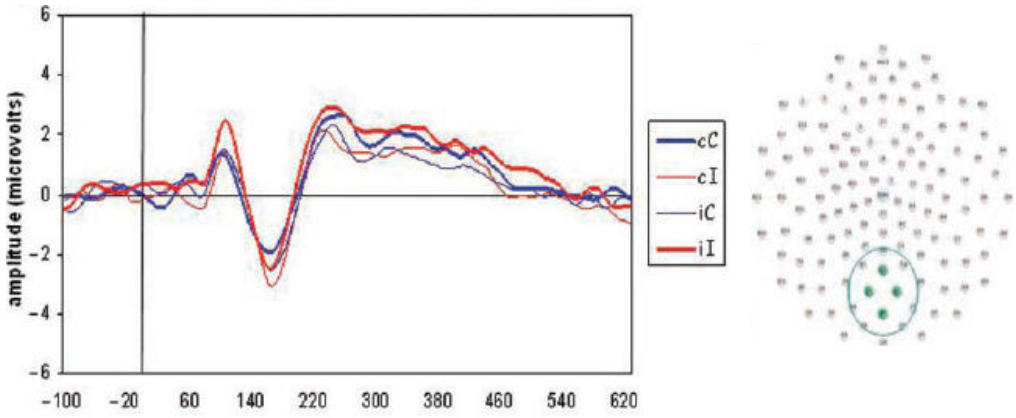


Figure 3.3: ERP waveforms of Scerif et al. (2006) as a function of previous compatibility (context) and current trial type for the typical flanker trials. Above right shows the electrode locations where the ERP waveforms were measured. cC = preceding compatible context followed by a compatible trial, cI = preceding compatible context followed by an incompatible trial, iC = preceding incompatible context followed by a compatible trial, while iI = preceding incompatible context followed by an incompatible trial (adapted from Scerif et al. (2006)).

With regards to the ERP data of Scerif et al. (2006), P1 amplitude was analysed in two contexts; first, within typical flanker sequences, and second, for no-target trials. For the typical flanker trials, there was an interaction between current compatibility and previous compatibility with higher P1 amplitudes for ii trials (see Figure 3.3). The authors propose that this effect cannot be reconciled within the idea that the detection of conflict results in increased attentional focus toward the target, and thus, decreased perceptual stimulation, as this would predict a reduced P1 amplitude.

Regarding no-target trials (cNoT = preceding compatible context, iNoT = preceding incompatible context), P1 amplitude was higher when preceded by compatible, rather than incompatible flanker arrays. This is consistent with the

prediction that attention becomes increasingly focused on the region of the relevant stimulus attribute after incompatible trials (see Figure 3.4).

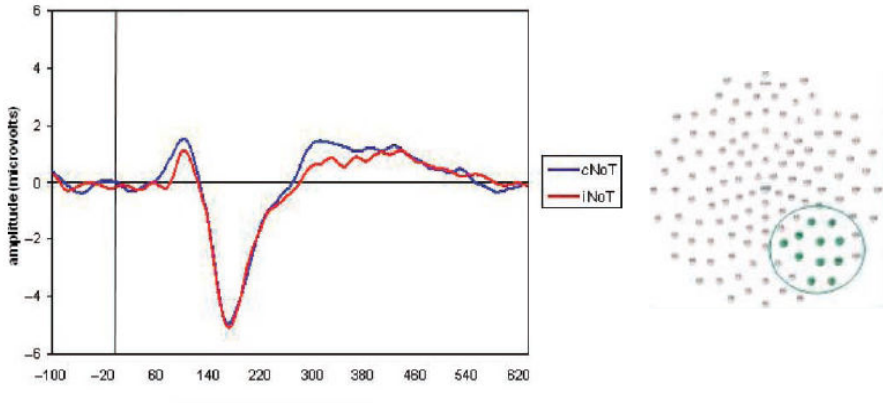


Figure 3.4: ERP waveforms of Scerif et al. (2006) as a function of previous compatibility (context) and No-Go flanker trial type. Also the electrode locations where the ERP waveforms were measured (adapted from Scerif et al. (2006)).

The above findings from the typical flanker trials and the trials involving no central target are inconsistent and difficult to reconcile within a simple spatial attention mechanism. Scerif et al. (2006) suggest that a multi-component account, including aspects of both spatial and non-spatial attention is required. They suggest that differences in spatial frequency between compatible and incompatible may explain the P1 effect observed in the standard flanker trials. Specifically, when the previous trial is incompatible, attention may tune to the higher spatial frequency of incompatible trials, producing an increased response (P1 amplitude) for incompatible trials. However, this interpretation is not entirely clear. Indeed, the predictions made from the flanker trials are not clear regarding differences in P1 amplitude depending upon previous conflict. For example, is a higher P1 amplitude predicted by focused attention on one item or relaxed attention toward all flanker items? This difficulty makes a straightforward interpretation of the standard flanker trials problematic.

The trials containing no central target remove this problem, and as a result, the prediction and interpretation of Scerif et al. (2006) is clearer. For example, when the central target is removed, increased attentional focus toward this location makes the clear prediction that P1 amplitude will be decreased as there will be reduced visual stimulation. Thus, the finding of reduced P1 amplitude following incompatible trials offers support for a potential spatial component in the resolution of conflict within a flanker task.

3.1.1 Limitations of the Scerif et al. (2006) study

Scerif et al. (2006) manipulated the preceding trial context using a series of either three compatible or three incompatible trials. This was done due to the use of the trial sequence for a parallel fMRI experiment. Although this is not of major concern, it does not follow the standard analysis procedure for the investigation of conflict adaptation effects. For example, does the presentation of three consecutive incompatible trials produce a stronger conflict signal when compared to the standard procedure where conflict is determined by the conflict on the preceding trial only? If this is the case, then one would expect increased conflict adaptation effects. However, the conflict adaptation effects observed in the Scerif et al. (2006) study are relatively small (~ 16 ms).

Previous research has shown that response repetitions and alternations may contribute to the conflict adaptation effects in different proportions (see 1.8). Indeed, if the conflict adaptation effect is driven by mainly by response repetitions in the flanker paradigm, as demonstrated previously (e.g. Mayr et al. 2003, Nieuwenhuis et al., 2006), this would be difficult to reconcile within a purely top-down control view related to increased perceptual processing related to the target.

Scerif et al. (2006) considered the influence of response sequence in their analysis. The three-way interaction between response sequence, previous compatibility and current compatibility was not significant (p = .17). However, closer inspection of condition means shows that the size of the conflict adaptation effect after repetition trials was numerically larger (~27 ms) compared to alternation trials (~11 ms). Thus, the lack of a significant three-way interaction may be due to power problems, resulting from the relatively small sample size (n=11).

The data from the standard flanker trials are unclear regarding any spatial attention mechanism. For these trials, increased P1 amplitude was observed for incompatible trials that were preceded by incompatible trials. The explanation offered proposes a feature-based explanation involving differences in spatial frequency between compatible and incompatible trials. However, this explanation is very post-hoc in nature. Indeed, evidence suggests that spatial frequency only affects ERP components at latencies beyond 150 ms (e.g. Martinez, Russo, Anllo-Vento, & Hillyard, 2001), whereas the amplitude difference observed in the Scerif et al. (2006) study occurred before 120 ms. Thus, it is important that this observed increase in P1 amplitude for incompatible trials that are preceded by incompatible trials can be replicated in order that a consistent interpretation can be made.

In addition to the reported modulation of the P1 component within the standard flanker trials, there appears to be differences in amplitude at the N1 component. Although no statistical analysis was reported, visual inspection (see Figure 3.3) indicates a larger N1 amplitude for incompatible trials that were preceded by a compatible context. This dissociation between the P1 and N1 effect is unclear. Indeed, if the P1 effect is driven by changes in spatial frequency as

suggested by the authors, it is likely the effect should also be evident for the N1 component. There are two reasons for this: first, the latency of the N1 effect is more in keeping with previous reports demonstrating that spatial frequency affects ERP components at latencies beyond those observed for the P1 effect (e.g. Martinez et al., 2001; Bass, Kenemans, & Mangun, 2002), and second, previous dissociations between the P1 and N1 have proposed that the N1 indexes detailed perceptual processing (e.g. Mangun, 1995). It is likely that attention toward spatial frequency requires detailed perceptual processing beyond that indexed by the P1 component.

3.1.2 Experimental Aims

The present experiments aimed to further investigate the role of conflict detection and subsequent effects on early visual processing using ERPs. The experiments are based on the same rationale as that adopted by Scerif et al. (2006). Specifically, if the detection of conflict results in increased control by biasing attention toward the task relevant stimulus feature – the central target item in the case of the flanker task – then there should be a modulation of sensory evoked ERP components depending upon the preceding conflict context and current trial characteristics.

The present experiments will try to address some of the limitations within the Scerif et al. (2006) study. First, the analysis of conflict adaptation effects from preceding compatibility will be analysed in a trial-by-trial fashion considering only the compatibility of the immediately preceding trial. Second, an increased number of participants will be used in order to increase statistical power, and third, an analysis of effects over both P1 and N1 components will be conducted.

Overall, are the effects reported by Scerif et al. regarding context effects on subsequent visual processing consistent and replicable?

The first experiment reported examines effects on early visual components within a standard endogenous cueing paradigm. While the attention effects observed within the above flanker task are the result of interactions with the stimulus array, without explicit instruction about where to attend, a comparison between these effects and those observed within a standard cueing paradigm may be useful. This will also help validate the technique adopted within the flanker task used in the subsequent experiment reported. The flanker task will involve standard flanker trials with the addition of what will be called 'probe trials'. These probe trials are intermixed within the standard flanker sequence and involve the presentation of a stimulus in one of the locations determined by the stimulus array. Although this technique deviates from that adopted by Scerif et al. (2006), the use of such probe trials to investigate attentional processes has been validated within the attention literature.

The logic behind the use of these probe trials is similar to that adopted by Luck and Hillyard (1995). Within a visual search array, Luck and Hillyard required participants to report the absence or presence of either colour or shape of a target among an array of distracters. Following the onset of the search array, task irrelevant probes were presented at locations determined by the relevant or irrelevant colour. Luck and Hillyard demonstrated enhanced ERP components elicited by probes presented at relevant as opposed to irrelevant locations. Similar probe trials are the trials of greatest interest for the present experimental hypothesis. It is predicted that the amplitude of early visual components will depend upon the location of the presented probe and the compatibility of the

previous trial. Specifically, when the previous trial is incompatible, attention will be focused toward the central location within the flanker array. When a probe is presented centrally, higher amplitudes of visual components are expected than to probes that are presented laterally (see Figure 3.5).

Figure 3.5: Schematic of proposed attentional focus toward central location after an incompatible trial.

To conclude, the present experiments will further examine the conflict adaptation effect by investigating modulations of early visual components as a function of previous conflict.

3.2 Experiment 1

3.2.1 Rationale

The first experiment adopts a standard attention cueing paradigm. As mentioned previously, this will validate the probe technique and provide potential for comparison between attention effects observed within a standard cueing paradigm and those when attention is manipulated by preceding compatibility.

3.2.2 Method Section

3.2.2.1 Participants

16 University of Glasgow students, aged 19 to 26 years (mean 21 years, 4 male) participated in both experimental tasks in exchange for pay (£6 per hour). Ethical approval for the study was obtained from the Ethics committee of the Faculty of Mathematical and Information Sciences, University of Glasgow. All

participants gave informed consent. All participants reported normal or corrected to normal vision. 14 of the participants were right handed with a mean handedness of 0.83 (Oldfield, 1971).

3.2.2.2 Apparatus and Stimuli

The cue (S1) consisted of a filled arrow that pointed equiprobably either to the left or to the right. The imperative stimulus (S2) was either a square (non-target) or an identical square with a small section (3 pixels) removed from the upper edge positioned centrally (target = Landolt square). S1 subtended 1.8 degrees visual angle in height and 0.9 degrees of visual angle in width while S2 subtended 1 degree visual angle in both height and width. The difference between the target and the non-target stimulus was small to ensure that the task was difficult enough that attentional allocation toward the cued target was necessary to make the discrimination possible. The Landolt square served as the target and required a response, whereas the non-target demanded no response. The participant responded by means of a force-sensitive key that consisted of a leaf spring (100 x 19 mm). A force of 50 cN was required in order for a response to be registered (cf. Leuthold, Sommer & Ulrich, 1996 for details).

3.2.2.3 Design

The spatial orienting task involved two types of trials: valid and invalid trials. Valid trials were presented with probability $p = 0.8$ and invalid trials with probability $p = 0.2$. Valid trials consisted of trials where the cue pointed in the direction of the subsequent target location, whereas in invalid trials, the cue pointed in the opposite direction. Target stimuli were infrequent occurring on only

20 % of trials. The conditions of interest were validity (valid *vs.* invalid) and location (left *vs.* right), resulting in a 2 x 2 design.

A practice block of a sequence of 20 trials was completed at the beginning of the experimental session. Data from the practice block was not included in the analysis. Following the practice block, participants completed 5 blocks of 100 experimental trials, plus an additional single warm-up trial at the beginning of each block. Again, these trials were not included in the analysis. In total, this resulted in 525 trials in one session taking approximately 40 minutes to complete.

3.2.1.4 Procedure

Participants were instructed to allocate attention toward the cued location in order to improve their target discrimination performance and that such attentional allocation should not require any eye movements. hEOG was measured in order to detect any eye movements toward the target. In addition, instructions informed participants about the requirements not to blink during stimulus presentation. These instructions were given to the participant verbally and were also displayed on the screen at the beginning of the experiment. Special care was taken in order to make sure that participants understood the above requirements. Participants sat approximately 80 cm from the screen.

The experimental task was to detect the target stimulus (Landolt square). A schematic of the trial sequence is presented in Figure 3.6. A trial began with the presentation of a fixation cross positioned at the centre of the screen. The fixation cross remained visible for 500 ms before being replaced by the arrow cue (S1). S1 remained visible for 300 ms and was followed by a blank screen for 500 ms. The target (S2) was presented either at the location cued by the arrow (80 % valid)

or the uncued location (20 % invalid). The target stimulus remained on the screen for 150 ms followed by a blank interval of 800 ms. Then the next trial started with the presentation of the fixation cross. Feedback about performance was given. Thus, after target trials there was an additional 2500 ms between trials during which feedback was provided. This took one of four forms. First, correct identification of the target stimulus was given the feedback "Correct".

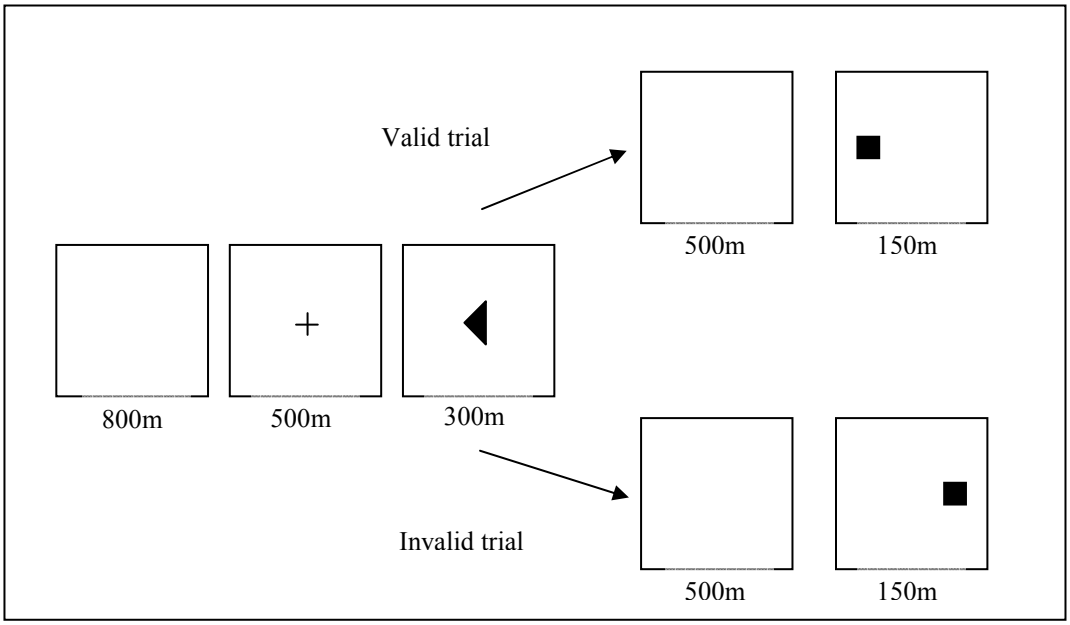


Figure 3.6: Example of trial sequence for attention control task 1. In the upper trial sequence the cue indicates that attention should be paid to the left location. This is where the subsequent stimulus is presented in that location (valid trial). The bottom trial sequence is an invalid trial where the stimulus is presented at the uncued location.

Second, responding to non-targets was given the feedback "Error! Only Respond to Targets". Third, no response to a target trial was given the feedback "Miss! Please press response key to target item". Fourth, responses that were generated within 150ms of stimulus presentation were given the feedback "Too fast!". Feedback information remained on screen for 1500 ms followed by an interval of

1000 ms before the next trial started. The onset of feedback error messages was accompanied by a 3000 Hz tone of 150 ms duration.

3.2.3 Data analysis

3.2.3.1 Behavioural data

Error rates for target trials were recorded and were analyzed by a repeated measure ANOVA with the within-subject factors validity (valid *vs.* invalid) and side (left *vs.* right).

3.2.3.2 ERP Data

3.2.3.2.1 P1 and N1 Components

The analysis epoch started 100 ms prior to cue onset and lasted for a total duration of 1600 ms. A 100-ms pre target interval was used as a baseline. In order to investigate attentional effects on visual processing of standard trials, mean P1 and N1 amplitudes at electrode sites PO7 and PO8 were analysed in 50 ms intervals between 90-140 ms and 150-200 ms, respectively. PO7 and PO8 were chosen as the P1 and N1 components were largest at these sites. Mean amplitudes were analysed by a repeated measures ANOVA with the within-subject factors validity (valid vs. invalid), side (left vs. right) and electrode (PO7 vs. PO8).

3.2.4 Results

3.2.4.1 Behavioural Data

Error rates to valid and invalidly cued trials are displayed in Figure 3.7. Error rate for target detection was lower for valid than for invalid trials (11.8 %

vs. 62.8 %); $F(1, 15) = 47.4$, $MSE = 878.6$, $p < .0001$. Cue validity did not interact with side; $F(1, 15) = 3.18$, $MSE = 137.96$, $p > .05$.

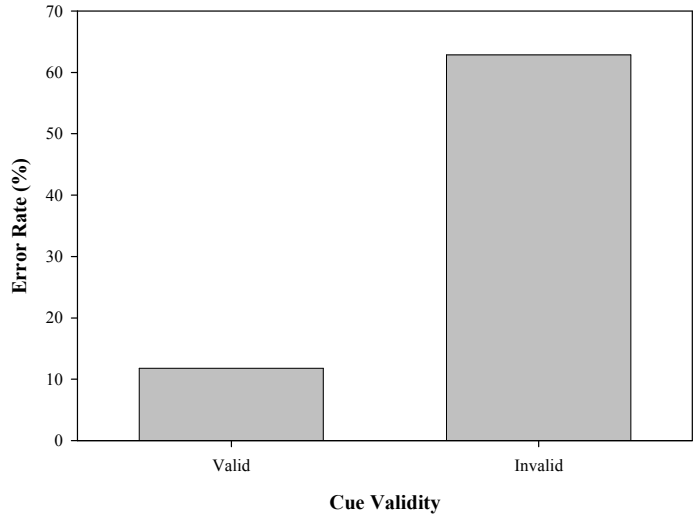


Figure 3.7: Error rates to target trials as a function of cue validity

3.2.4.2 ERP Data

Grand averaged ERP waveforms for electrodes PO7 and PO8 are displayed in Figure 3.8.

3.2.4.2.1 P1 component

There was a main effect of validity with mean P1 amplitude for valid targets being larger (3.36 μV) than for invalid targets (1.81 μV); $F(1, 15) = 27.8$, $MSE = 2.76$, $p < .0001$. There was a significant two-way interaction between side and electrode; $F(1, 15) = 8.89$, $MSE = 4.97$, $p < .01$, with P1 amplitude being larger over the electrode located ipsilateral to the stimulus location.

3.2.4.2.2 N1 component

Only the two-way interaction between side and electrode was significant; $F(1, 15) = 44.3$, $MSE = 6.47$, $p < .0001$, indicating a larger N1 amplitude over the electrode contralateral to stimulus presentation.

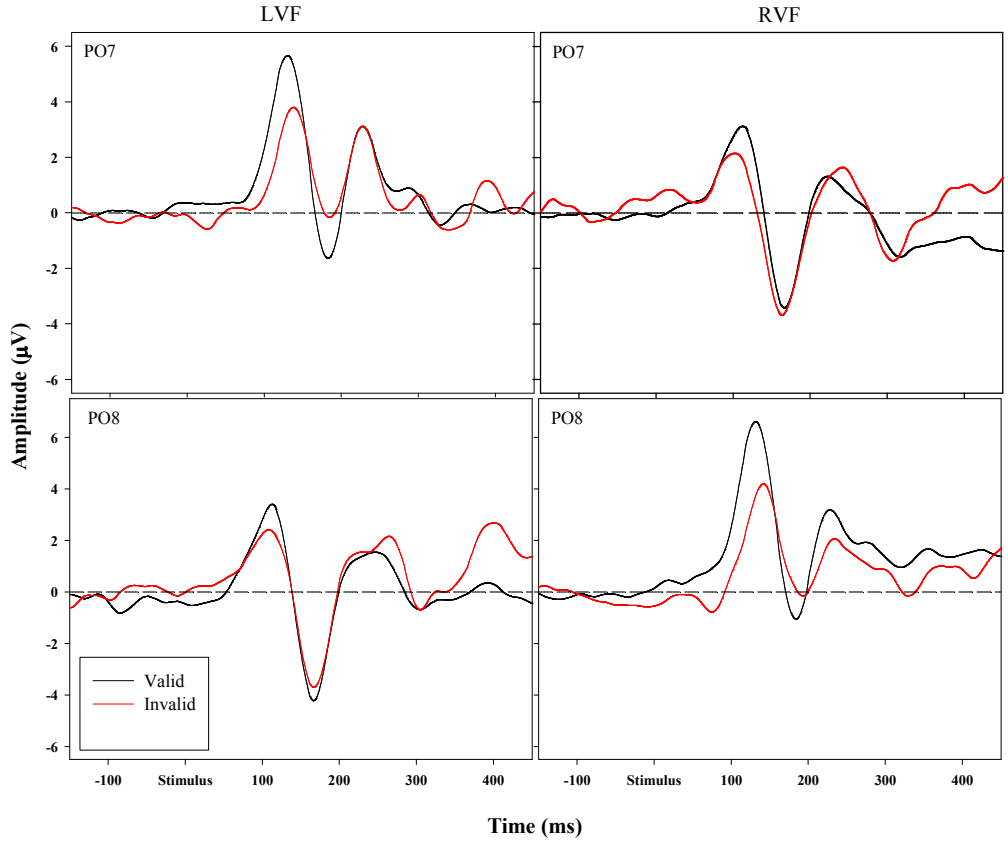


Figure 3.8: P1 and N1 components for stimuli presented to the left visual field (left column) and stimuli presented to the right visual field (right column) as a function of cue validity at electrode site PO7 (top row) and PO8 (bottom row). NB. ERP analysis was conducted on standard trials only that required no response to the target.

3.2.5 Discussion

The experiment was designed to demonstrate standard attentional effects on early visual components when attention is explicitly cued. The participants task was to direct attention toward the side indicated by the cue. A subsequent stimulus was presented at either the location indicated by the cue ($p = 0.8$) or the opposite

location (p = 0.2). This subsequent stimulus was termed a target when it required a response. These target trials served to keep the participants interested in the task, and to assess behaviourally, the extent to which attention was effectively cued. If the cue effectively directed attention toward the intended location, and if the task was demanding in terms of needing attention to perform the task, then one would expect that targets presented in the uncued location would be missed more often than targets presented in the cued location. The results demonstrated that this was the case with clear attentional effects in terms of behaviour. Error rates for targets presented at the uncued location were significantly higher than error rates to targets presented at the cued location. Thus, it can be concluded that participants followed task instructions and attended to the location indicated by the cue.

In terms of the effects of attention on early visual processing, non-target trials served as the trials of interest. For the P1 component, the results demonstrated that P1 amplitude was significantly larger for valid than invalid trials. In addition, P1 amplitude was larger at electrode sites ipsilateral to the stimulus location. For the N1 component, there was no main effect of trial validity. In contrast to the P1 effect, N1 amplitude was larger over electrode sites contralateral to the stimulus location.

The finding of an attention effect in P1 amplitude but not in N1 amplitude using a detection task replicates previous findings from the attention literature (e.g. Mangun & Hillyard, 1991). Thus, the lack of an attention effect in N1 amplitude is likely a result of the task requirements adopted here, with the N1 effect only being evident when the task requires a two-choice discrimination task (Mangun & Hillyard, 1991).

In conclusion, the present experiment demonstrated clear attentional effects on the amplitude of the P1 component but not the N1 component within a paradigm where attention is explicitly cued and required a simple detection response.

3.3 Experiment 2

3.3.1 Rationale

Experiment 2 investigates whether such attentional effects observed under explicit cue instruction in Experiment 1 can also be observed when there is no explicit cue as to where to attend. Here, in a similar fashion to Scerif et al. (2006), it is proposed that differences in preceding compatibility within a standard flanker task will result in differences in attentional allocation in the current trial. Specifically, the occurrence of an incompatible trial produces conflict that will result in increased control being exerted on the following trials. This increased control will manifest itself as increased attentional allocation toward task-relevant information, that is, in the case of the flanker task, increased attentional allocation toward the central spatial location.

3.3.2 Method Section

3.3.2.1 Participants

As Experiment 1.

3.3.2.2 Apparatus and Stimuli

Stimuli consisted of filled solid arrows that either pointed to the right or the left. All stimuli were presented in white on black background on a standard computer monitor (15 inch). The target stimulus was presented in the centre of the

display. Additional flanker stimuli (either pointing in the same direction as the target or pointing in the opposite direction) were presented to the left and right of the target stimulus. The centre-to-centre distance between two items within the flanker array was approximately 3.2 degrees of visual angle. Each flanker array subtended 7.5 degrees of visual angle in width and 1.8 degrees of visual angle in height. In addition to the arrow stimuli, the probe stimulus consisted of a square presented in the same luminance as the arrow stimuli subtending 1 degree of visual angle in both height and width. A tone of 3000 Hz was presented in response to error trials and lasted for 150 ms. Responds were by means of force-sensitive keys that consisted of two leaf springs (100 x 19 mm) mounted in front of the participant positioned approximately 30 cm apart horizontally. A force of 50 cN was required in order for a response to be registered.

3.3.2.3 Design

Experimental trials were either compatible or incompatible. On compatible trials, the central stimulus and the flankers matched, whereas on incompatible trials the two flanker stimuli pointed in the opposite direction to that of the central target stimulus.

Additional experimental conditions were created subsequently when considering a sequential analysis of flanker compatibility and response. This resulted in a 2(current compatibility: compatible vs. incompatible) x 2(previous compatibility: compatible vs. incompatible) x 2(response type: response alternation vs. response repetition) design.

3.3.2.4 Procedure

At the beginning of the experiment verbal instructions were given to the participant. Instructions were also displayed that remained on screen until the participant initiated the trial sequence by pressing the appropriate key. The experimental task was to respond to the direction of the centrally presented target arrow. That is, the left-pointing target arrow demanded a left button response while the right-pointing target arrows demand a right button response. Participants were informed that only the central arrow served as a target and that the flanker stimuli were to be ignored. In addition, participants were informed that probe stimuli would be presented randomly intermixed within the trial sequence at one of three locations (random) defined by the locations of the flanker array and that these probe stimuli required no response. Thus, central probes were presented at fixation with left and right probes presented at approximately 3.5 degrees of visual angle to the left and right respectively.

A schematic of the trial sequence is presented in Figure 3.9. A trial began with the presentation of a fixation cross. This was presented for 200 ms followed by a blank screen for 500 ms. The presentation of the arrow stimuli or the probe stimulus then followed. The arrow stimuli remained on screen until a response was made or 2000 ms elapsed. When no response was made within 2000 ms or when an incorrect response was made, an error tone sounded for 150 ms. All error trials were removed from the analysis as were trials following errors. The next trial began with the presentation of the fixation cross followed again by the 500 ms blank screen. Probe trials were inter-mixed randomly (20 %) within the flanker trial sequence. The probe was presented to one of three locations defined by the locations of the flanker stimuli and remained on screen for 150 ms. A blank

screen of 500 ms followed this in order to more closely resemble the timing parameters of a trial where a response is required. It was possible during the experimental procedure that two (or more) probes would be presented sequentially. However, such instances of consecutive probe trials were removed from the analysis post-hoc.

A practice block of a sequence of 30 trials was completed at the beginning of the experimental session. Data from the practice blocks was not analysed. Following the practice block, participants completed 14 blocks of 90 trials. The first four trials of each block were treated as a warm-up and thus were discarded from the analysis. In total, 1346 trials were presented in *one* session, taking approximately 70 minutes to complete. During each break, feedback regarding accuracy and mean response time for the previous block was given.

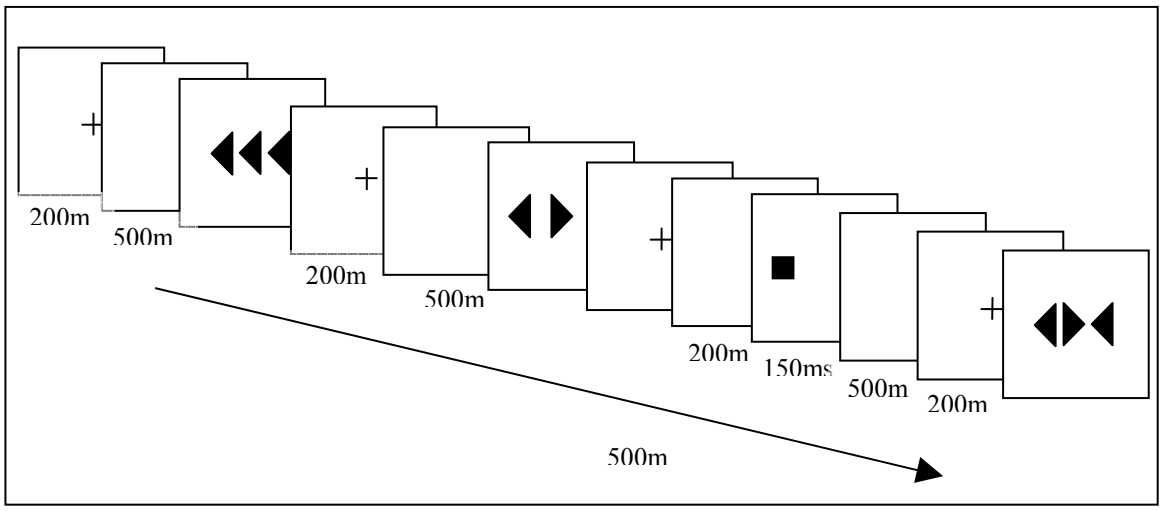


Figure 3.9: Schematic of trial sequence. Probe trials were randomly intermixed within blocks of standard flanker trials.

3.3.3 Data analysis

3.3.3.1 Behavioural data

Trials with incorrect responses, those following an incorrect response and with a RT < 150 ms (anticipation) and > 2000 ms (miss) were excluded from the RT analysis. Statistical analyses were performed by repeated-measures ANOVA. For the analysis of RT and error rate for flanker trials, the within-subject variables were current compatibility (compatible vs. incompatible), previous compatibility (compatible vs. incompatible), and response sequence (alternation vs. repetition).

3.3.4 ERP Data

3.3.4.1 P1 and N1 Components

An averaging epoch time-locked to stimulus onset encapsulating 500 ms pre-stimulus and 1000 ms post-stimulus duration was used. ERP waveforms were aligned to a 100-ms pre-stimulus baseline. Mean amplitude of ERP waveforms within the time interval 70-130 ms for the P1 component and 130-200 ms for the N1 component at electrode sites PO7 and PO8 was computed for all conditions. Analysis was performed by repeated measures ANOVA. For the flanker trials the within-subject variables were current compatibility (compatible vs. incompatible), previous compatibility (compatible vs. incompatible), response sequence (alternation vs. repetition) and electrode site (PO7 vs. PO8). For the probe trials the within-subject factors were previous compatibility (compatible *vs.* incompatible), probe location (left vs. right vs. middle) and electrode (PO7 vs. PO8).

3.3.4.2 LRP

S-LRP onsets were measured relative to a 100-ms pre-stimulus baseline to the point in time where LRP amplitude exceeded a predefined criterion of -0.8 μV in that specific condition. The LRP-R interval was determined using the same onset criteria as the S-LRP with waveforms aligned to a 100-ms baseline that started 500 ms before the response. The within-subject variables were current compatibility (compatible *vs.* incompatible) and previous compatibility (compatible *vs.* incompatible).

3.3.5 Results

3.3.5.1 Behavioural Data

3.3.5.1.1 RT

Mean RT for the flanker trials are shown in Figure 3.10 separately for response repetitions (left panel) and response alternations (right panel). Overall, there was a main effect of compatibility with faster responses to compatible trials (479 ms) than to incompatible trials (518 ms); $F(1, 15) = 54.83$, $MSE = 864.05$, $p < .0001$, resulting in a flanker compatibility effect of 39 ms. No other main effects were significant (all Fs < 1, ps > .69). Importantly, the two-way interaction between current compatibility and previous compatibility was significant; $F(1, 15) = 17.31$, $MSE = 139.81$, $p < .001$. The compatibility effect was 17 ms larger if the preceding trial was compatible rather than incompatible, reflecting the conflict adaptation effect (cf. Gratton et al., 1992). However, this effect was modulated by response sequence as indicated by the significant Current Compatibility x Previous Compatibility x Response Sequence interaction; $F(1, 15) = 12.32$, *MSE*

= 253.35, $p < .001$. The conflict adaptation effect was present only for response repetitions (37 ms) but absent for response alternation trials (-2 ms).

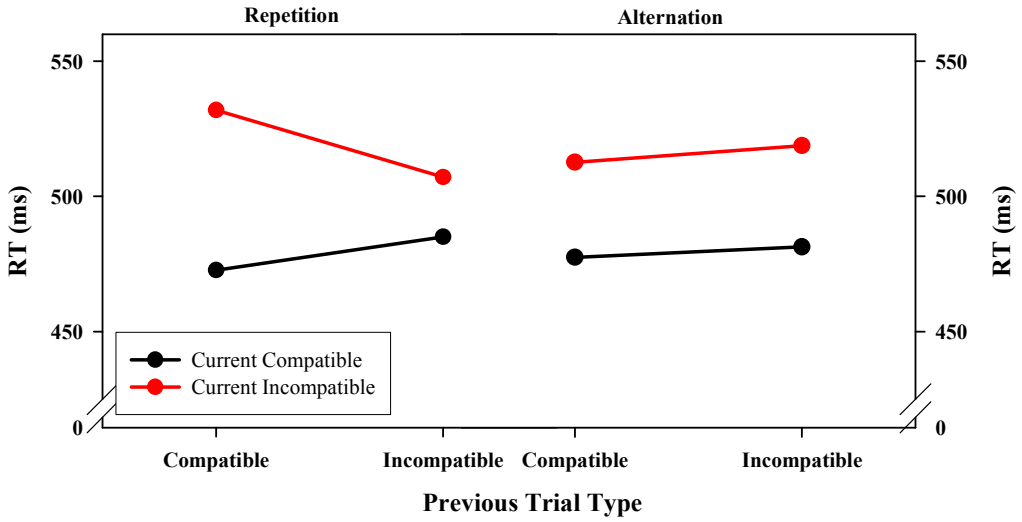


Figure 3.10: Mean RT as a function of previous compatibility and current compatibility plotted separately for response alternation trials (left panel) and response alternation trials (right panel).

3.3.5.1.2 Error Rate

Mean error rates for the flanker trials are shown in Figure 3.11 separately for response repetitions (left panel) and response alternations (right panel). An analogous analysis to that conducted on RT was performed for error rates. Overall, there was a main effect of compatibility with more errors being made to incompatible trials (3.57 %) than to compatible stimuli (1.19 %); $F(1, 15) = 22.58$, $MSE = 8.02$, $p < .001$. There was a main effect of previous compatibility with more errors being made when the previous trial was compatible (2.89 %) than when the previous trial was incompatible (1.86 %); $F(1, 15) = 7.68$, $MSE = 4.36$, $p < .05$. However, like the RT data, the Current Compatibility x Previous Compatibility interaction; $F(1, 15) = 7.66$, $MSE = 3.40$, $p < .05$, was modulated by Response Sequence; $F(1, 15) = 7.41$, $MSE = 4.65$, $p < .05$. The conflict

adaptation effect in error rate was present for response repetitions (3.89 %) but was absent for response alternation trials (-0.27 %).

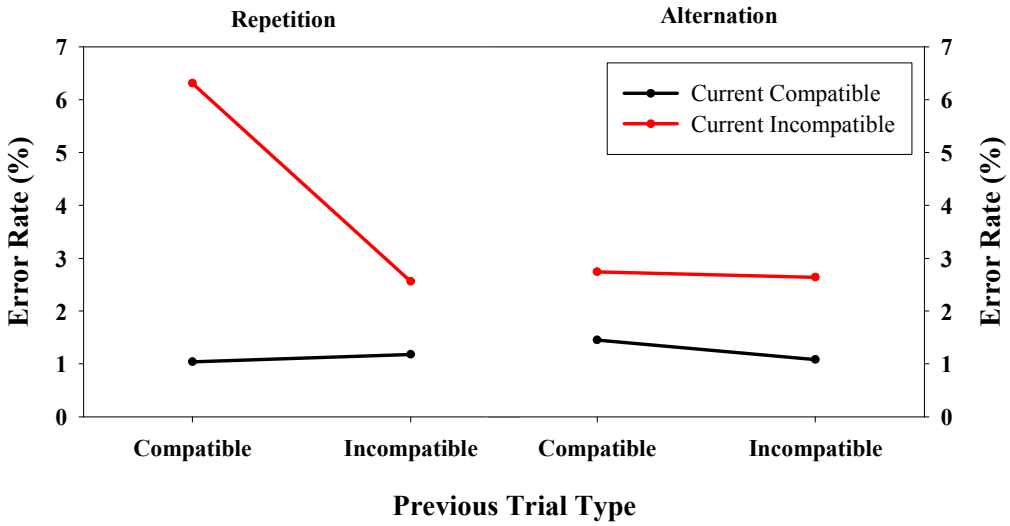


Figure 3.11: Mean error rate as a function of previous compatibility and current compatibility type plotted separately for response repetition trials (left panel) and response alternation trials (right panel).

3.3.5.2 ERP Data

3.3.5.2.1 Flanker trials

Grand average waveforms for each of the flanker conditions are displayed in Figure 3.12.

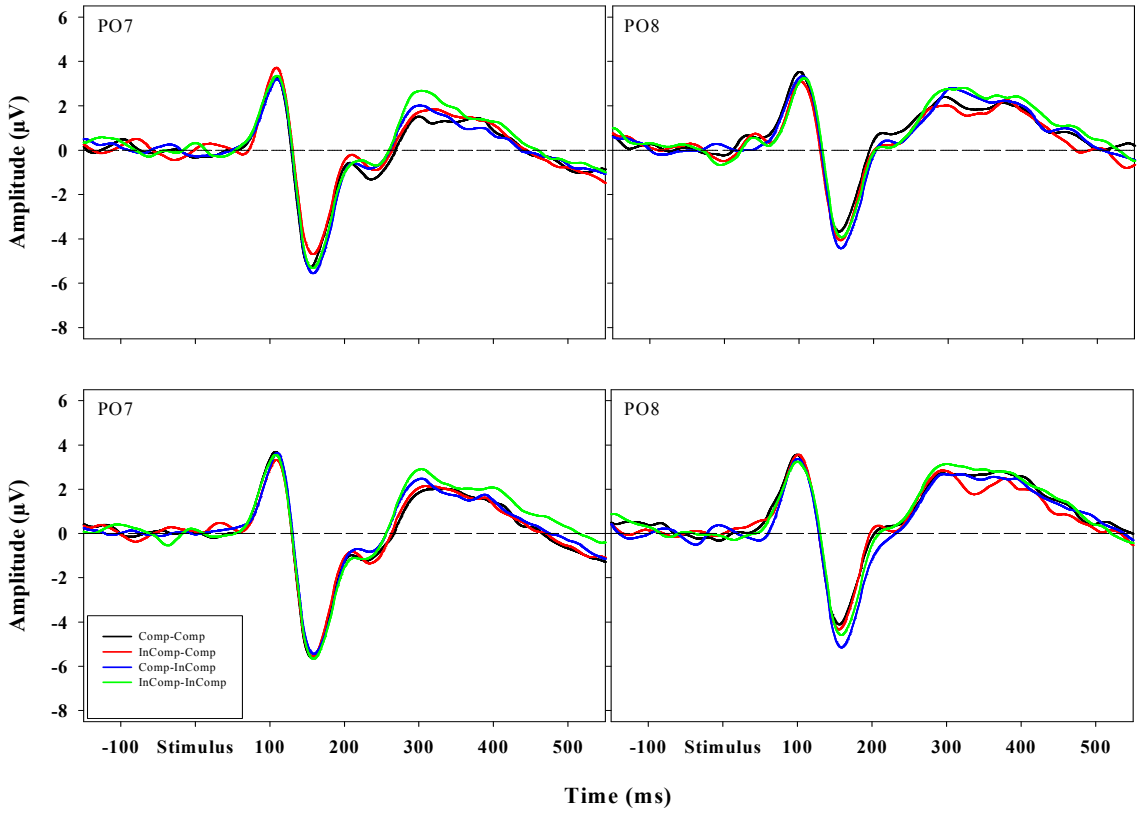


Figure 3.12: P1 and N1 Components at electrode sites PO7 (left) and PO8 (right) for response repetition trials (top row) and response alternation trials (bottom row) as a function of previous compatibility and current compatibility.

3.3.5.2.1.1 P1 Component

None of the main effects were significant (all Fs < 1.33, ps > .27) nor were any of the two-way interactions (all Fs < 1.18, ps > .29). There was a significant three-way interaction between previous compatibility, response sequence and electrode; $F(1, 15) = 7.90$, $MSE = 0.22$, $p < .05$. This three-way interaction suggests that previous compatibility did little to influence response alternation trials but

produced reverse effects at electrode sites PO7 and PO8 for response repetition trials (see Figure 3.13).

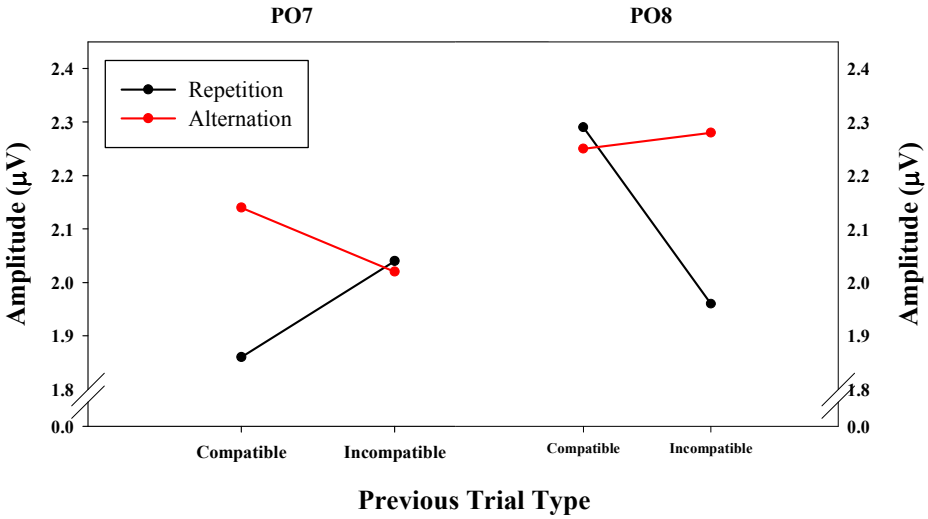


Figure 3.13: Mean P1 amplitude as a function of previous trial type and response sequence plotted separately for electrode site PO7 (left panel) and PO8 (right panel).

3.3.5.2.1.2 N1 Component

There was a main effect of current compatibility with mean N1 amplitude being larger for incompatible trials (-3.05 μV) than for compatible trials (-2.73 μV); $F(1, 15) = 7.83$, $MSE = 0.85$, $p < .05$, and of response sequence with mean N1 amplitude being larger for alternation trials (-3.08 μV) than repetition trials (-2.69 μV); $F(1, 15) = 16.21$, $MSE = 0.60$, $p < .01$.

None of the two-way interactions were significant (all Fs < 1.83, ps > .20). The three-way interaction between previous compatibility, current compatibility and electrode was significant; $F(1, 15) = 6.65$, $MSE = 0.60$, $p < .05$. For Comp-Comp trials, mean N1 amplitude was approximately 1.3 μV greater over PO7 than PO8. This difference was reduced to 0.7 μV when the previous trial was incompatible. For Comp-InComp trials mean N1 amplitude was 0.5 μV greater over PO7 than PO8 while for two consecutive incompatible trials, mean N1

amplitude was approximately 1 μV greater over PO7 than PO8. None of the other three-way interactions were significant (all *F*s < 2.55, *p*s > .13).

3.3.5.2.1.3 LRP data

3.3.5.2.1.3.1 S-LRP

Stimulus-locked LRP waveforms are displayed in Figure 3.14. Onsets were measured between 100 and 400 ms post stimulus. There was a significant main effect of current compatibility with the S-LRP interval for compatible trials being shorter (229 ms) compared to incompatible trials (267 ms); $F_c(1, 15) = 4.35$, $MSE = 46.33$, $p = .055$. There was no significant main effect of previous compatibility nor was the two-way interaction between previous and current compatibility significant (all F_cs < 1).

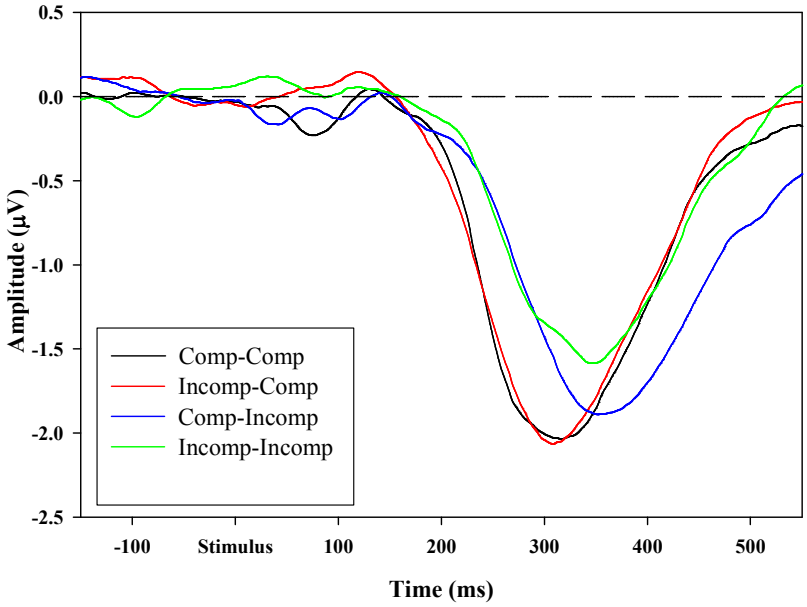


Figure 3.14: Stimulus-locked LRP interval for the flanker trials.

3.3.5.2.1.3.2 LRP-R

Response-locked LRP waveforms are displayed in Figure 3.15. Onsets were measured between 300 ms and 100 ms pre-response. None of the main effects or lower level interactions reached significance (all *F*s < 1).

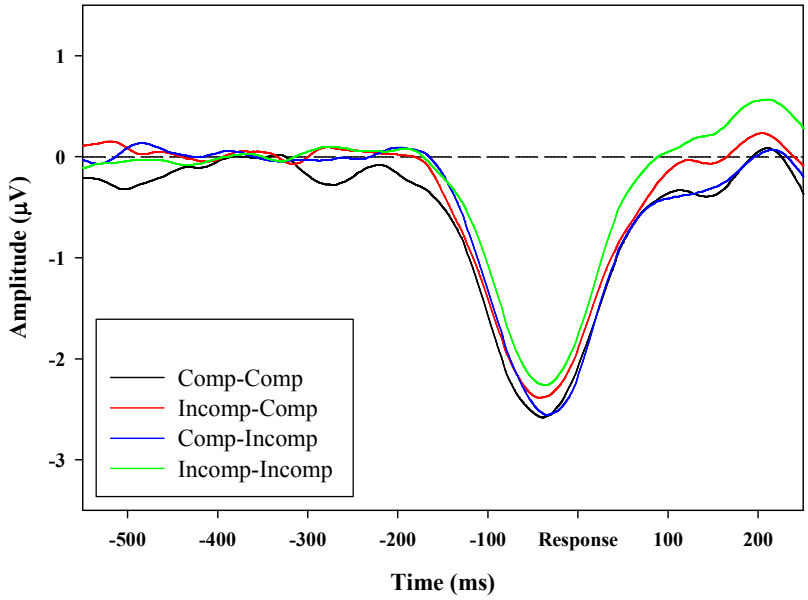


Figure 3.15: Response locked LRP interval for the flanker trials.

3.3.5.2.2 Probe Trials

Grand averaged waveforms for each of the probe conditions are displayed in Figure 3.16.

3.3.5.2.2.1 P1 Component

There was a significant main effect of probe location with mean P1 amplitude for probe stimuli presented in the centre location (1.94 µV) being larger than at the left (0.73 µV) and right (1.15 µV) locations; $F(2, 30) = 6.68$, *MSE* =

3.57, $p < .01$. Importantly, the two-way interaction between previous compatibility and probe location was not significant; $F < 1$, $p > .08$. No other main effect or interaction was significant (all Fs < 1.03, ps > .37).

3.3.5.2.2.2 N1 Component

None of the main effects were significant; all Fs < 1. The two-way interaction between probe position and electrode was significant; $F(2, 30) = 28.60$, $MSE = 5.24$, $p < .0001$, indicating a larger N1 amplitude contralateral to probe location. For left location probes, mean N1 amplitude was higher over PO8 (-1.65 μV) compared to PO7 (1.23 μV). For right location probes, mean N1 amplitude was higher over PO7 (-1.53 μV) compared to PO8 (1.71 μV). For the central probe location mean P1 peak amplitudes were similar over PO7 and PO8 (0.32 μV vs. 0.11 μV respectively). Importantly, in terms of attentional modulation dependent upon previous trial conflict, the two-way interaction between previous compatibility and probe position was not significant; $F(2, 30) = 1.14$, $MSE = 2.44$, $p > .05$.[2]

[2] It is possible that the use of an average window measure across lateral electrode locations with lateralised stimuli hide some effects of amplitude. However, additional analyses using peak amplitudes within the same time frame did not reveal any effects of note that differ to those observed when using an average window measure.

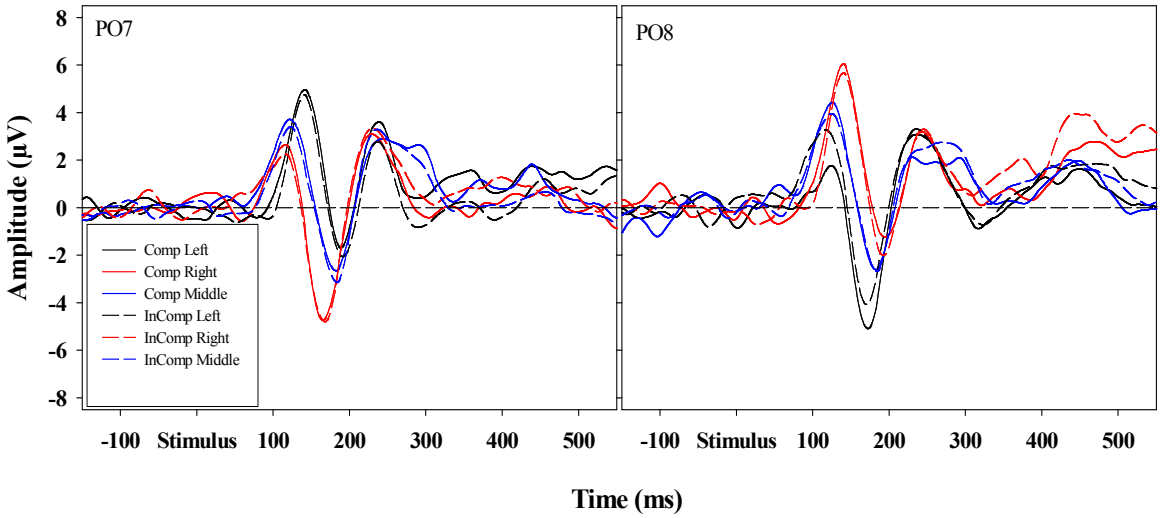


Figure 3.16: P1 and N1 components at electrode sites PO7 (left) and PO8 (right) as a function of previous compatibility and probe location.

3.3.6 Discussion

The present experiment investigated the conflict adaptation effect within the flanker task. Specifically, does the detection of conflict in a previous trial result in increased control in the current trial by causing a focusing of attention toward task-relevant information, that is, the central spatial location within the flanker array? This was investigated by recording ERPs to additional probe stimuli presented at one of three locations determined by the locations of the flankers within the array. It was predicted that the amplitude of early visual components would be dependent upon previous conflict and the probe location. Specifically, when the previous trial is incompatible, conflict is detected and attention on the current trial will be focused on the central location. When the probe is presented in this central location, higher amplitudes of early ERP components were predicted when compared to probes that are presented laterally.

Before considering the ERP data, the behavioural data needs to be discussed. First, is the typical conflict adaptation effect evident in the behavioural

results from the standard flanker trials? The typical interference effect (RT difference) between compatible and incompatible trials was observed with faster responses to compatible trials than to incompatible trials. In addition, this interference effect was reduced both in terms of RT and error rate when the previous trial was incompatible compared to compatible and reflects the typical conflict adaptation effect (cf. Gratton et al., 1992). This result supports the idea that after the occurrence of conflict, increased control is exerted in the current trial to reduce the influence of future conflict. The size of the conflict adaptation effect within the present experiment was 17 ms. This compares to a conflict adaptation effect of 16 ms within the Scerif et al. (2006) study. The similarity of the conflict adaptation effects across the present experiment and the Scerif et al. (2006) study suggests that considering conflict across the previous trial only and across the context of the three previous trials are comparable. However, these observed conflict adaptation effects are relatively small. For example, Nieuwenhuis et al. (2006) observed conflict adaptation effects of approximately 60 ms (Exp 1.) within a similar flanker task. Why the observed effects are smaller in the present study is unclear. One likely explanation concerns Nieuwenhuis et al.'s use of delay of 100 ms between the presentation of the flankers and the central target. This was done to increase processing conflict. The flankers and the central target in both the present experiment and that of Scerif et al. were presented simultaneously. This difference in conflict adaptation effects fits well with the idea that the experience of greater conflict will produce increased control. Indeed, Kunde and Wühr (2006), within a prime-target paradigm, demonstrated that the size of the conflict adaptation effect varied accordingly to the size of conflict with longer prime durations producing greater conflict modulation. Such results offer

support to a top-down control view that the detection of conflict recruits control mechanisms that reduce the influence of conflict in subsequent trials and that the size of conflict experienced determines the extent to which control mechanisms are implemented.

However, the above analysis from the present experiment does not consider the influence of response repetitions and alternations. If the conflict adaptation effect differs depending upon whether the response repeated or alternated, it is difficult to attribute the effect solely to a top-down mechanism of control (Mayr et al., 2003). The analysis of the conflict adaptation effect across response repetitions and alternations indicated that it was specific to response repetitions only. The finding from the present experiment that the conflict adaptation effect within a flanker task is evident only for response repetitions replicates previous results using a flanker paradigm (e.g. Mayr et al., 2003; Nieuwenhuis et al., 2006). This result differs from that of Scerif et al. (2006) where they demonstrated that the effect of response repetitions and alternations did not significantly affect the conflict adaptation effect. The reason for this discrepancy between the influence of response sequence between the present experiment and that of Scerif et al. is unclear. Although subtle differences between the paradigms adopted are evident, for example, the use of a three-trial preceding context in the study of Scerif et al. and the use of additional probe trials in the present study, it is unclear how these difference might influence the effect. A more likely explanation relies on statistical power. Although response sequence did not significantly affect the conflict adaptation effect within the Scerif et al. study, they did observe more (~ 16 ms) conflict adaptation in response repetition

trials than on response alternation trials. It is possible that with an increased sample size, as in the present study, that this effect would become significant.

The above behavioural findings question the need for a top-down control view of conflict adaptation effects within the flanker task. Instead, they highlight the importance of bottom-up processing confounds related to differences in RT caused by disproportionate influences of response properties across different sequence transitions (see 1.8; Mayr et al., 2003). However, Scerif et al. (2006) observed context effects on subsequent visual processing that were not influenced by response sequence. Indeed, their results, at least partly, support the idea that the experience of conflict leads to recruitment of control processes that are implemented by a perceptual biasing toward task relevant information. It is difficult to reconcile this potential perceptual biasing mechanism within a purely bottom-up processing account.

The Scerif et al. (2006) study demonstrated that, for the standard flanker trials, P1 amplitude was increased for incompatible trials that were preceded by incompatible trials across central occipital electrode sites. The present experiment failed to replicate this finding when analysing the P1 at electrode sites where the component was largest, namely, over lateral occipital sites PO7 and PO8. P1 amplitude was not affected by previous or current compatibility nor their interaction (*N.B.* An identical analysis to that conducted over PO7 and PO8 was performed over central occipital sites to mirror the analysis of Scerif et al., but again, P1 amplitude was unaffected by previous and current compatibility). Although Scerif et al. offer an explanation of their observed effect in terms of a feature-based account related to spatial frequency, as mentioned previously, this account is unclear. As spatial frequency was not manipulated explicitly within the

present study, any explanation or interpretation would be entirely speculative in nature. What the present results from the standard flanker trials do show is that the observed P1 effect within the Scerif et al. study is inconsistent. Thus, further research would be needed before a confident interpretation of this effect can be made.

Analysis of the N1 component in the present experiment, again across electrode sites PO7 and PO8, indicated that current compatibility influenced N1 amplitude with a larger N1 amplitude for incompatible trails than compatible trials. It is a possibility that this increased N1 amplitude for incompatible trials reflects increased detailed perceptual processing required for these trials when compared to compatible trials and that this increased detailed perceptual processing is indexed by the N1 (e.g. Mangun, 1995). However, this effect was not influenced by previous compatibility and thus, cannot be the result of increased target processing after the detection of conflict in the previous trial.

The above ERP results concerned the P1 and N1 amplitudes within standard flanker trials. However, it is the probe trials that make the clearest predictions regarding the influence of previous conflict on subsequent visual processing. Scerif et al. (2006) demonstrated that after an incompatible trial, P1 amplitude was reduced for flanker arrays that contained no central target compared to identical flanker arrays that were preceded by compatible trials. The authors proposed that this effect was the result of increased attention toward the central location after an incompatible trial and as there was no central target within such no-target trials, there was reduced visual stimulation, thus producing a reduced P1 amplitude. The present experiment investigated this by presenting probe stimuli in central and lateral locations and compared the amplitude of visual

components depending upon previous trial conflict. The results showed that P1 amplitude to probe stimuli was affected by probe location with higher P1 amplitudes to probes presented centrally compared to those presented laterally. This validates the probe technique somewhat, as it is expected that participants will generally attend to the central location over other locations. Most importantly, however, this effect was not modulated by previous compatibility nor was the main effect of previous compatibility significant.

N1 amplitude was not affected by probe location when considered across hemisphere. This is consistent with the results of Experiment 1 which demonstrated a lack of an attention effect on N1 amplitude and also previous results suggesting that an N1 attention effect is only evident when making a two-choice discrimination (e.g. Mangun & Hillyard, 1991). The observed interaction between probe location and electrode for N1 amplitude reflects latency differences across lateral electrode sites when stimuli are presented at lateral locations and is consistent with the organisation of the visual cortex. For example, stimuli presented in the left visual field will produce visual components that peak earlier across electrode sites in the right visual cortex, and vice versa.

The above ERP results from the probe trials, for both the P1 and N1 component do not show any effects of attention depending upon probe location and previous compatibility. Again, like the ERP data for the standard flanker trials, the data from the current probe trials cannot replicate the findings of the no-target trials from the Scerif et al. (2006) study. The results from the present experiment offer no additional support to the idea of a focusing of attention toward the target location after an incompatible trial.

It is difficult to reconcile the findings from the present experiment and those of Scerif et al. (2006). Concentrating on the flanker arrays with no central target from the Scerif et al. study and the probe trials from the present study – those trials that make the clearest predictions – it is possible that procedural differences contributed. For example, it might be argued that probe stimuli were treated differently by participants than the standard flanker stimuli. For example, attention might be captured by these stimuli in an automatic fashion irrespective of their location and the previous context. However, this is unlikely for two reasons. First, the stimulus sequence was unpredictable and the probes were presented following the same time course as the standard flanker trials. Hence, the participant had no way of knowing what trial was going to be presented next. Increased attentional focus toward the central location after an incompatible trial should occur irrespective of whether the next trial constituted a standard flanker trial or a probe trial. Second, the probe trials did demonstrate attentional effects in P1 amplitude depending on their location, albeit, irrespective of previous compatibility.

A close inspection of the amplitude difference from the no-target trials in the study of Scerif et al. (2006) indicates a possible latency difference in the onset of the P1 component between no-target trials that were preceded by compatible and incompatible trials respectively. It is possible that such a latency difference might produce an observed difference in amplitude when using an area measure that encompasses the onset of one component before the onset of the component in the other condition. It is difficult to say why this latency difference might occur between no-target trials, especially when the onset of the P1 component is consistent across the standard flanker trials. Indeed, a latency difference between

conditions cannot be explained by differences in attentional allocation as attention has been shown to influence component amplitude only (e.g. Gonzalez et al., 1994).

When considering the standard flanker trials from the Scerif et al. (2006) study and the standard flanker trials from the present experiment, the observed P1 amplitude increase for incompatible trials preceded by incompatible trials in the Scerif et al. (2006) was not replicated. Again, it is unclear why this might be. Scerif et al. proposed a feature-based explanation that relies on differences between spatial frequency between compatible and incompatible flanker arrays. One possible explanation for this discrepancy, although entirely speculative, concerns physical differences between the flanker arrays within the Scerif et al. study and those of the present experiment. The Scerif et al. study used standard flanker arrays that contained 7 arrow stimuli (1 central target and 6 surrounding flankers) while the present experiment contained 3 arrow stimuli (1 central target and 2 surrounding flankers). The use of 7 flanker stimuli over 3 within visual arrays that subtend similar degrees of visual angle in the horizontal dimension means that the flanker arrays within the Scerif et al. study contained higher spatial frequencies compared to the present study. It is possible that this difference contributed to the discrepancy between results.

Additional procedural considerations from the present experiment are also warranted. For example, the present experiment presented a fixation cross between trials. This is a common procedure within cognitive tasks and is used to ensure participants are attending in the correct location. It is possible that the use of such a fixation cross interfered with attentional allocation to locations defined by the stimulus flanker array. For example, if attention is relaxed after the

occurrence of a compatible trial, the presentation of a central fixation cross might refocus attention toward the central location irrespective of previous trial type. Indeed, it could be argued that the fixation cross acted in a similar fashion to a peripheral cue that captures attention.

In conclusion, the present experiment demonstrated conflict adaptation effects in behaviour (both RT and error rate) between standard flanker trials. However, these conflict adaptation effects were specific to response repetition trials only. The ERP data offered no support for the proposal that the detection of conflict leads to a perceptual biasing mechanism that reduces future conflicts by focusing on task-relevant stimulus features.

3.4 Experiment 3

3.4.1 Rationale

The following experiment continued with the investigation of the effect of conflict on early visual processing. It adopts a flanker task similar to that used in Experiment 2 and is based on the same rationale used there. However, minor alterations have been made. These alterations include the use of NoGo trials in a similar fashion to those used by Scerif et al. (2006) in place of the probe trials used in Experiment 2. This will allow a more direct comparison between results observed previously. However, Experiment 3 will extend the Scerif et al. study by involving the use of two different NoGo trial types. The first will be identical to that used by Scerif et al. and comprises a flanker array that omits the central target. The second NoGo trial type consists of only the central target with the surrounding flankers removed. Scerif et al.'s conclusion from their no-target trial type is based on one data point only, namely, an increased P1 amplitude for a no-

target flanker when it was preceded by a compatible trial compared to an incompatible trial. It is proposed that the use of a second NoGo trial type consisting of only a central target will provide an additional condition that, according to a spatial explanation of attentional allocation, predicts opposite effects on visual component amplitudes compared to the flanker array with the central target omitted. Specifically, for a NoGo trial containing only the central target, after an incompatible trial, increased attention toward the central target will produce increased visual component amplitudes when compared to those preceded by a compatible array.

Additional changes between the present experiment and Experiment 2 include the removal of the fixation cross between trials for the reasons highlighted above. Also, a flanker array identical to that of Scerif et al. (2006) containing 7 flanker stimuli will be used.

3.4.2 Method Section

3.4.2.1 Participants

16 University of Glasgow students, aged 18 to 46 (mean 24.4 years, 7 male) participated in the experiment in exchange for pay (£6 per hour). Ethical approval for the study was obtained from the Ethics committee of the Faculty of Information and Mathematical Sciences, University of Glasgow. All participants gave informed consent. All participants reported normal or corrected-to-normal vision. All of the participants were right handed with a mean handedness score of 0.9 (Oldfield, 1971).

3.4.2.2 Apparatus and Stimuli

Apparatus and stimuli were identical to Experiment 2 except that the flankers were presented at three locations to the left and right of the central stimulus respectively giving 6 flanker stimuli in total.

Participants sat approximately 80 cm from the screen with each arrow stimulus array subtending 7.5 degrees of visual angle in width and 1.8 degrees of visual angle in height. The centre-to-centre distance between the items within the flanker array was approximately 1.8 degrees of visual angle. A tone of 3000 Hz was presented in response to error trials.

3.4.2.3 Design

Experimental trials were either compatible or incompatible standard flanker trials and two NoGo trial types, one consisting of only the central target stimulus (NoGo target) and the second consisting of only the flanker stimuli (NoGo flanker) (see Figure 3.17). Compatible trials were trials where the central stimulus and the stimuli to the left and right (flankers) matched. Incompatible trials were trials where the six flanker stimuli pointed in the opposite direction to that of the central stimulus. These standard flanker conditions were predominant occurring on 75 % of the trials. The NoGo trials occurred on 25 % of the trials (50 % NoGo target, 50 % NoGo flanker) and did not require a response.

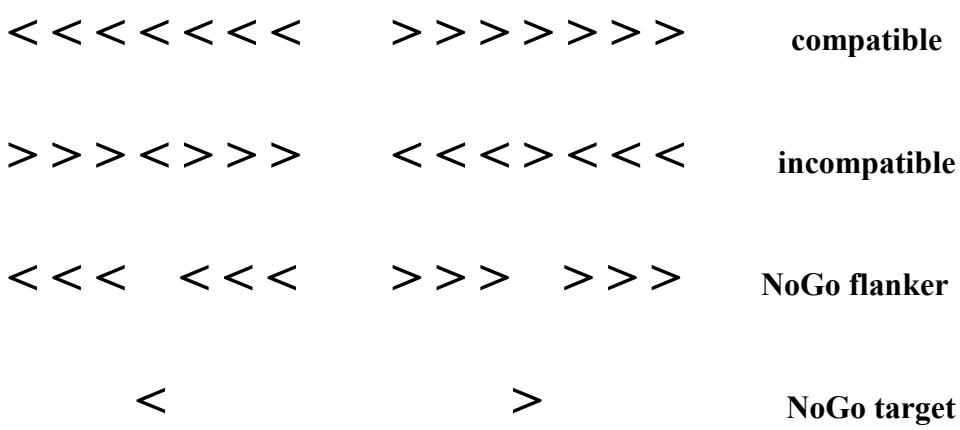


Figure 3.17: Schematic of the stimuli used. The top row shows compatible flanker arrays requiring left (left column) and right (right column) responses respectively. The second row shows incompatible flanker arrays requiring left (left column) and right (right column) responses respectively. The third row shows the trial type termed 'NoGo flanker' with the central target removed. The bottom row shows the trial type termed 'NoGo target' with the surrounding flankers removed. Both NoGo trial types required no response.

Additional experimental conditions were created subsequently when considering a sequential analysis of stimulus and response sequence. For the standard flanker trials this resulted in a 2(current compatibility: compatible vs. incompatible) x 2(previous compatibility: compatible vs. incompatible) x 2(response type: response alteration vs. response repetition) ANOVA.

When considering the NoGo trials, a 2(previous compatibility; compatible vs. incompatible) x 2(trial type; NoGo target vs. NoGo flanker) ANOVA was conducted on mean amplitudes of P1 and N1 components.

3.4.2.4 Procedure

The procedure was identical to Experiment 2 except the following. Participants were informed of the NoGo conditions, specifically, the need to

withhold a response when only a central target was presented (NoGo target) or when only flanker stimuli were present (NoGo flanker).

All error trials were removed from the analysis as were trials that followed an error. The next trial began after the presentation of a blank interval of 1200 ms duration. NoGo trials were intermixed randomly (25 % of trials) with the condition that a NoGo trial could not follow another NoGo trial. NoGo stimuli remained on screen for 1000 ms followed by the 1200 ms blank interval before the next trial.

A practice block of a sequence of 20 trials was completed at the beginning of the experimental session. Data from the practice block were not analysed. Following the practice block, participants completed 16 blocks of 130 trials. The first 2 trials of each block were considered practice trials and as a result were discarded from the analysis. In total, 2100 trials were presented in one session, taking approximately 70 minutes to complete. Blocks of trials were separated by a brief break, during which feedback regarding accuracy and mean response time for the previous block was given.

3.4.3 Data analysis

3.4.3.1 Behavioural data

Trials with incorrect responses, those following an incorrect response, and with RT < 150 ms (anticipation) > 2000 ms (miss) were excluded from the RT analysis. Statistical analyses were performed by repeated-measures ANOVA. For the analysis of RT and error rate for flanker trials, the within-subject variables were current compatibility (compatible vs. incompatible), previous compatibility (compatible vs. incompatible), and response sequence (alternation vs. repetition).

3.4.3.2 ERP Data

3.4.3.2.1 P1 and N1 Components

The averaging epoch was identical to that used in Experiment 2. Mean amplitude of ERP waveforms were determined between 60-120 ms for the P1 component and between 120-200 ms for the N1 component at electrode sites PO7 and PO8. Mean amplitudes were analyzed via a repeated measures ANOVA. For the standard flanker trials, the within-subject variables were previous compatibility (compatible vs. incompatible), current compatibility (compatible vs. incompatible), response sequence (repetition vs. alternation) and electrode (PO7 vs. PO8). For the NoGo trials, the within-subject variables were previous compatibility (compatible vs. incompatible), NoGo trial type (flankers only vs. target only) and electrode (PO7 vs. PO8).

3.4.3.2.2 LRP

3.4.3.2.2.1 S-LRP and LRP-R

S-LRP waveforms were aligned to a 100-ms pre-stimulus baseline. Due to amplitude differences across conditions, a predefined criterion of 0.7 μV was used to determine onset latencies for the S-LRP interval. Onsets were measured between 100 -500 ms post stimulus. The LRP-R interval was determined using a 1 μV criterion, with waveforms aligned to a 100-ms baseline that started 400 ms before the response. Onsets were measured between 300-100 ms pre-response. The within-subject variables were current compatibility (compatible vs. incompatible) and previous compatibility (compatible vs. incompatible).

3.4.3.2.2.2 NoGo LRP

Waveforms were aligned to a 100-ms pre-stimulus baseline. An area measure between 300-500 ms post-stimulus was made. The within-subject variables were previous compatibility (compatible vs. incompatible) and NoGo trial type (NoGo target vs. NoGo flanker). The NoGo LRP was calculated relative to the direction of the arrow presented.

3.4.4 Results

3.4.4.1 Behavioural Data

3.4.4.1.1 RT

Mean RT is shown in Figure 3.18 separately for response repetitions (left panel) and response alternations (right panel). Overall, there was a main effect of compatibility with responses to compatible trials being faster (421 ms) than responses to incompatible trials (479 ms); F (1, 15) = 122.78, MSE = 885.07, p < .0001), giving a flanker compatibility effect of 58 ms. No other main effects were significant (all ps > .05). Importantly, the two-way interaction between current compatibility and previous compatibility was significant; F(1, 15) = 41.17, MSE = 130.11, p < .0001, and this effect was further modulated by the response sequence as indicated by the significant Current Compatibility x Previous Compatibility x Response Sequence interaction; F(1, 15) = 56.02, MSE = 145.23, p < .0001. The conflict adaptation effect for response repetitions was 58 ms compared to -6 ms for response alternation trials.

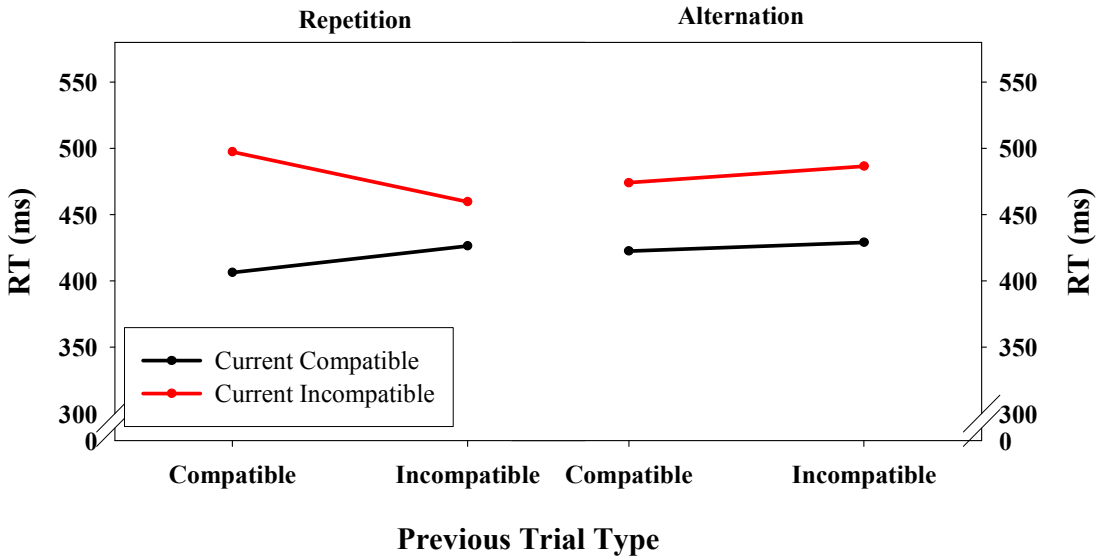


Figure 3.18: Mean RT as a function of previous compatibility and current compatibility plotted separately for response repetition trials (left panel) and response alternation trials (right panel).

3.4.4.1.2 Error Rate on Go Trials

An analogue analysis to that of RT was conducted on error rates. Mean error rate for the flanker trials are shown in Figure 3.19 separately for response repetitions (left panel) and response alternations (right panel). Overall there was a main effect of compatibility with more errors being made to incompatible stimuli (3.85 %) than to compatible stimuli (0.76 %); $F(1, 15) = 39.85$, $MSE = 7.64$, $p < .0001$.

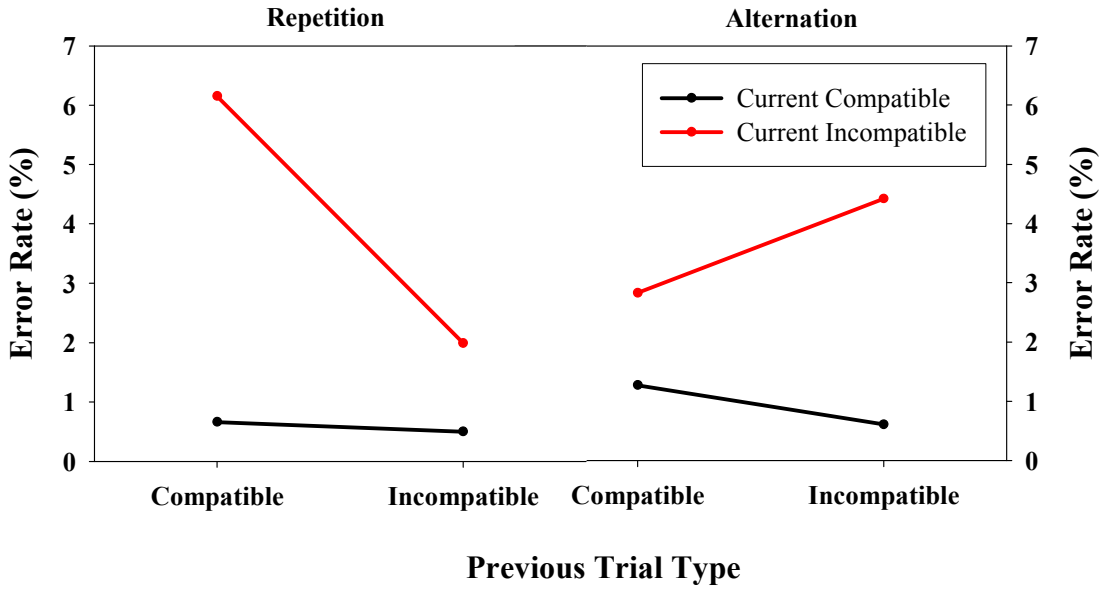


Figure 3.19: Mean error rate as a function of previous compatibility and current compatibility plotted separately for response repetition trials (left panel) and response alternation trials (right panel).

The significant Previous Compatibility x Current Compatibility x Response Sequence interaction; $F(1, 15) = 13.53$, $MSE = 5.78$, $p < .01$), indicated a reliable conflict adaptation effect for response repetition trials (4 %) but a reverse effect for response alternation trials (-2.25 %).

3.4.4.1.3 Error Rate on NoGo Trials

There was a significant main effect of NoGo trial type with more errors being made to NoGo targets (8.01%) than NoGo flankers (1.26%); $F(1, 15)$, $MSE = 112.91$, $p < .01$. There was a significant two-way interaction between previous compatibility and response sequence; $F(1, 15) = 5.01$, $MSE = 4.30$, $p < .05$. When the previous trial was compatible, error rate was similar for both response repetitions and alternations (4.90 % *vs.* 4.74 % respectively), whereas when the

previous trial was incompatible, error rate was higher for response alternations than repetitions (5.19 % *vs.* 3.72 % respectively).

3.4.4.2 ERP data

3.4.4.2.1 Flanker Trials

3.4.4.2.1.1 P1 Component

Grand average waveforms for each of the flanker conditions are displayed in Figure 3.20. None of the main effects were significant (all Fs < 2.59, ps > .13). There was a significant interaction between current compatibility and response sequence; $F(1, 15) = 10.41$, $MSE = 0.32$, $p < .01$. Mean P1 amplitude was larger on incompatible trials (2.28 μV) than on compatible trials (1.98 μV) for response alternations while for response repetitions, mean P1 amplitude was larger on compatible trials (2.09 μV) than on incompatible trials (1.94 μV). No other two-way or lower level interaction was significant (all Fs < 1).

3.4.4.2.1.2 N1 Component

N1 amplitude was larger at PO7 (-3.30 μV) than PO8 (-1.25 μV); $F(1, 15) = 7.98$, $MSE = 33.80$, $p < .05$. N1 peak amplitude was also larger when the previous trial was compatible (-2.45 μV) than when the previous trial was incompatible (-2.10 μV); $F(1, 15) = 25.35$, $MSE = 0.31$, $p < .0001$, and when the response alternated rather than repeated (-2.41μV vs. -2.14μV); $F(1, 15) = 4.88$, $MSE = 0.92$, $p < .05$.[3]

[3] In a similar fashion to Experiment 1, additional analyses were conducted on peak amplitudes within the same time windows. However, such analyses did not reveal patterns in the data that differed in a meaningful manner to that offered by the averaged window analysis.

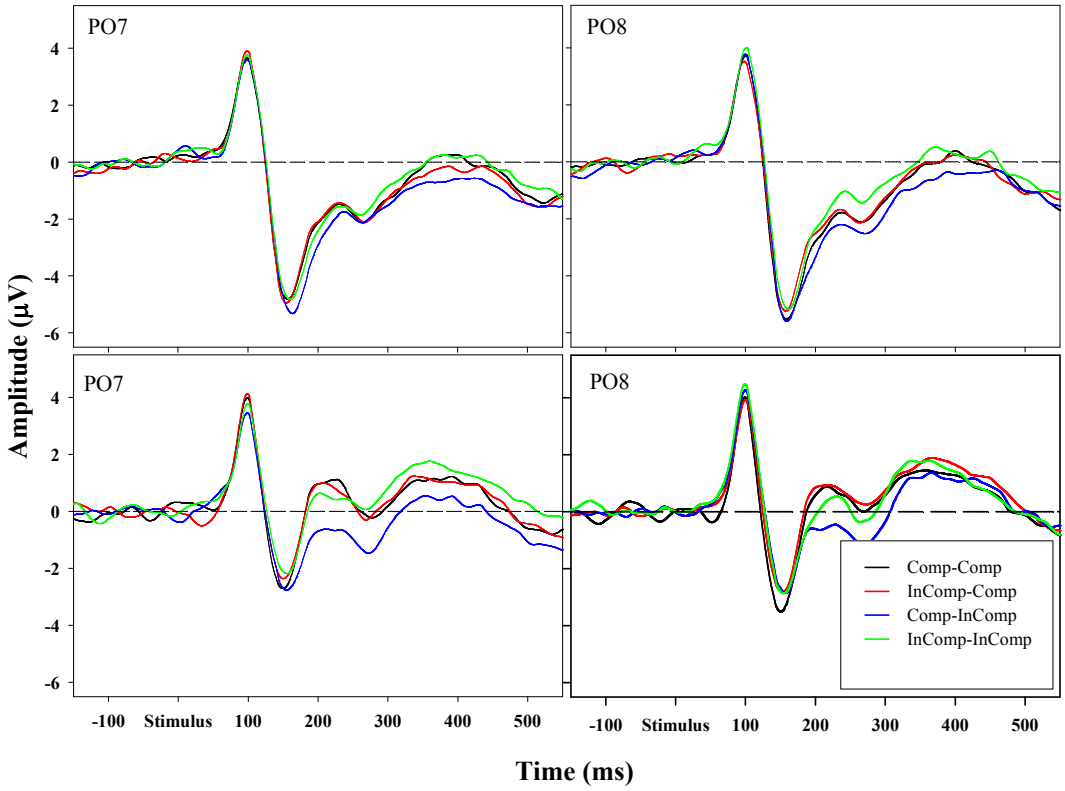


Figure 3.20: P1 and N1 Components at electrode sites PO7 (left) and PO8 (right) for response repetition trials (top row) and response alternation trials (bottom row) as a function of previous compatibility and current compatibility.

3.4.4.2.1.3 LRP

3.4.4.2.1.3.1 S-LRP

Stimulus-locked LRP waveforms are displayed in Figure 3.21. There was a significant main effect of current compatibility with the S-LRP interval for compatible trials being shorter (239 ms) than for incompatible trials (330 ms); $F(1, 15) = 54.85$, $MSE = 21.69$, $p < .0001$.

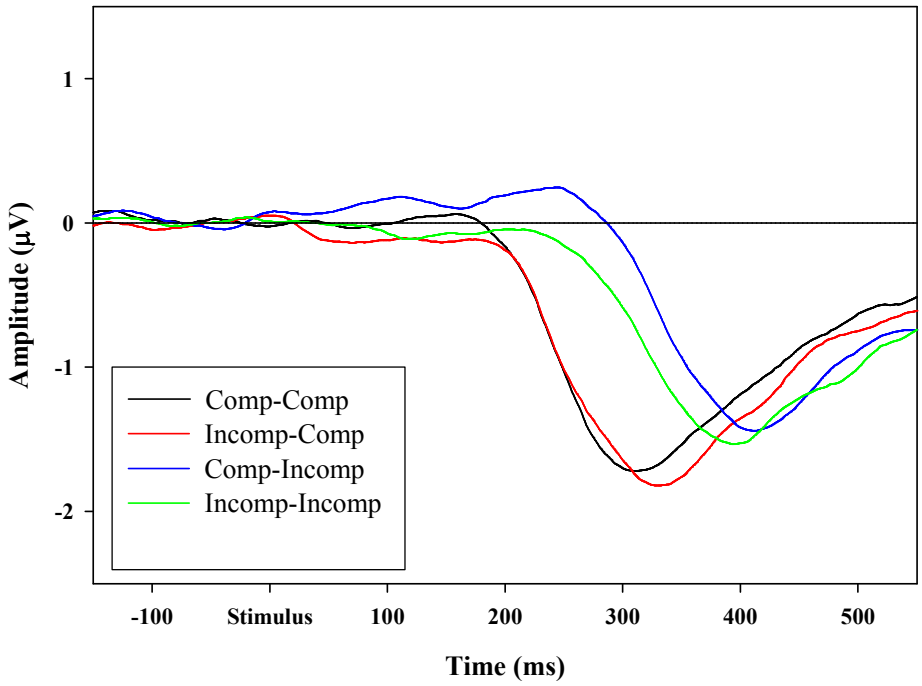


Figure 3.21: Stimulus-locked LRP interval for the standard flanker trials.

3.4.4.2.1.3.2 LRP-R

Response-locked LRP waveforms are displayed in Figure 3.22. There were no significant effects.

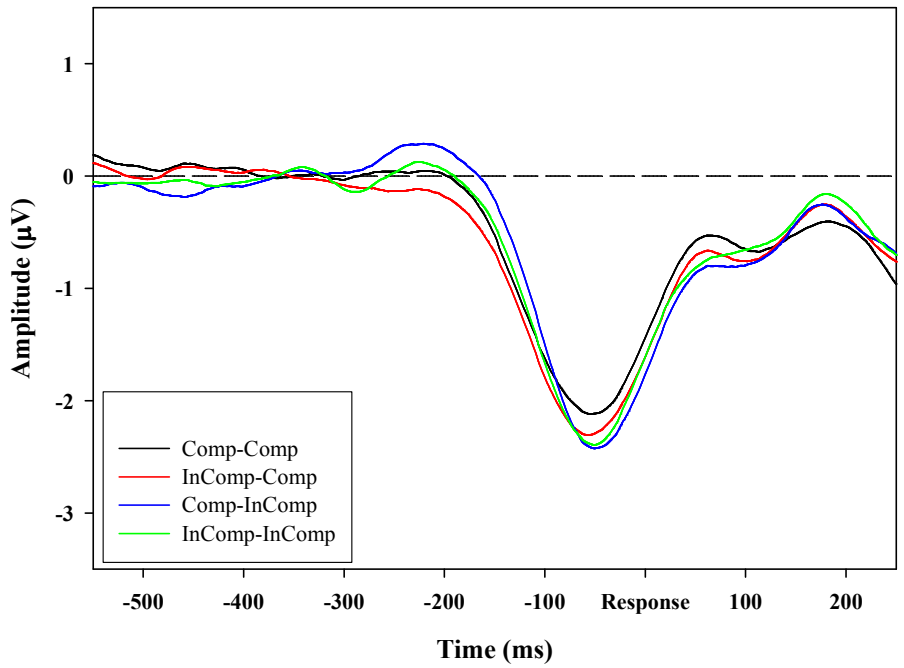


Figure 3.22: locked LRP interval for the standard flanker trials.

3.4.4.2.2 NoGo Trials

3.4.4.2.2.1 P1 Component

Grand averaged waveforms for each of the NoGo conditions are displayed in Figure 3.23. None of the main effects were significant (all *F*s < 1). Importantly, the two-way interaction between previous trial compatibility and NoGo trial type was not significant; (STATS), nor were any of the lower level interactions.

3.4.4.2.2.2 N1 Component

There was a significant main effect of NoGo trial type with larger mean N1 amplitude to NoGo flanker trials than NoGo target trials (-3.72 µV vs. -2.31 µV respectively); $F(1, 15) = 9.86$, $MSE = 6.49$, $p < .01$. Importantly, the main effect of NoGo trial type was not modulated by previous trial compatibility; (STATS). No other main effect or interaction was significant.

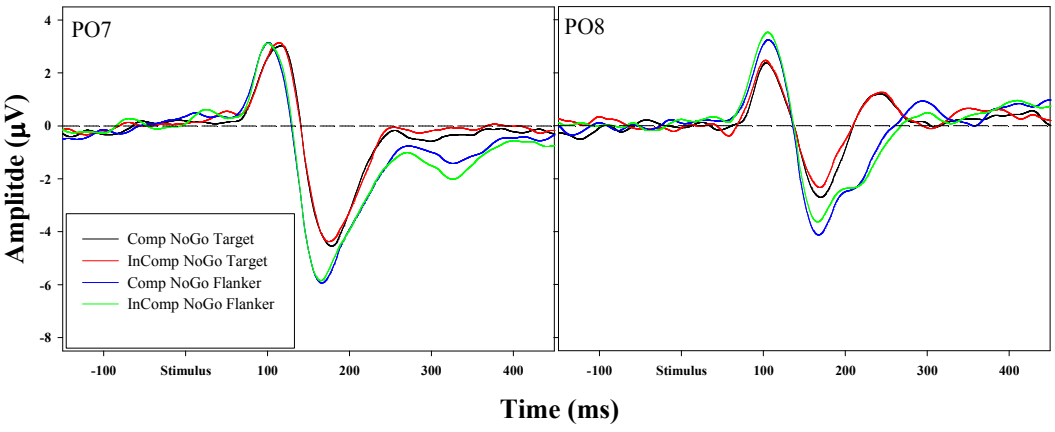


Figure 3.23: P1 and N1 Components at electrode sites PO7 (left) and PO8 (right) for NoGo trials as a function of previous compatibility.

3.4.4.2.2.3 NoGo LRP

NoGo LRP waveforms are displayed in Figure 3.24. There was no significant main effect of either previous compatibility or NoGo trial type; *F*s <

1.45, *p*s > .25. However, the two-way interaction between previous compatibility and NoGo trial type, although insignificant, warrants mention as it demonstrates a trend; $F(1, 15) = 2.90$, $MSE = 0.01$, $p = .11$. When the previous trial was incompatible, mean LRP amplitude for NoGo targets was higher than for NoGo flankers (-0.63 µV vs. -0.03 µV respectively). When the previous trial was compatible, mean LRP amplitude was similar for both NoGo targets and NoGo flankers (-0.13 µV vs. -0.22 µV respectively).

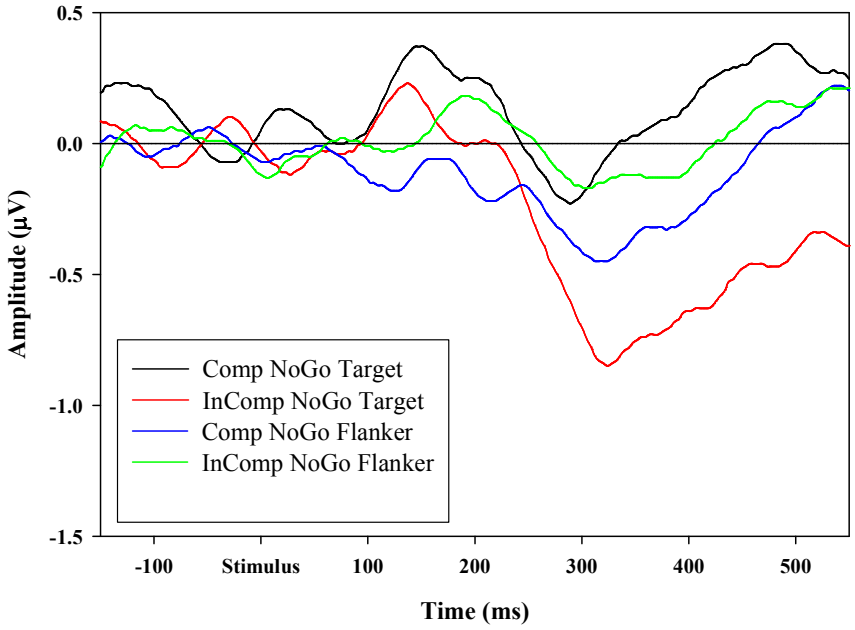


Figure 3.24: NoGo LRP for trials containing only the central target (NoGo target) and for trials with only containing the surrounding flankers (NoGo flanker) when preceded by compatible and incompatible flanker trials.

3.4.5 Discussion

Again, the present experiment investigated the conflict adaptation effect within the flanker task. Specifically, does the detection of conflict in a previous trial result in increased control in the current trial by causing a focusing of attention toward task-relevant information, that is, the central spatial location within the flanker array? This was investigated by recording ERPs to non-

standard flanker trials that consisted of either the removal of the central target with only the flankers presented or only the central target with no flanker stimuli presented. It was predicted that the amplitude of early visual components would be dependent upon the previous trial conflict and the NoGo flanker type. When the previous trial is incompatible, conflict is detected and attention on the current trial will be focused on the central location. When the NoGo trial type consists of only the central target, higher amplitudes of early ERP components were predicted when preceded by incompatible flanker arrays. Alternatively, when the NoGo trial type consists of only the flankers with no central target, higher amplitudes of early ERP components were predicted when preceded by compatible flanker arrays.

When considering the RT data, the typical interference effect (RT difference) between compatible and incompatible trials was observed with faster responses to compatible trials than to incompatible trials. In addition, this interference effect was reduced both in terms of RT and error rate when the previous trial was incompatible compared to compatible and reflects the typical conflict adaptation effect (cf. Gratton et al., 1992). However, this effect was modulated by response sequence with the conflict adaptation effect only being evident for response repetitions in terms of both RT and error rate. The size of this conflict adaptation effect was 58 ms for response repetitions, being considerably larger compared to 27 ms observed for response repetitions in the Scerif et al. (2006) study, but comparable to that observed in similar flanker tasks (e.g. Nieuwenhuis et al., 2006). This difference between the size of the conflict adaptation effect across response repetitions in the present experiment and that of Scerif et al. may be the result of Scerif et al. use of three preceding trials to

manipulate conflict rather that considering the previous trial only. Indeed, this difference may also explain the discrepancy between the conflict adaptation effect in terms of response sequence. Response sequence influenced the conflict adaptation effect in the present experiment but not in the flanker task of Scerif et al. However, as mentioned previously, this may be due to limitations of statistical power in their study rather than procedural differences related to considering conflict over the previous three trials rather than only the previous one.

The observed interference effect (RT difference between compatible and incompatible trials) was larger in the present study than in Experiment 2 ($F(1, 30) = 7.17$, $MSE = 874.57$, $p < .05$). It is likely that this is due to differences in the flanker arrays. The present experiment used 6 flanker stimuli compared to 2 used in Experiment 2. This increase in irrelevant information is proposed to produce increased processing conflict. Indeed, the additional observation that the conflict adaptation effect was larger in the present study compared to Experiment 2 fits with the idea that the experience of greater conflict will produce increased control.

However, like the results of Experiment 2, the conflict adaptation effect was specific to response repetitions only, and thus, it is difficult to attribute the effect solely to a top-down mechanism of control (Mayr et al., 2003). This finding from the present experiment that the conflict adaptation effect within a flanker task is evident only for response repetitions replicates previous results using a flanker paradigm (e.g. Mayr et al, 2003; Nieuwenhuis et al., 2006).

Although the above behavioural results question the need for a top-down control view of conflict adaptation effects within the flanker task, any evidence that perceptual processing is biased toward the target depending upon previous trial conflict would offer additional support for a top-down mechanism.

The Scerif et al. (2006) study demonstrated that, for the standard flanker trials, P1 amplitude was increased for incompatible trials that were preceded by incompatible trials across central occipital electrode sites. Like the results from Experiment 2, the present experiment failed to find any influence on P1 amplitude depending upon current and previous compatibility. However, P1 amplitude was affected by current compatibility and response sequence. The meaning or interpretation of this interaction is unclear. However, it does indicate that target sequence can influence visual processing within the flanker array.

N1 amplitude was affected by previous compatibility being larger when the previous trial was compatible compared to incompatible. Whether this reflects an effect of decreased visual stimulation resulting from focused attention toward the central target following a compatible trial is unclear. N1 amplitude was also affected by response sequence being higher when the target alternated than when it repeated. A possible explanation of this effect can be offered by considering the central target only. If the response repeats then this must be a stimulus repetition whereas a response change also involves a response repetition. Thus, the reduced N1 for response repetitions likely reflects some form of stimulus adaptation. In summary, similarly to the results from the standard flanker trials for Experiment 2, the present results did not replicate Scerif et al. (2006). Specifically, there was no modulation of either the P1 or N1 components depending upon previous and current compatibility.

The above ERP results concerned the P1 and N1 amplitudes within standard flanker trials. However, it is the NoGo trials that make the clearest predictions regarding the influence of conflict on subsequent visual processing. Scerif et al. (2006) demonstrated that after an incompatible trial, P1 amplitude

was reduced for flanker arrays that contained no central target compared to identical flanker arrays when preceded by a compatible trial. The authors explained this result emphasising a top-down spatial effect of attentional allocation. The present experiment replicated their procedure using a flanker array containing no central target. Additionally, a NoGo trial containing only the central target was presented. These two NoGo trial types make opposite predictions regarding visual ERP component amplitudes. Specifically, if increased attention is directed toward the target location following an incompatible trial, there should be a reduced P1 amplitude for NoGo trials containing no central target and an increased P1 amplitude for NoGo trials that only contain the central target. The results demonstrate that P1 amplitude was not modulated by previous compatibility or NoGo trial type. Again, this fails to replicate the findings of Scerif et al. (2006). As the present experiment contained an identical condition to that of Scerif et al., this result questions the consistency of their result, and thus, the conclusions made. N1 amplitude was influenced by NoGo trial type with a larger N1 amplitude to NoGo trials where the central target was omitted compared to NoGo trials containing only the target. However, this was not modulated by previous compatibility and likely reflects increased visual stimulation from the presentation of 6 flanker stimuli compared to the presentation of a single target. Why this same effect of NoGo trial type was not evident in P1 amplitude is unclear.

The above data from the NoGo trials, for both the P1 and N1 components do not show any effect of attention depending upon NoGo trial type and previous compatibility. Again, like the ERP data for Experiment 2, the data from the current experiment cannot replicate the findings from Scerif et al. (2006) study.

The results from the present experiment offer no additional support to the idea of a focusing of attention toward the target location after an incompatible trial.

Considering only the identical conditions from the present experiment to that of Scerif et al. (2006), it is unclear why the results are inconsistent. As indicated, these conditions were identical in terms of the flanker arrays and the nature of the NoGo trial type. As the present study contained an increased number of participants and also an increased number of trials of interest, a lack of statistical power in the present experiment is unlikely to offer any explanation regarding the observed discrepancy. This leaves one potential explanation and this concerns differences between the nature of the previous compatibility between Experiment 2 and the present experiment. As mentioned previously, Scerif et al. considered the compatibility sequence of the previous three trials within a constrained sequence. Thus, their condition that contained no central target was preceded by either three consecutive compatible or incompatible trials. It is possible that after three consecutive incompatible trials, attention becomes increasingly focused toward the centre location and that this increased focusing is greater than that observed when only one incompatible trial preceded. A possible explanation for this is that attention needs time before it can be directed accordingly (e.g. Posner, 1980), and thus, by the fourth trial, enough time has elapsed for this to occur. However, this explanation is unlikely due to the time course of trials within the present experiment. An interval of 1200 ms was presented between individual trials with this interval being long enough to allow attentional allocation. Indeed, attention effects were demonstrated in Experiment 1 where the interval between the attention directing cue and the subsequent stimulus

was 500 ms. Thus, the time course of events in the present experiment is unlikely to occlude any trial-by-trial attention effects.

In conclusion, the present experiment, like the results of Experiment 2, demonstrated conflict adaptation effects in behaviour (both RT and error rate) between standard flanker trials. However, these conflict adaptation effects were specific to response repetition trials only. The ERP data offered no support for the proposal that the detection of conflict leads to a perceptual biasing mechanism that reduces future conflicts by focusing on task relevant stimulus features.

3.5 Chapter Summary

The present chapter investigated perceptual processing related to the central target after the detection of conflict within a flanker paradigm. Experiment 1 demonstrated standard attention effects within a typical cueing paradigm and replicated previous findings of an effect on P1 amplitude but not on N1 amplitude when using a simple detection task (e.g. Mangun & Hillyard, 1991). The second and third experiments investigated whether such attentional effects could be observed when attention is not cued explicitly but rather by interactions with stimuli and their previous context. Specifically, does the detection of conflict result in a focusing toward task relevant features of a stimulus in future trials? Both experiments demonstrated conflict adaptation effects in behaviour. However, these conflict adaptation effects were specific to response repetitions only, and thus question the need for a top-down control view within the flanker task (Mayr et al., 2003). The ERP results from the second and third experiments provided no evidence that the detection of conflict influences perceptual processing of future trials and thus questions the previous results of Scerif et al. (2006).

Chapter 4. Conflict Adjustment in a Pictorial Stroop Task: Influences of Relevant and Irrelevant Stimulus Dimensions on Cognitive Processing

4.1 Introduction

The cognitive control model of Botvinick et al. (2001) proposes that the ACC monitors for conflict and signals this information to areas within the DLPFC that implement control mechanisms. It is thought that these control mechanisms result in attentional biasing toward task-relevant information (see 1.8).

Egner and Hirsch (2005) investigated whether this attentional biasing mechanism amplified the neural representation of the relevant stimulus, inhibited the neural representation of the irrelevant stimulus, or a combination of both. Using similar logic to that adopted by Kanwisher and colleagues (see 1.9), Egner and Hirsch used activation within the FFA as a dependent measure of the neural processing of a face stimulus. Their task was a modified Stroop task that involved the presentation of a face with superimposed text written over the face. The stimulus was considered compatible when both the face and text indicated the same response and was considered incompatible when they indicated different responses (see Figure 4.1). The task involved participants responding 'actor' or 'politician' to either the face or the text. It is important to note that the stimuli used by Egner and Hirsch (2005) never consisted of an exact face-text match. For example, a picture of a politician was never paired with the text of that same politician, only the text of another politician. In this situation, both the face and text contain the information 'politician' and thus, are considered compatible. These trials are compared to incompatible trials where the text and face are from different categories (politician vs. actor). The relevant dimension (text vs. face) was manipulated block-wise.

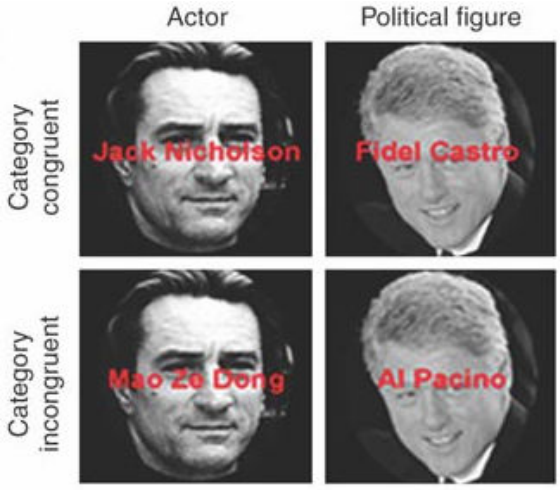


Figure 4.1: Stimulus examples from Egner and Hirsch (2005). The stimulus is compatible (or congruent) when both the face and the text are from the same category (*i.e.* both 'actors' or both 'politicians') (adapted from Egner & Hirsch, 2005).

Previous compatibility determined the level of control (compatible = low control, incompatible = high control) while current compatibility determined the level of conflict (compatible = low conflict, incompatible = high conflict). Behaviourally, conflict adaptation predicts that less interference from high conflict trials will be observed under conditions of high control compared to low control (see 1.6). More importantly, by measuring activity within the FFA to a stimulus containing a face, under conditions of both low and high control, and when the face stimulus served as both the target and the distracter, Egner and Hirsch proposed that insights into the nature of the biasing mechanism could be made. Specifically, if control is mediated by target amplification, increased FFA activation is predicted for the high control compared to the low control condition, when the face serves as the target. Alternatively, if control is mediated by distracter suppression, decreased FFA activation is predicted under the high control compared to the low control condition, when the text serves as the target.

The behavioural data from Egner and Hirsch (2005) produced the typical interference effects with faster responses to compatible than incompatible stimuli

in both the face task (711 vs. 725 ms) and the text task (862 vs. 903 ms). In addition, conflict adaptation effects were observed. Responses were faster to incompatible stimuli under high control (previous trial incompatible) compared to low control (previous trial compatible) conditions in both the face and text tasks. For the face task, the conflict adaptation effect was 27 ms, whereas for the text task, the conflict adaptation effect was 29 ms (see Figure 4.2). Additional behavioural analyses investigated the influence of response repetitions and alternations and indicated that the conflict adaptation effect was similar across both types of trial sequence.

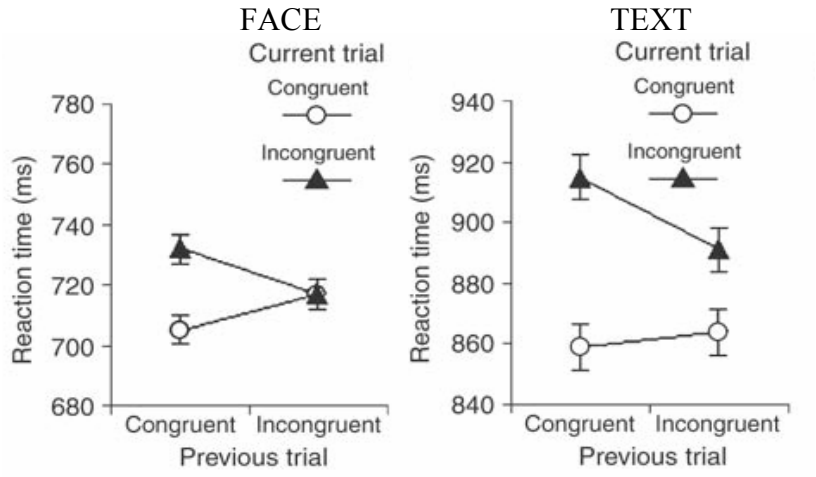


Figure 4.2: Behavioural results of Egner and Hirsch (2005) indicating typical conflict adaptation effects following an incompatible trial for both the 'face' task (left) and the 'text' task (right) (*N.B.* misaligned y axis) (adapted from Egner & Hirsch, 2005).

The imaging data of Egner and Hirsch (2005) demonstrated different levels of activation within the FFA depending upon the relevant stimulus dimension and the compatibility sequence. When the 'face' served as the target, activation within the FFA was higher under conditions of high control compared to low control for incompatible trials. In contrast, when the text served as the

target, there was no difference in levels of FFA activation across conditions (see Figure 4.3).

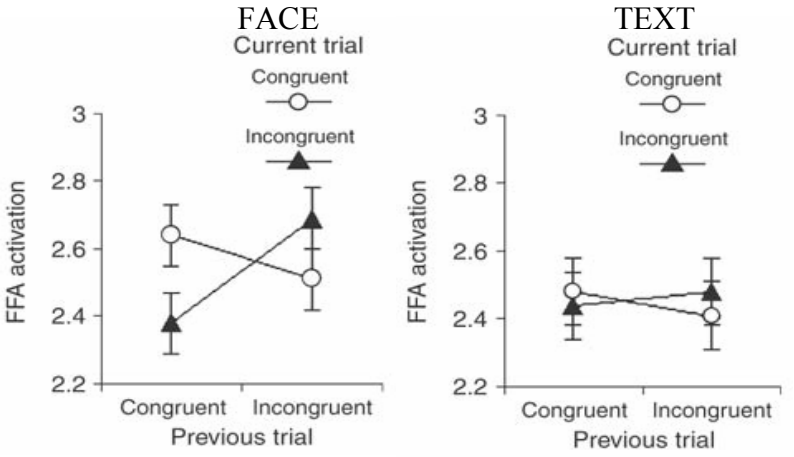


Figure 4.3: fMRI data of Egner and Hirsch (2005) showing FFA activation as a function of previous and current compatibility (or congruency) for the 'face' task (left) and the 'text' task (right) (adapted from Egner & Hirsch, 2005).

To provide further evidence that the increase in activation within the FFA when the face served as the target was specific to the FFA and not the result of a general effect on high-level visual areas, Egner and Hirsch (2005) compared the activation within the FFA to that within the PPA under conditions of low and high control. This analysis demonstrated that the effect of control was specific to brain regions involved in the processing of the task relevant stimulus feature (see Figure 4.4).

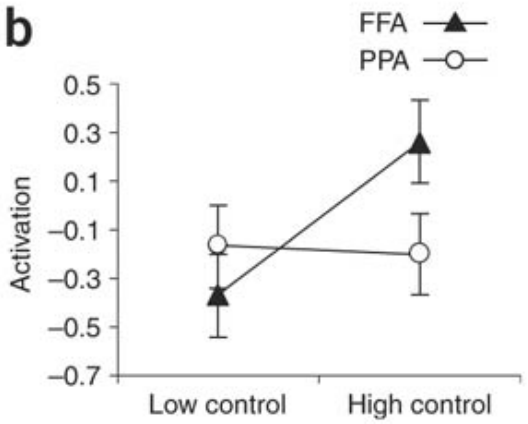


Figure 4.4: fMRI data of Egner and Hirsch (2005) comparing activation within the FFA and PPA under conditions of low and high control when the face served as the target (adapted from Egner & Hirsch, 2005).

The above imaging results show an enhanced response within a face processing area under conditions of high control when a face stimulus serves as the target. If areas within the DLPFC implement top-down control, then Egner and Hirsch (2005) hypothesised that increased connectivity between areas within the DLPFC that implement control and the FFA should be observed in the high control compared to the low control condition when the face served as the target. Analysis revealed a cluster of voxels within the right DLPFC that demonstrated task-specific and control-specific increments in functional integration with the FFA. This result is predicted by the proposal that regions within the DLPFC implement control mechanisms (e.g. Botvinick et al., 2001; Kerns et al., 2004).

From the above results, Egner and Hirsch (2005) propose that conflict is resolved by the amplification of the neural response to the target rather than the inhibition of the neural response to the distracter. The authors suggest that this target-feature enhancement may be achieved by attentional top-down signals that increase pre-stimulus baseline activity in areas associated with the future target. This increased baseline activity produces a bias in the competition for processing resources for future behaviour.

To summarise the above findings, Egner and Hirsch (2005) demonstrated behavioural conflict adaptation effects using a pictorial version of the Stroop task. Imaging data demonstrated that future target processing was increased under conditions of high control and that this increased target processing was related to input from regions within the DLPFC proposed to be involved in the regulation of control.

The findings of Egner and Hirsch (2005) are interesting as they offer a potential mechanism by which conflict is resolved, namely, the amplification of

the cortical response to task-relevant information. However, Egner and Hirsch's (2005) interpretation that this target amplification is the result of an increase in baseline activity that occurs before stimulus presentation is not fully supported by their results. Their results show that for incompatible trials, FFA activation is higher when the previous trial was incompatible compared to when the previous trial was compatible. This is consistent with target amplification following the detection of conflict. When considering compatible trials, FFA activation is higher when the previous trial is compatible compared to when the previous trial is incompatible. As participants cannot predict stimulus sequence, explanations solely based on an increase in baseline activity when conflict is detected would predict additive effects rather than the interaction observed (see Figure 4.3). That is, when trial N-1 is incompatible, this triggers control adjustments in terms of biasing baseline activity. Hence, if the fMRI BOLD response is measuring only this activity change, then it should be independent from the event in trial N. However, due to the slow temporal resolution of fMRI, the FFA activation observed will likely reflect activity at a large range of latencies, both before and after stimulus presentation.

4.1.2 Experimental Aims

The forthcoming experiments aim to further investigate the proposal that the effect of conflict is reduced by amplifying the neural response to the relevant stimulus. Egner and Hirsch (2005) used activity within the FFA as a dependent measure of target processing when a face stimulus served as the relevant and irrelevant stimulus dimension. Here, the N170 amplitude will be used as the dependent measure. The use of the N170 as a dependent measure of neural

processing of face stimuli is based on the proposal that the response of the FFA measured via fMRI and the N170 measured via ERPs may derive from the same neural source (e.g. Halgren et al., 2000). Also, modulations in N170 amplitude have been observed in tasks requiring participants to attend to or ignore a face stimulus when it served as either the relevant or irrelevant stimulus for current behaviour (see 1.4.8.1).

Egner and Hirsch (2005) demonstrated cortical amplification to task relevant stimuli, that is, increased activation in the FFA under high control conditions when responding to the face. This was done by comparing the activity within the FFA to activity within the PPA. In a similar fashion, it is proposed that the P1 component can be used to investigate the specificity of target processing. For example, face stimuli have been shown to produce effects approximately 170 ms post stimulus with little or no effects on earlier ERP components (see 1.4.8.1). Thus, it is predicted that the P1 component should be unaffected by the experimental manipulations.

A similar paradigm to that used by Egner and Hirsch (2005) is adopted. As mentioned earlier, the stimuli used by Egner and Hirsch never consisted of an exact face-text match. It is unclear whether these compatible trials produce conflict at the level of stimulus encoding. The present experiments will investigate this by introducing an additional stimulus type that consists of exact face-text match. If stimulus conflict also results in the recruitment of control processes, it is predicted that larger conflict adjustment effects will be observed when comparing fully compatible trials (exact face-text match) to incompatible trials than when comparing category compatible trials (face-text category match) to incompatible trials (see 1.7.6.1). In addition, a greater number of stimuli will be used. This will

reduce the number of stimulus repetitions and reduce the potential predictability of the sequence.

Two different tasks will be used in different experiments using the same stimuli. The first task will be a 'gender' decision while the second will be a 'profession' decision. It is predicted that making a decision based on gender will be easier than a decision based on profession. This prediction is based on models of face recognition (e.g. Bruce & Young, 1986; Burton, Bruce & Johnston, 1990) that propose that distinct and sequential stages are involved in the recognition of a face. Making a category judgement requires that semantic information is retrieved and this occurs at the person identity node (PIN) stage within the model. A decision based solely on gender does not require such semantic information and can be based on lower level structural properties of the face. From this, it is proposed that a gender decision will produce less conflict than a decision based on profession, and thus, any observed conflict adaptation effects should be larger for the more difficult task.

In terms of the N170 amplitude, it is predicted that, if target amplification is the mechanism by with conflict is resolved, the amplitude of the N170 will vary dependent upon the face stimuli's relevance and the level of conflict experienced on the previous trial. For example, when responding to the face as the relevant stimulus dimension, the experience of conflict from superimposed incompatible text is predicted to result in the cortical amplification of neural responses related to the relevant stimulus. It is predicted that this cortical amplification of the relevant stimulus will be evident by increased N170 amplitude. Alternatively, if there is any inhibition of the irrelevant stimulus dimension, it is predicted that the

amplitude of the N170 will be reduced after the detection of conflict when responding to the text as the relevant stimulus dimension.

4.2 Pictorial Stroop Experiment 1 (Gender Decision)

4.2.1 Method Section

4.2.1.1 Participants

20 University of Glasgow students, aged 18 to 25 years (mean 20.8 years, 5 male) participated in exchange for pay (£6 per hour). Ethical approval for the study was obtained from the Ethics committee of the Faculty of Information and Mathematical Sciences, University of Glasgow. All participants gave informed consent. All participants reported normal or corrected to normal vision. 19 of the participants were right handed as assessed by the Edinburgh handedness inventory (Oldfield, 1971) (Mean handedness score = 89.5).

4.2.1.2 Apparatus and Stimuli

Stimuli consisted of grey scale images of ten famous actors (5 male, 5 female) and ten famous pop stars (5 male, 5 female). The actor category contained images of Brad Pitt, Ben Stiller, Courtney Cox, Cameron Diaz, Harrison Ford, Jennifer Aniston, Julia Roberts, Nicholas Cage, Sean Connery and Uma Thurman. The popstar category contained images of Britney Spears, David Bowie, Elton John, Elvis Presley, Geri Halliwell, Kylie Minogue, Paul McCartney, Robbie Williams, Madonna and Victoria Beckham (see Figure 4.5).

Figure 4.5: Face stimuli. Top row - male actors, second row – male pop stars, third row – female actresses, bottom row – female pop stars (N.B. For the profession classification task (Experiment 2) it can be argued that some stimuli (e.g. Madonna) may belong to both categories. In this case, participants were informed to respond according to the most well known category (e.g. Madonna is better known as a pop star than she is as an actress).

In addition to the face stimuli, text presented in red font and uppercase letters (Helvetica, 24 point) of the actors and pop stars name was presented. The face images subtended approximately 10 degrees visual angle in height and 7 degrees visual angle in width while the text stimuli subtended 1 degree visual angle in height and varied in width according to the length of the name. Three characters subtended approximately 2.5 degrees of visual angle

4.2.1.3 Design

Experimental trials were one of three types: fully compatible, category compatible or incompatible. Fully compatible trials consisted of an exact FACE-TEXT match, for example, Brad Pitt's face with the text "BRAD PITT" written across the face in red font. Category compatible stimuli consisted of a face stimulus and text from the same category, for example, the stimulus of Elton John's face with the text "HARRISON FORD" is category compatible when making a gender classification. An incompatible stimulus consists of a face and text from different categories, for example, with gender classification, a male face with female text (or vice versa) (see Figure 4.6). Compatible, category compatible and incompatible trials occurred with equal probability.

Figure 4.6: Stimulus examples. Left = compatible, middle = category compatible, right = incompatible.

The experimental task was to respond to the gender of the stimulus. The stimulus contained two pieces of gender information; first, the gender of the face, second, the gender of the text. Whether the participant was to respond according to the text or the face was instructed at the beginning of each block with the relevant dimension alternating between blocks (12 blocks in total). The relevant dimension order (e.g. FACE → TEXT, TEXT → FACE) was counter-balanced across participants.

Additional experimental conditions were created subsequently when considering a sequential analysis of stimulus compatibility and response sequence. This resulted in a 3(current compatibility: compatible vs. category compatible vs. incompatible) x 3(previous compatibility: compatible vs. category compatible vs. incompatible) x 2 (response type: response alteration vs. response repetition) x 2 (relevant stimulus dimension: FACE vs. TEXT) design.

4.2.1.4 Procedure

Participants were tested in a single session that lasted approximately 80 minutes. At the beginning of the experiment verbal instructions were given to the participant. Instructions were also displayed on screen and remained visible until the participant initiated the trial sequence by pressing the appropriate key. The experimental task was to respond to the gender of a stimulus. Half of the participants responded "MALE" with the right key while responding "FEMALE" with the left key. For the remaining half of participants this response mapping was reversed.

A trial began with the presentation of a blank interval for 500 ms duration. The blank interval was followed by the presentation of a fixation cross that

remained on screen for 300 ms followed by a 200 ms blank interval then the presentation of the stimulus. The stimulus remained on screen until a response was made or 2000 ms elapsed. When no response occurred within 2000 ms or when an incorrect response was made, an error tone sounded for 150 ms. All error trials were removed from the analysis.

Two practice blocks of a sequence of 20 trials were completed at the beginning of the experimental session, one responding to the face as the relevant dimension, the other responding to the text as the relevant dimension. Data from the practice block were not analysed. Following the practice block, participants completed 12 blocks of 124 trials. The first 4 trials of each block were considered warm up and as a result were discarded from the analysis. In total, 1528 trials were presented in one session. During the break, feedback regarding accuracy and mean response time for the previous block was given.

4.2.2 Data Analysis

4.2.2.1 Behavioural Data

Only trials with correct responses and those following a correct response with a RT between 150 ms (those RT less than this were considered to be anticipatory) and 2000 ms were included in the reaction time analysis. In addition, trials that contained exact stimulus repetitions were removed (e.g. trials involving subsequent presentations of the face 'MADONNA' were removed). Trial transitions from corresponding FACE/TEXT categories were allowed (e.g. a stimulus with a picture of Madonna to a stimulus with the TEXT Madonna). Statistical analyses were performed by means of repeated measures ANOVA. For the analysis of RT and error rate, the within-subject variables were current

compatibility (compatible vs. category compatible vs. incompatible), previous compatibility (compatible vs. category compatible vs. incompatible), relevant stimulus dimension (FACE vs. TEXT), and response sequence (repetition *vs.* alternation).

4.2.2.2 ERP Data

4.2.2.2.1 Early Visual Components

ERP data were averaged into epochs aligned to stimulus onset (-200 to 1300 ms) for stimulus-locked waveforms. In order to investigate possible attention effects on early stimulus processing, the mean amplitude of waveforms within the interval 70-120 ms for the P1 component and 120-180 ms for the N170 component at lateral electrode sites PO7, PO8, O1 and O2 was calculated. This was computed for all conditions and was analysed by means of a repeated measures ANOVA with the within-subject factors current compatibility (compatible, category compatible vs. incompatible), previous compatibility (compatible, category compatible vs. incompatible), relevant stimulus dimension (TEXT vs. FACE) hemisphere (right vs. left) and electrode pair (PO7/PO8 vs. O1/O2).

4.2.3 Results

4.2.3.1 Behavioural Data

4.2.3.1.1 Reaction Time

Mean RTs are shown in Figure 4.7 for the FACE task and Figure 4.8 for the TEXT with separate plots for response repetitions (left panel) and response alternations (right panel). When responding to the FACE as the relevant dimension, participants were significantly faster than when the TEXT was the

relevant dimension (599 vs. 693 ms); $F(1, 19) = 110.05$, $MSE = 14510.22$, $p < .0001$. There was a significant main effect of current compatibility with responses to compatible stimuli being the fastest (627 ms) compared to category compatible (636 ms) and incompatible responses (676 ms); $F(2, 38) = 140.49$, $MSE = 1171.45$, $p < .0001$. Current compatibility interacted with response sequence; $F(2, 38) = 5.21$, $MSE = 580.82$, $p < .05$. This reflects the fact that RT increased (~5 ms) for response alternations for the compatible and category compatible conditions, whereas RT decreased (~7 ms) for response alternations for incompatible trials. Current compatibility also interacted with relevant stimulus dimension; $F(1, 19) = 42.81$, $MSE = 1269.76$, $p < .0001$, reflecting the fact that the compatibility effect was smaller in the FACE task (22 ms) than in the TEXT task (77 ms).

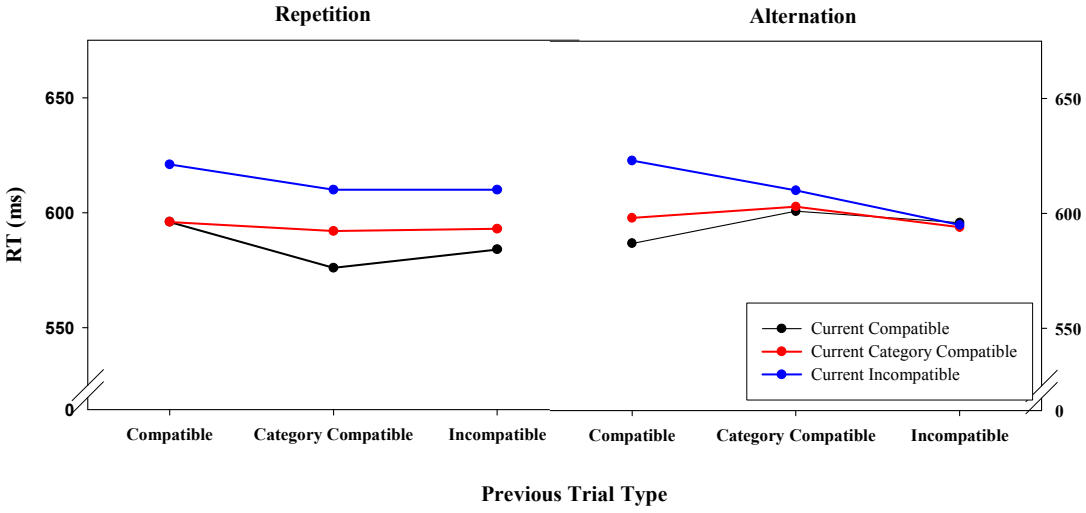


Figure 4.7: Mean RT as a function of previous trial type and current trial type for the FACE task plotted separately for response alternation trials (left panel) and response alternation trials (right panel).

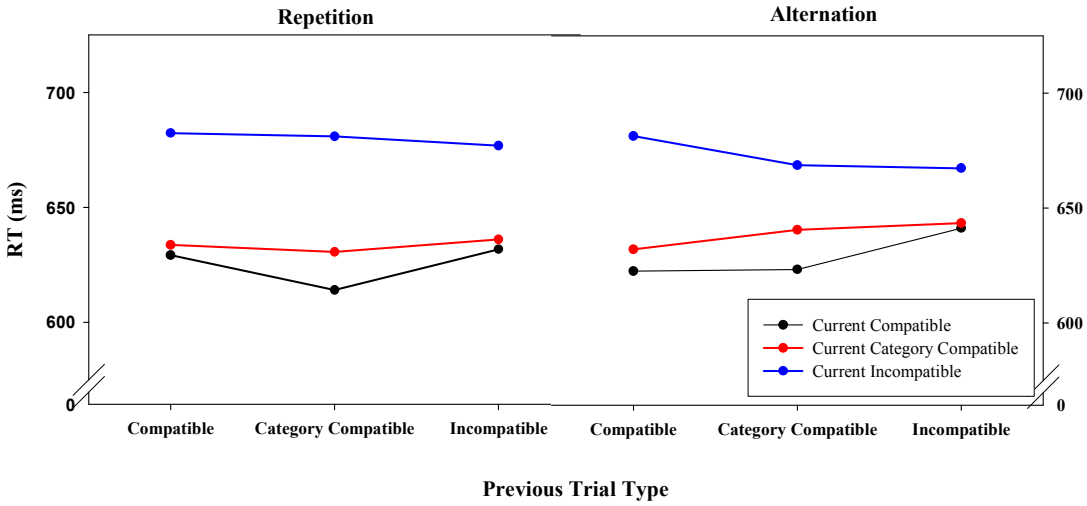


Figure 4.8: Mean RT as a function of previous trial type and current trial type for the TEXT task plotted separately for response alternation trials (left panel) and response alternation trials (right panel).

Importantly, in terms of conflict adaptation, current compatibility interacted with previous compatibility; $F(4, 76) = 4.26$, $MSE = 809.50$, $p < .01$, whereas the Current Compatibility x Previous Compatibility x Response Sequence interaction was not significant; $F(4, 76) = 1.24$, $MSE = 1014.84$, $p = .3$. The two-way interaction between current and previous compatibility reflects the difference in the conflict adaptation effect between the three levels of compatibility (compatible, category compatible and incompatible). Thus, three comparisons can be made: first, a comparison between compatible and category compatible trials (stimulus conflict), second, a comparison between category compatible and incompatible trials (response conflict) and third, a comparison between compatible and incompatible trials (stimulus and response conflict). When comparing compatible and category compatible trials, previous compatibility and current compatibility demonstrated a trend; $F(1, 19) = 3.06$, $MSE = 648.96$, $p < .1$, resulting from a conflict adaptation effect of approximately -10 ms. Thus, when the previous trial was category compatible, there was a larger

RT difference between compatible and category compatible trials than when the previous trial was compatible. When comparing category compatible trials and incompatible trials, there was no evidence of conflict adaptation as indicated by the non-significant Current Compatibility x Previous Compatibility interaction ($F < 1$), nor was this interaction influenced by response sequence ($F < 1$). When comparing compatible and incompatible trials only, there was a significant interaction between previous and current compatibility; $F(1, 19) = 6.75$, $MSE = 1223.13$, $p < .05$. This reflects the fact that the interference effect was larger when the previous trial was compatible (~ 56 ms) compared to when the previous trial was incompatible (~ 36 ms) resulting in a conflict adaptation effect of 20 ms.

4.2.3.1.2 Error Rate

An analogous ANOVA to that performed on RT was performed on mean error rates. Mean error rates are shown in Figure 4.9 for the FACE task and Figure 4.10 for the TEXT with separate plots for response repetitions (left panel) and response alternations (right panel). When responding to the FACE as the relevant dimension, responses were significantly less error prone than when the TEXT was the relevant dimension (2.67 % *vs.* 3.63 %); $F(1,19) = 27.21$, $MSE = 6.11$, $p < .0001$. There was a significant main effect of current compatibility; $F(2, 38) = 35.78$, $MSE = 22.74$, $p < .0001$, due to a higher error rate for incompatible (5.27 %) than compatible (2.19 %) or category compatible trials (1.99 %). There was a significant main effect of response sequence with a higher error rate for response repetitions than alternations (3.52 % *vs.* 2.78 %); $F(1, 19) = 7.65$, $MSE = 12.73$, $p < .05$. Similarly to the reaction time data, current compatibility interacted with relevant stimulus dimension; $F(2, 38) = 19.15$, $MSE = 13.70$, $p < .0001$. This

reflects the fact that the compatibility effect was smaller in the FACE task (1.3 %) than in the TEXT task (5 %). Whereas current compatibility did not interact with previous compatibility ($F < 1$), the interaction between relevant stimulus dimension, current, and previous compatibility demonstrated a trend; $F(4, 76) = 2.61$, $MSE = 7.47$, $p = .056$. When responding to the face as the relevant dimension, the conflict adaptation effect from compatible to category compatible trials was 1.25 %, -0.53 % from compatible to incompatible trials and -1.02 % from category compatible to incompatible trials. When the TEXT was the relevant dimension the conflict adaptation effect from compatible to category compatible trials was 1.13 %, 1.89 % from compatible to incompatible trials and 1.95 % from category compatible to incompatible trials. No other interactions were significant.

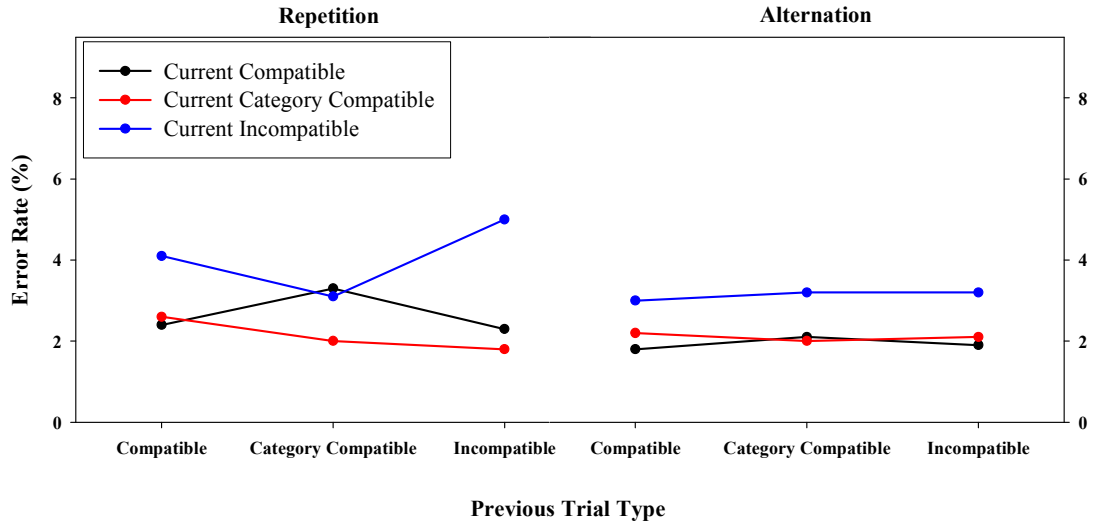


Figure 4.9: Mean error rate as a function of previous trial type and current trial type for the FACE task plotted separately for response alternation trials (left panel) and response alternation trials (right panel).

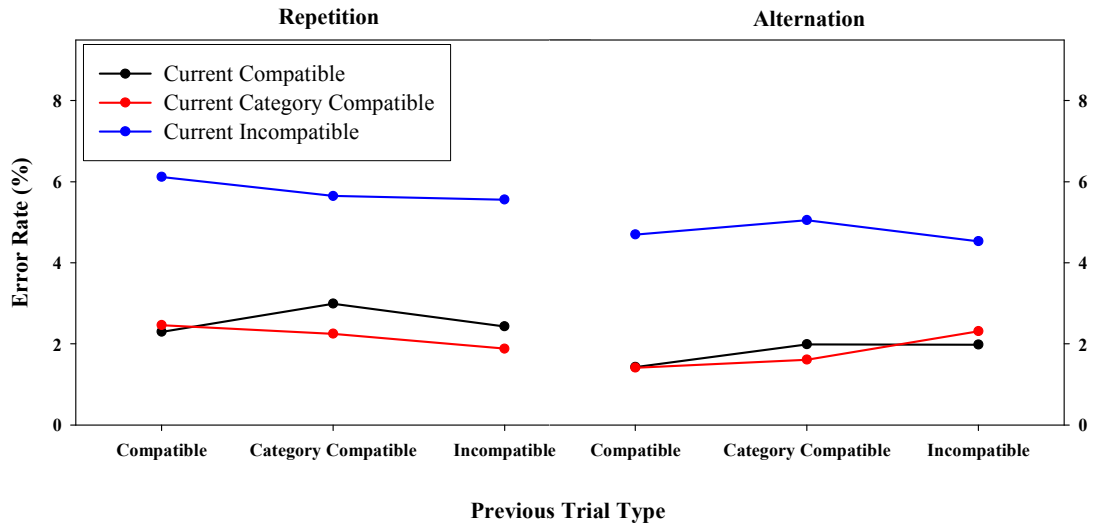


Figure 4.10: Mean error rate as a function of previous trial type and current trial type for the TEXT task plotted separately for response alternation trials (left panel) and response alternation trials (right panel).

4.2.3.2 ERP Data

4.2.3.2.1 P1 Component

Grade average waveforms for each of the conditions are displayed in Figure 4.11 for the FACE as the relevant stimulus dimension and in Figure 4.12 for the TEXT as the relevant stimulus dimension. There was a significant main effect of relevant stimulus dimension. Mean P1 amplitude was larger when the FACE was the relevant stimulus dimension than when the TEXT was relevant (5.03 µV *vs.* 4.5 µV, respectively); $F(1, 19) = 17.13$, $MSE = 6.12$, $p < .001$. No other main effects were significant. There was a significant two-way interaction between relevant stimulus dimension and hemisphere with mean P1 amplitude being larger over the left hemisphere (5.29 µV) than the right hemisphere (4.76 µV) when the FACE was relevant, with this difference being more pronounced when the TEXT was relevant (5.21 µV vs. 3.77 µV, respectively); $F(1, 19) = 9.51$, $MSE = 7.79$, $p < .01$. There was a significant interaction between hemisphere and electrode; $F(1, 19) = 7.89$, $MSE = 47.05$, $p < .05$, indicating larger P1 amplitudes

over left than right occipital electrodes O1/O2, whereas this asymmetry was absent for PO7/PO8. This interaction was modulated by relevant stimulus dimension resulting in a three-way interaction; $F(1, 19) = 6.13$, $MSE = 0.83$, $p < .05$. When the FACE was the relevant stimulus dimension mean amplitude at PO7 was 5.14 μV compared to 5.45 μV at O1, 5.74 μV at PO8 and 3.79 μV at O2. When the TEXT was the relevant stimulus dimension mean amplitude at PO7 was 5.14 μV compared to 5.27 μV at O1, 4.60 μV at PO8 and 2.94 μV at O2.

4.2.3.2.2 N170 Component

N170 was larger over O1/O2 than PO7/PO8 electrodes (-4.0 μV *vs.* -3.0 μV respectively); $F(1, 19) = 6.37$, $MSE = 51.27$, $p < .05$. There was a significant main effect of relevant stimulus dimension with larger mean N170 amplitude when the FACE was the relevant dimension (-3.91 μV) compared to when the TEXT was the relevant stimulus dimension (-3.09 μV); $F(1, 19) = 5.51$, $MSE = 43.44$, $p < .05$. A significant interaction between relevant stimulus dimension and electrode; $F(1, 19) = 8.20$, $MSE = 5.59$, $p < .05$, indicated a stronger effect of stimulus dimension (TEXT vs. FACE) at electrode sites O1/O2 (-3.4 μV vs. -4.6 μV) than PO7/PO8 (-2.8 vs. -3.25 μV). No other effects were significant.

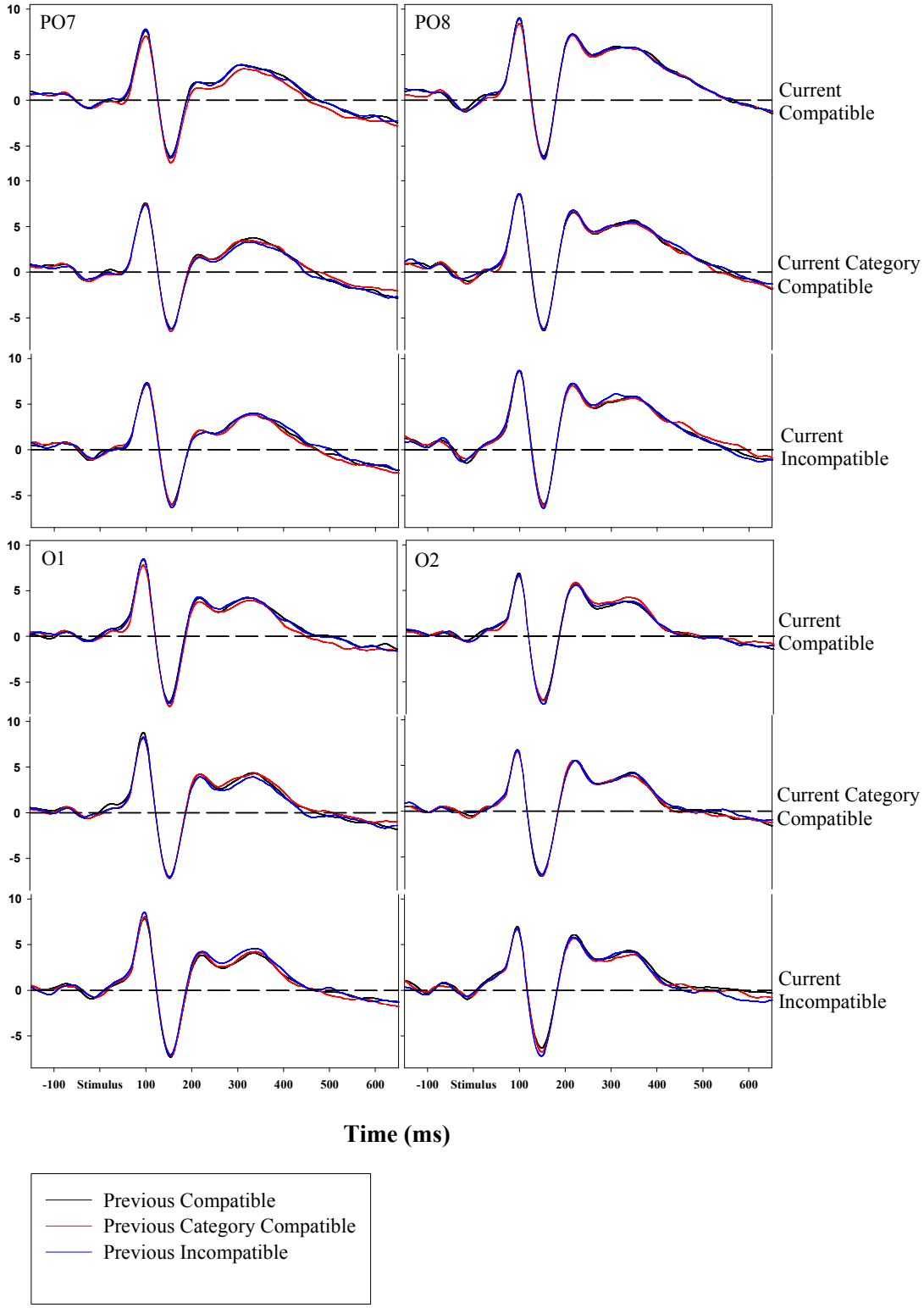


Figure 4.11: Grand average waveforms at electrode sites PO7, PO8, O1 and O2 as a function of current compatibility (top, middle and bottom rows of each electrode figure) and previous compatibility when responding to the FACE as the relevant stimulus dimension.

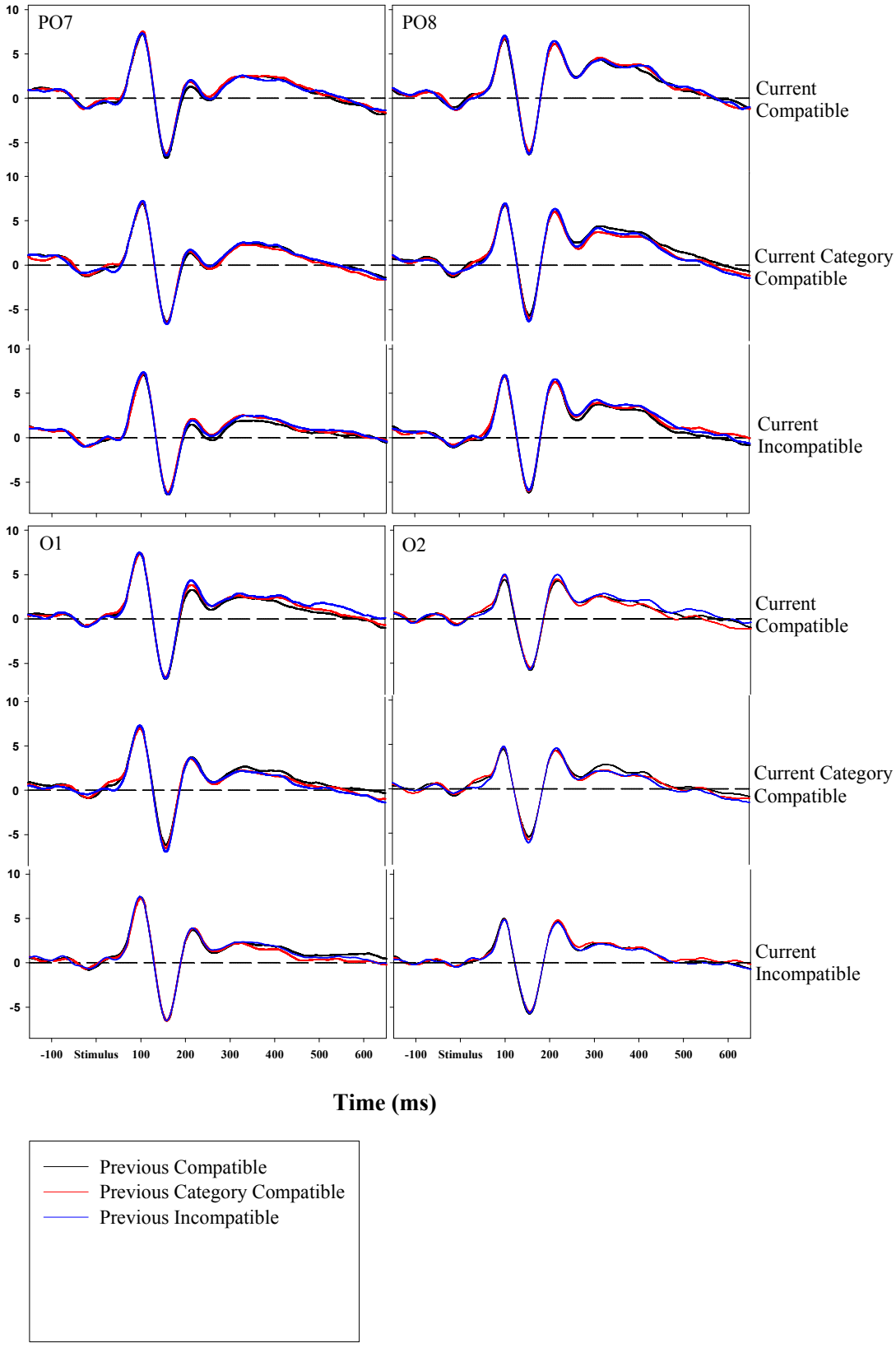


Figure 4.12: Grand average waveforms at electrode sites PO7, PO8, O1 and O2 as a function of current compatibility (top, middle and bottom rows of each electrode figure) and previous compatibility when responding to the TEXT as the relevant stimulus dimension.

4.2.3.3 Exploratory analysis

Visual inspection of the grand average waveforms showed that the processing of the FACE and the TEXT as the relevant stimulus dimension started to deviate from one another approximately 220 ms post stimulus across lateral electrode sites and continued to differ until approximately 400 ms post stimulus.

An analogous ANOVA to that performed on mean P1 and N170 amplitudes was performed on the mean amplitude within this time interval (220 – 400 ms). Mean amplitude was higher when the FACE was the relevant stimulus dimension compared to TEXT as the relevant dimension (3.69 vs. 2.32 μV respectively); $F(1, 19) = 16.25$, $MSE = 41.59$, $p < .001$, and was also higher over the right (3.62 μV) than the left hemisphere (2.4 μV). The effect of hemisphere was modulated by electrode; $F(1, 19) = 24.51$, $MSE = 16.52$, $p < .0001$, due to a larger hemispheric asymmetry at PO7/PO8 (2.12 vs. 4.4 μV) than O1/O2 (2.68 vs. 2.83 μV) electrodes.

Visual inspection also identified differences in the waveforms over midline electrode sites that appeared to be long lasting with no defined time point. Mean ERP amplitudes were determined in 200-ms time windows (200-400 ms, 400-600 ms 600-800 ms and 800-1200 ms) and analysed in separate ANOVAs with the factors relevant stimulus dimension, current compatibility, previous compatibility and electrode (FcZ vs. Cz vs. CpZ vs. Pz vs. POZ). Table 4.1 summarizes the results of these analyses.

Table 4.1: Summary of results from exploratory midline electrode analysis.

	Mid 200-400	Mid 400-600	Mid 600-800	Mid 800-1200
T/F	Ns	Ns	***	Ns
CurComp	***	**	***	Ns
PreComp	Ns	Ns	Ns	Ns
Elect	***	***	***	*
T/F*CurComp	Ns	Ns	Ns	**
T/F*PreComp	Ns	Ns	Ns	Ns
CurComp*PreComp	Ns	Ns	Ns	Ns
T/F*Elect	***	***	***	**
CurComp*Elect	Ns	Ns	***	*
PreComp* Elect	Ns	Ns	*	Ns
T/F*CurComp*Pre Comp	Ns	Ns	Ns	Ns
T/F*CurComp *Elect	Ns	Ns	*	***
T/F*PreComp*Elect	Ns	Ns	Ns	Ns
CurComp*PreComp *Elect	Ns	Ns	Ns	Ns
T/F*CurComp*PreComp*Elect	Ns	Ns	Ns	Ns

Ns = non sig., * = $p < .1$ (note: only trend), ** = $p < .05$, *** = $p < .01$

As this analysis was entirely exploratory in nature and not based on any predefined experimental hypotheses, a full report of all significant effects is unwarranted. Instead, only those interactions related to conflict control and its relation to processing of relevant stimulus dimension will carry any weight. These interactions include the Previous Compatibility x Current Compatibility

and its interaction with relevant stimulus dimension. As can be seen from Table 4.1, there is no significant effect of previous compatibility, current compatibility or any interaction with relevant stimulus dimension across any time interval.

4.2.4 Discussion

The present experiment investigated the conflict adaptation effect within a modified version of the Stroop paradigm. More specifically, it was proposed that N170 amplitude, an ERP component that shows an enhanced response to face stimuli (see 1.4.8), could be used to investigate attentional allocation toward stimulus features when a face stimulus served as a target or distracter after the detection of conflict. If, after the detection of conflict, control mechanisms are recruited in order to bias attentional processing toward task relevant stimulus features, it was predicted that there would be an increase in N170 amplitude when responding according to a property of a face stimulus. Alternatively, if control mechanisms reduce conflict by inhibiting processing of task irrelevant stimulus features, it was predicted that there would be a reduction in N170 amplitude when a face stimulus serves as a distracter. Both predictions of target amplification and distracter inhibition are plausible attentional mechanisms (e.g. Kastner & Ungerleider, 2001) and thus, may provide an explanation of how top-down control is implemented.

Egner and Hirsch (2005) demonstrate that, via the use of the BOLD response within the FFA, a region proposed to show specificity to faces, cognitive control mechanisms implemented after the detection of conflict amplify cortical responses to task-relevant information only. Thus, they conclude that target-feature amplification is the mechanisms of cognitive control in resolving conflict.

The behavioural data from the present experiment demonstrated that participants were significantly faster when responding to the face than when responding to the text. In addition, the typical interference effect was significant. There was an interference effect of 11 ms between compatible and category compatible trials and an interference effect of 40 ms between category compatible trials and incompatible trials. These overall interference effects were influenced by relevant stimulus dimension with the interference effect being smaller when responding according to the face (22 ms) than when responding according to the text (77 ms). These results replicate those of Egner and Hirsch (2005) who also demonstrated that participants were faster when responding according to the face than when responding according to the text and that interference effects were larger in the text task (39 ms) than in the face task (14 ms). The larger interference effects observed in the current study compared to those observed by Egner and Hirsch are likely to be due to the additional condition consisting of an exact face-text match in the present experiment. Indeed, when considering the interference effect between category compatible trials and incompatible trials, a comparison identical to that of Egner and Hirsch, almost identical interference effects are observed across the face task (14 ms vs. 15 ms).

Similar observations can be made when considering the error rate. The error rate was higher when responding to the text than when responding to the face. Error rate was also higher for incompatible trials than compatible trials and this interference effect was more evident for the text task than the face task.

The above descriptions of the behavioural data related to standard interference effects demonstrated that the task used was effective. In the simplest of cases, compatible trials produced the fastest RTs, followed by category

compatible trials (those considered to produce stimulus conflict), with incompatible trial producing the slowest RTs. This was observed for both the face and text tasks, although to a greater extent for the text task. The faster RTs when responding to the face than when responding to the text and also the greater interference effects observed when responding to text indicate that it was more difficult for participants to ignore the face stimulus than it was to ignore the text. However, the presence of distracting text information still influenced behaviour as indicated by the slower RTs to incompatible trials when the face was relevant.

In terms of conflict adaptation, the two-way interaction between previous and current compatibility was significant and was not influenced by response sequence. The results demonstrated that the greatest amount of conflict adaptation was observed between compatible and incompatible trials. This is as predicted as incompatible trials consist of both stimulus conflict and response conflict while compatible trials contain no conflict. When comparing compatible and category compatible trials, no conflict adaptation effect was observed. Thus, when stimulus conflict is experienced on a previous trial, the influence of such stimulus conflict is not reduced on the current trial. When considered together, the above behavioural results concerning the conflict adaptation effect suggest that it is the occurrence of response conflict that determines subsequent behavioural adjustments. Indeed, such a result is consistent with previous results that have shown that although trials that involve stimulus conflict can produce behavioural costs in terms of RT, only trials that involve response conflict result in ACC activation (Van Veen et al., 2001). As it is the ACC that is proposed to detect conflict and signal this information to other brain areas (e.g. DLPFC) to implement top-down control, any behavioural adjustment after stimulus conflict

trials would be problematic for models of cognitive control that rely on a detection mechanism within the ACC (e.g. Botvinick et al., 1999; Botvinick et al., 2001).

In terms of the ERP data, the amplitude of the P1 component did show a significant main effect of relevant stimulus dimension with a larger amplitude when the face was relevant than when the text was relevant. As all stimuli contained face and text information in every trial, this effect is probably due to relevant stimulus size. For example, the face stimulus occupies a much larger area on the screen than does the text. However, this modulation of P1 amplitude was not influenced by compatibility sequence. This is consistent with experimental predictions as face specific effects are proposed to be evident at later latencies only.

Similarly to the P1, the amplitude of the N170 was influenced by relevant stimulus dimension with a higher amplitude when the face was the relevant stimulus dimension compared to when the text was the relevant stimulus dimension. Again, this was not influenced by compatibility sequence. Thus, there is a discrepancy between the sequential effects observed by Egner and Hirsch (2005) for BOLD activity within the FFA and the effects observed here for the amplitude of the N170 component. To preview the explanation discussed more thoroughly within the chapter general discussion, it is proposed that temporal differences between the techniques (fMRI vs. ERPs) form the basis (e.g. Furey et. al., 2006; see chapter general discussion).

To summarise the results from Experiment 1, significant interference effects were observed in overt behaviour within an adapted pictorial Stroop task. Responses were fastest to fully compatible trials, followed by responses to

category compatible trials proposed to consist of stimulus conflict. Responses were slowest to trials proposed to consist of both stimulus and response conflict. Behavioural adjustments were not evident after only stimulus conflict, and thus, support the proposal that it is the detection of response conflict that triggers control mechanisms. Most importantly, there was no evidence in the ERP data that the processing of target relevant stimuli is enhanced after the detection of conflict.

4.3 Pictorial Stroop Experiment 2 (Profession Decision)

4.3.1 Method Section

4.3.1.1 Participants

20 University of Glasgow students, aged 18 to 28 years (mean 21.4 years, 7 male) participated in exchange for pay (£6 per hour). Ethical approval for the study was obtained from the Ethics committee of the Faculty of Information and Mathematical Sciences, University of Glasgow. All participants gave informed consent. All participants reported normal or corrected to normal vision. 17 of the participants were right handed as assessed by the Edinburgh handedness inventory (Oldfield, 1971) (Mean handedness score = 80.5).

4.3.1.2 Apparatus and Stimuli

Apparatus and stimuli were identical to those used in Experiment 1.

4.3.1.3 Design

All aspects of the design and analysis were identical to Experiment 1 except the following: the experimental task changed from responding to the gender to responding according to profession (POP STAR *vs.* ACTOR).

4.3.1.4 Procedure

All aspects of the procedure were identical to Experiment 1 except the task judgement was now based on profession. Half of the participants responded "ACTOR" with the right key while responding "POP STAR" with the left key. For the remaining half of participants this response mapping was reversed.

4.3.2 Data analysis

All aspects of data analysis in terms of behavioural data and ERP data were identical to that performed in Experiment 1.

4.3.3 Results

4.3.3.1 Behavioural Data

4.3.3.1.1 RT results

Mean RTs are shown in Figure 4.13 for the FACE task and Figure 4.14 for the TEXT with separate plots for response repetitions (left panel) and response alternations (right panel). When responding to the FACE as the relevant dimension, participants were significantly faster than when the TEXT was the relevant dimension (750 vs. 786 ms); $F(1,19) = 10.06$, $MSE = 24343.73$, $p < .01$. There was a significant main effect of current compatibility with responses to compatible trials being the fastest (734 ms) compared to category compatible trials (770 ms) and incompatible trials (799 ms); $F(2, 38) = 106.47$, $MSE = 2385.79$, $p < .0001$. Unlike the RT results from the gender classification task, current compatibility did not interact with previous compatibility ($F < 1$), indicating that the size of the congruency effect was similar after all levels of previous conflict, whereas current compatibility and previous compatibility did

interact with response sequence; $F(4, 76) = 3.07$, $MSE = 1504.08$, $p < .05$. Again, like the data from the gender classification task, the conflict adaptation effect can be considered between the three levels of compatibility (compatible, category compatible and incompatible). Three comparisons can be made: first, a comparison between compatible and category compatible trials (stimulus conflict), second, a comparison between category compatible and incompatible trials (response conflict) and third, a comparison between compatible and incompatible trials (stimulus and response conflict). When comparing compatible and category compatible trials, the conflict adaptation effect was not evident indicated by the insignificant Previous Compatibility x Current Compatibility interaction; $F(1, 19) = 1.52$, $MSE = 1163.60$, $p = .23$, nor was this interaction influenced by response sequence; $F(1, 19) = 0.02$, $MSE = 552.98$, $p = .90$. This indicates that the size of the interference effect was similar after compatible and category compatible trials for both response repetitions and alternations. When comparing category compatible trials and incompatible trials, there was no evidence of conflict adaptation as indicated by the non-significant Current Compatibility x Previous Compatibility interaction ($F < 1$). However, this interaction was influenced by response sequence; $F(1, 19) = 4.32$, $MSE = 2070.55$, $p = .52$. For response repetition trials, the conflict adaptation effect was -17 ms while for response alternation trials, the conflict adaptation effect was 25 ms. Thus, following an incompatible trial, the influence of response conflict was reduced for alternation trials but increased for repetition trials. When comparing compatible and incompatible trials only, the interaction between previous and current compatibility demonstrated a significant trend; $F(1, 19) = 3.86$, $MSE = 570.20$, $p = .06$. However, this was influenced by response sequence; $F(1, 19) =$

8.83, *MSE* = 1188.06, $p < .05$. For response repetition trials, the conflict adaptation effect was -32 ms for response repetitions, whereas for response alternation trials the conflict adaptation effect was 35 ms. Thus, following an incompatible trial, the influence of response conflict was reduced for alternation trials but increased for repetition trials.

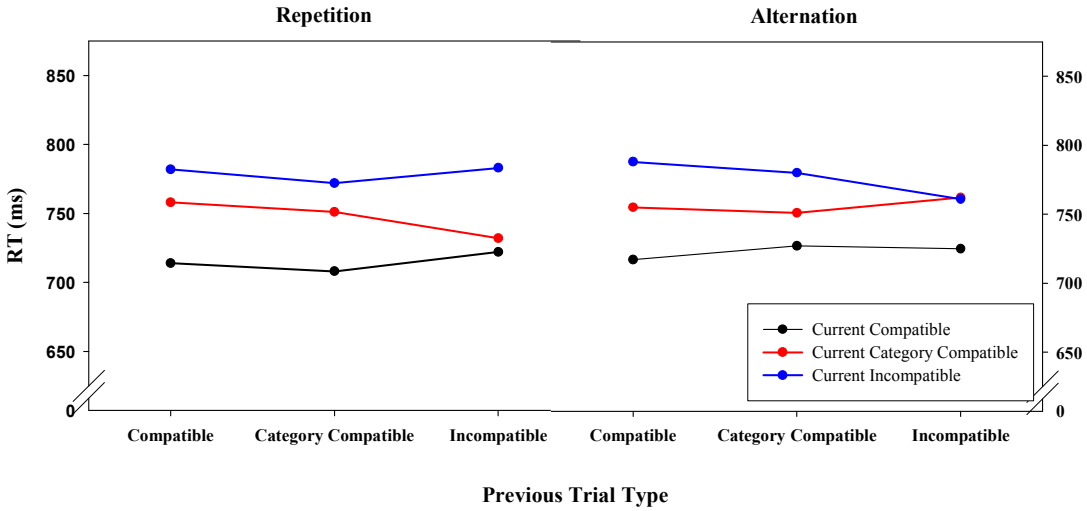


Figure 4.13: Mean RT as a function of previous trial type and current trial type for the FACE task plotted separately for response alteration trials (left panel) and response alternation trials (right panel).

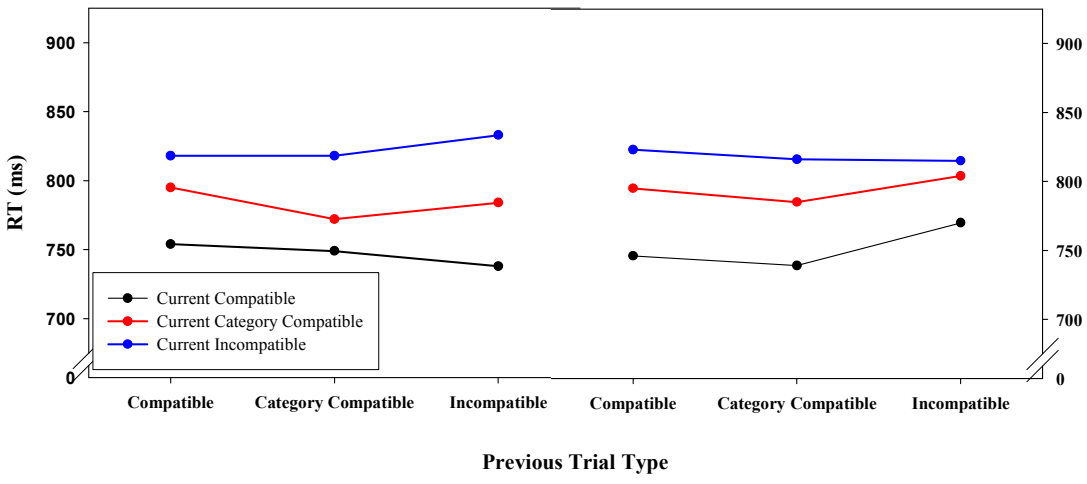


Figure 4.14: Mean RT as a function of previous trial type and current trial type for the TEXT task plotted separately for response alteration trials (left panel) and response alternation trials (right panel).

4.3.3.1.2 Error rate

An analogue ANOVA to that on RT was performed on mean error rates. Mean error rates are shown in Figure 4.15 for the FACE task and Figure 4.16 for the TEXT with separate plots for response repetitions (left panel) and response alternations (right panel). Unlike the gender decision task, there was no significant main effect of relevant stimulus dimension ($F < 1$) with participants producing similar error rates when responding to the face and text (5.78 *vs.* 6.07 %). There was a significant main effect of current compatibility with compatible stimuli producing 4.12 % errors, category compatible stimuli 4.70 % errors and incompatible stimuli 8.96 % errors; $F(2, 38) = 63.38$, $MSE = 26.40$, $p < .0001$). No other main effects or interactions reached significance ($ps > .05$).

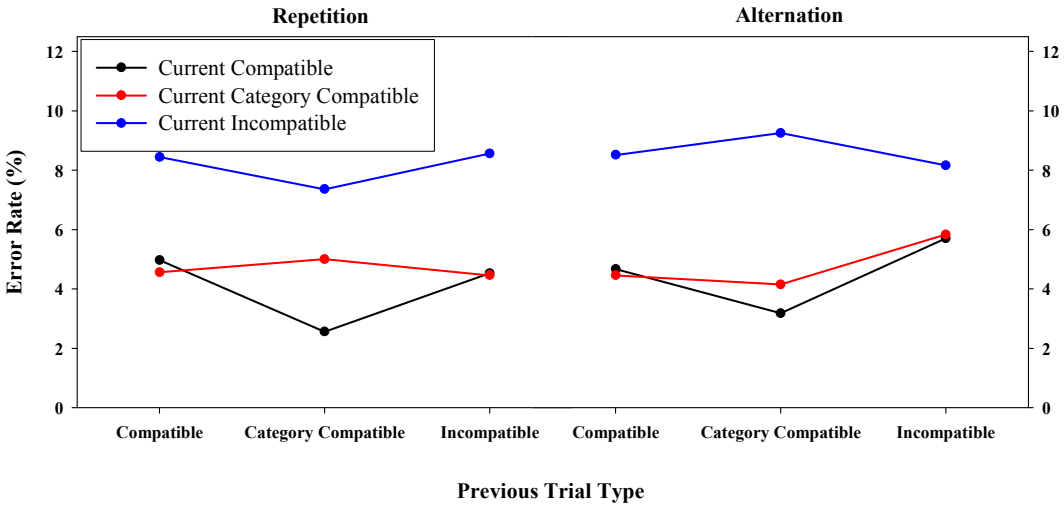


Figure 4.15: Mean error rate as a function of previous trial type and current trial type for the FACE task plotted separately for response alternation trials (left panel) and response alternation trials (right panel).

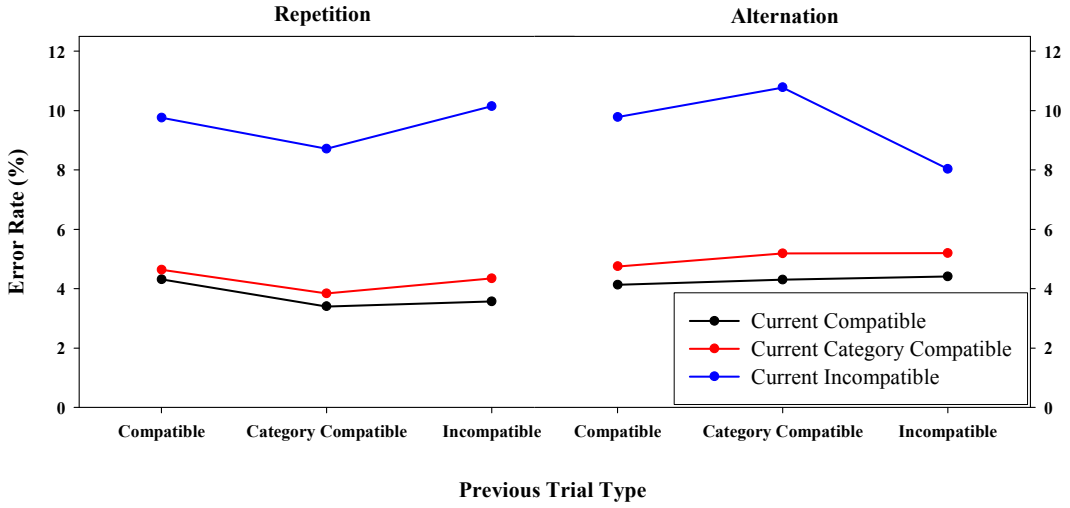


Figure 4.16: Mean error rate as a function of previous trial type and current trial type for the TEXT task plotted separately for response alternation trials (left panel) and response alternation trials (right panel).

4.3.3.2 ERP Data

4.3.3.2.1 P1 Component

Grand average waveforms for each of the conditions are displayed in Figure 4.17 for the FACE as the relevant stimulus dimension and in Figure 4.18 for the TEXT as the relevant stimulus dimension. There was a significant main effect of hemisphere with higher mean amplitude over the right hemisphere (PO8/O2) than over the left hemisphere (PO7/O1) (5.99 vs. 4.03 μV); $F(1, 19) = 13.34$, $MSE = 103.08$, $p < .01$. No other main effects were significant. However, the main effect of relevant stimulus dimension demonstrated a trend. Mean P1 amplitude when the FACE was the relevant dimension tended to be larger (5.22 μV) than when the TEXT was the relevant dimension (4.80 μV); $F(1, 19) = 3.68$, $MSE = 17.33$, $p = .07$. No other main effects or lower level interactions were significant.

4.3.3.2.2 N170 Component

The main effect of electrode was significant; $F(1, 19) = 11.46$, $MSE = 77.72$, $p < .01$, indicating larger mean N170 amplitude over O1/O2 (-5.11 μV) than over PO7/PO8 (-3.53 μV). There was a main effect of previous compatibility; $F(2, 38) = 4.69$, $MSE = 2.34$, $p < .05$. Mean N170 amplitude was larger when the previous trial was compatible (-4.49 μV) than when it was category compatible (-4.22 μV) or incompatible (-4.25 μV). Relevant stimulus dimension interacted with electrode; $F(1, 19) = 8.99$, $MSE = 8.40$, $p < .01$. When TEXT was the relevant dimension, mean N170 amplitude across PO7/PO8 was -3.36μV compared to -5.39μV across O1/O2. This difference was reduced when the FACE was the relevant dimension being -3.72 μV at PO7/PO8 and -4.84 μV at O1/O2. No other main effects or interactions were significant.

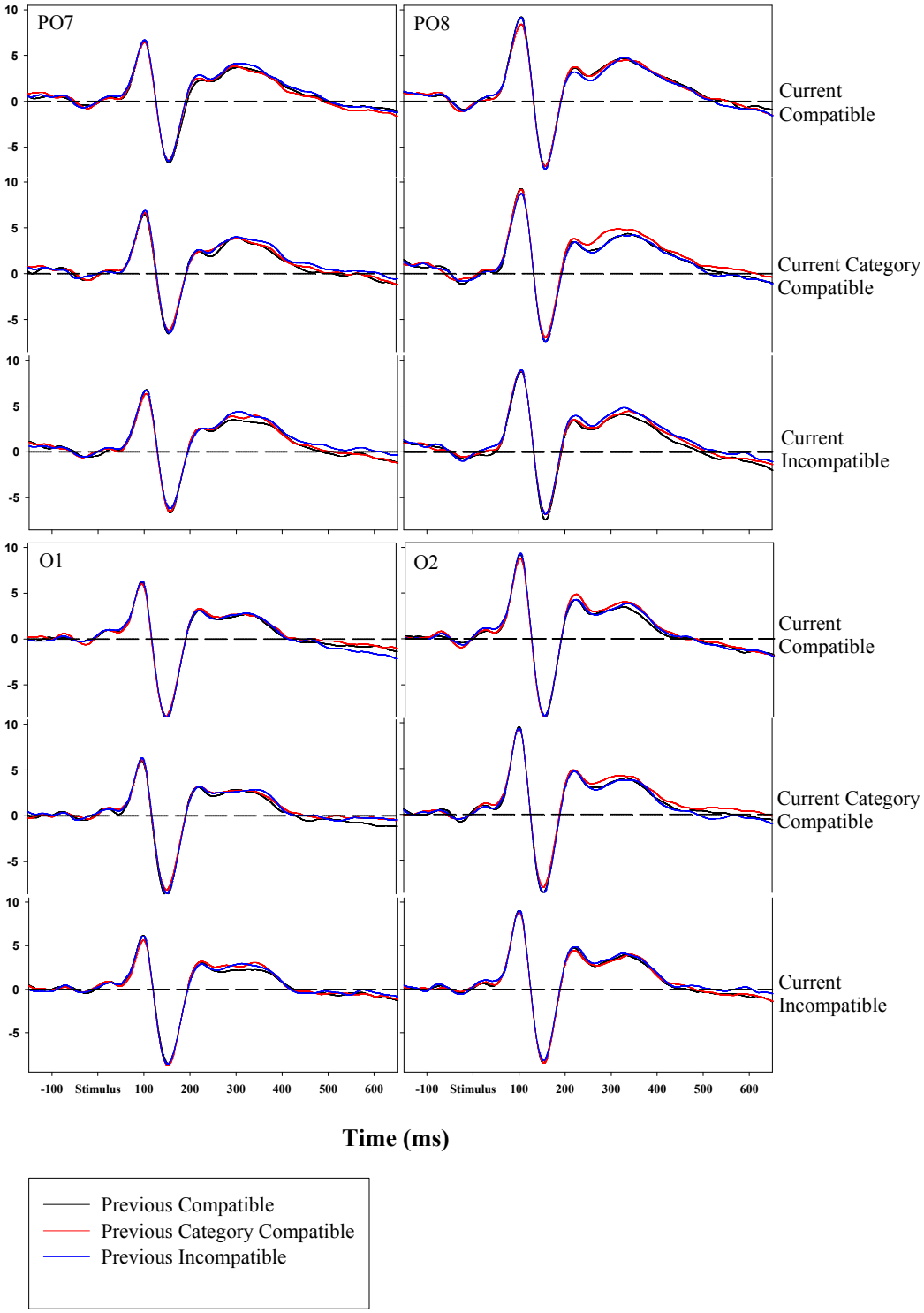


Figure 4.17: Grand average waveforms at electrode sites PO7, PO8, O1 and O2 as a function of current compatibility (top, middle and bottom rows of each electrode figure) and previous compatibility when responding to the FACE as the relevant stimulus dimension.

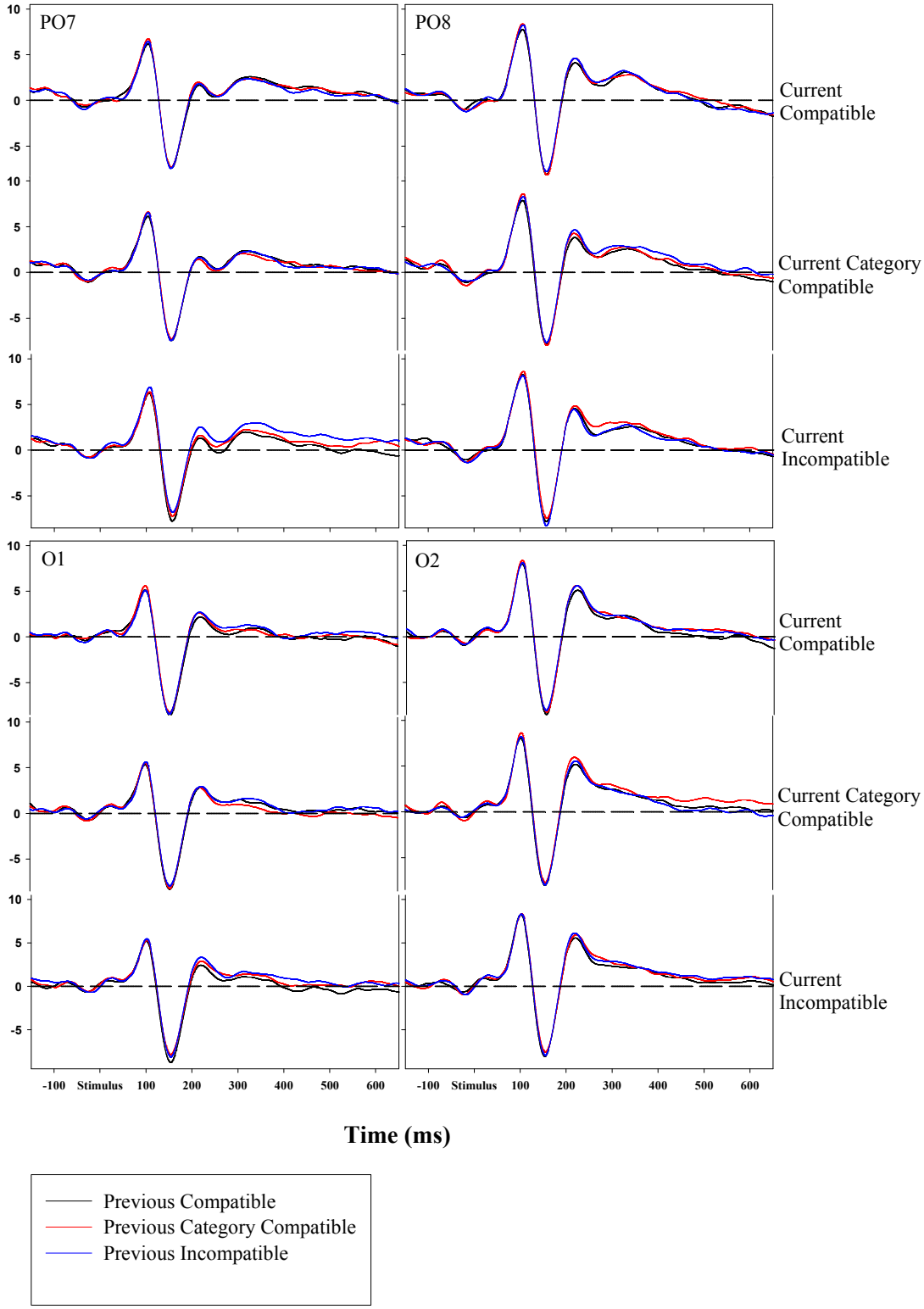


Figure 4.18: Grand average waveforms at electrode sites PO7, PO8, O1 and O2 as a function of current compatibility (top, middle and bottom rows of each electrode figure) and previous compatibility when responding to the TEXT as the relevant stimulus dimension.

4.3.3.3 Exploratory Analysis

Similarly to Experiment 1, visual inspection of the grand average waveforms showed that the processing of the FACE and the TEXT as the relevant stimulus dimension started to deviate from one another approximately 220 ms post stimulus across lateral electrode sites and continued to differ until approximately 400 ms post stimulus. An analogue ANOVA to that performed on mean P1 and N170 components was performed on the mean amplitude within this time interval. There was a significant main effect of relevant stimulus dimension with mean amplitude being higher when the FACE was the relevant dimension compared to TEXT as the relevant dimension (3.07 vs. 1.93 μV); $F(1, 19) = 12.64$, $MSE = 36.82$, $p < .01$. No other effects were significant.

Visual inspection also identified differences in the waveforms over midline electrode sites, which appeared to be long lasting with no defined time point. Mean ERP amplitudes were determined in 200-ms time windows (200-400 ms, 400-600 ms 600-800 ms and 800-1200 ms) and analysed in separate ANOVAs with the factors relevant stimulus dimension (TEXT vs. FACE), current compatibility (compatible vs. category compatible vs. incompatible), previous compatibility (compatible vs. category compatible vs. incompatible) and electrode (FcZ vs. Cz vs. CpZ vs. Pz vs. POZ). Table 4.2 summarizes the results of these analyses.

Table 4.2: Summary of results from exploratory analysis.

	Mid 200-400	Mid 400-600	Mid 600-800	Mid 800-1200
T/F	Ns	Ns	Ns	Ns
CurComp	Ns	***	*	Ns
PreComp	Ns	Ns	Ns	Ns
Elect	***	***	***	***
T/F*CurComp	Ns	***	**	Ns
T/F*PreComp	Ns	Ns	Ns	Ns
CurComp*PreComp	Ns	Ns	Ns	Ns
T/F*Elect	***	***	**	Ns
CurComp*Elect	**	Ns	*	**
PreComp* Elect	Ns	Ns	Ns	Ns
T/F*CurComp*Pre Comp	Ns	*	*	Ns
T/F*CurComp *Elect	Ns	Ns	**	**
T/F*PreComp*Elect	Ns	Ns	Ns	Ns
CurComp*PreComp *Elect	Ns	Ns	Ns	Ns
T/F*CurComp*PreComp *Elect	Ns	Ns	Ns	Ns

Ns = non sig., * = $p < .1$ (note: only trend), ** = $p < .05$, *** = $p < .01$

4.3.4 Discussion

Experiment 2 was based on the same experimental rationale adopted in Experiment 1. To recap, the current experiment investigated the conflict adaptation effect within a modified version of the Stroop paradigm and

investigated attentional mechanisms to stimulus features when they were relevant and irrelevant. This was done by presenting face stimuli both as the target and as the distracter and measuring N170 amplitude. If, after the detection of conflict, control mechanisms are recruited in order to bias attentional processing toward task relevant stimulus features, it was predicted that there would be an increase in N170 amplitude when responding according to a property of a face stimulus. Alternatively, if control mechanisms reduce conflict by inhibiting processing of task irrelevant stimulus features, it was predicted that there would be a reduction in N170 amplitude when a face stimulus serves as a distracter. The only difference between Experiment 1 and Experiment 2 was the task the participants were to perform. In Experiment 1 participants made the judgement 'male vs. female', while in Experiment 2, participants made the judgement 'pop star vs. actor/actress). All stimuli materials were the same. It was predicted that a judgement made on profession would be more difficult and create a greater level of conflict. From this it was predicted that any conflict adaptation effects should be greater in Experiment 2 as increased conflict should result in increased control mechanisms.

The behavioural data from the present experiment demonstrated that participants were significantly faster when responding to the face than when responding to the text, replicating the result of Experiment 1 and also the result of Egner and Hirsch (2005). In addition, the typical interference effect (difference between compatible and incompatible trials) was significant with responses to compatible stimuli being fastest, followed by those to category compatible stimuli, with responses to incompatible stimuli being the slowest. There was an interference effect of 36 ms between compatible and category compatible trials

and an interference effect of 29 ms between category compatible trials and incompatible trials. Unlike the data from Experiment 1, these overall interference effects (65 ms) were not influenced by relevant stimulus dimension with the interference effect being similar when responding according to the face (58 ms) and the text (71 ms). The similarity of the interference effects across the face task and the text task in the present experiment diverge from the results of Experiment 1 and also the results of Egner and Hirsch (2005). Indeed, the interference effects observed in the present experiment are much larger than those observed in the Egner and Hirsch study. Egner and Hirsch observed interference effects of 14 ms for the face task and 39 ms for the text task. There are several possible explanations for the increased interference effect observed in the present study. First, the present study used a much greater number of stimuli (20 faces compared to the 6 used by Egner and Hirsch). This increases the number of stimulus combinations dramatically and reduces potential predictability in the sequence. A second explanation relies on the task used. Although both the present task and the task used by Egner and Hirsch consisted of a profession classification, Egner and Hirsch used 'actor vs. politician' categories while the present study used 'popstar vs. actor' categories. It can be argued the pop star/actor category forms a more homogeneous sample than the actor/politician category and thus, produces more interference. Indeed, as noted in the methods, the boundary between pop star and actor can become faded (e.g. Madonna). However, the most likely explanation, and indeed the simplest, relies on the fact that the present experiment used three levels of compatibility. To compare identical conditions between the present study and that of Egner and Hirsch, one must consider the interference effects from category compatible stimuli to incompatible stimuli in the present experiment.

This results in an interference effect of 16 ms for the face task and 31 ms for the text task, closely resembling the data pattern from Egner and Hirsch.

When considering the error rate, participants made similar levels of errors across both the face and text tasks. This result differs from that of Experiment 1 where participants made more errors when responding to the text than the face. However, the interference effect in terms of error rate did replicate the previous results from Experiment 1. Compatible stimuli resulted in the fewest errors, followed by category compatible stimuli, with incompatible stimuli resulting in the highest error rate.

Like the behavioural data in Experiment 1, the above descriptions of the standard interference effect demonstrated that the task used was effective. In the simplest of cases, compatible trials produced the fastest RTs, followed by category compatible trials (those considered to produce stimulus conflict), with incompatible trial producing the slowest RTs. The faster RTs when responding to the face than when responding to the text and also the greater interference effects observed when responding to text (Experiment 1) indicate that is was more difficult for participants to ignore the face stimulus than is was to ignore the text. However, the presence of distracting text information still influenced behaviour as indicated by the slower RTs to incompatible trials when the face was relevant.

In terms of conflict adaptation, the two-way interaction between previous and current compatibility was not significant. This indicates that the size of the interference effect was similar after all levels of conflict. This deviates from the result obtained in Experiment 1. Why this should be is unclear. As mentioned previously, the only difference between the present experiment and Experiment 1 was the task used. However, the Previous x Current Compatibility interaction was

influenced by response sequence in the present experiment. Analysis indicated that while there was no evidence for conflict adaptation across either response repetitions or alternations between compatible and category compatible trials, conflict adaptation was evident for response alternations only when comparing category compatible trials to incompatible trials and compatible trials to incompatible trials. First, looking at category compatible trials and incompatible trials, there was a conflict adaptation effect of -17 ms for response repetitions and 25 ms for response alternations. Thus, after the occurrence of an incompatible trial, there was greater interference when the response repeated and less interference when the response alternated. This same pattern is evident when comparing compatible trials with incompatible trials (-32 ms vs. 35 ms for response repetitions and alternations respectively).

The lack of any conflict adaptation effects between compatible and category compatible trials replicates the finding from Experiment 1 and provides further evidence that it is the detection of response conflict and not stimulus conflict that triggers control mechanisms. However, the results from the comparisons between trials that do consist of response conflict (compatible → incompatible and category compatible → incompatible) are inconclusive. Any conflict adaptation effects that are evident are specific to response alternations, and indeed, any detection of conflict seems to result in a performance cost for response repetitions. This is an interesting result for several reasons. First, any conflict adaptation effects according to models of cognitive control (e.g. Botvinick et al., 1999; Botvinick et al., 2001) should be independent of bottom-up processes related to response sequence. Thus, observing conflict adaptation for response alternations is problematic for explanations of the effect that rely solely

on increased top-down processing. Second, although bottom-up processes of response sequence have been shown to be important in explaining aspects of the conflict adaptation pattern (cf. Mayr et al, 2003; see also Experimental Chapter 2), such explanations posit that it is response repetitions that drive the effect. In the present experiment, it is response alternations only that show typical conflict adaptation patterns. Previous research demonstrating the influence of response sequence on the conflict adaptation effect used a standard Erikson flanker experiment. Within such a paradigm, there is a limited number of possible stimuli (four), and as a result, there is a high number of trials where both the stimulus and response repeat. The present experiment used a larger number of stimuli and excluded trials where there was a direct stimulus repetition. Thus, it is unclear whether explanations of the conflict adaptation effect within the Eriksen flanker task are applicable in the present situation. What is clear is that a parsimonious model of cognitive control should be able to explain conflict adaptation effects that result from response conflict irrespective of its source (e.g. from flankers within a standard Flanker task or from irrelevant stimulus dimensions within a Stroop task). As a result, such differences across task type are problematic and warrant further research. Indeed, the differences between the conflict adaptation effect in terms of response sequence across Experiment 1 and 2 here is difficult to explain as both experiments involve the same stimuli, and thus, similar stimuli transition sequences. While the present results cannot offer any explanation regarding the influence of response sequence in terms of the conflict adaptation effect, they do highlight the importance of response sequence and task differences.

To summarise the behavioural results from the present Experiment, significant interference effects were observed in behaviour in accordance with the

predicted pattern (e.g. RT compatible trials < RT category compatible trials < RT incompatible trials). Conflict adaptation effects were evident for trials involving only conflict at the level of the response. This result is consistent with previous results that have shown that although trials that involve stimulus conflict can produce behavioural costs in terms of RT, only trials that involve response conflict result in ACC activation (Van Veen et al., 2001). However, such conflict adaptation effects were only evident for response alternations, a result that is inconsistent with previous findings that propose it is response repetitions that drive the conflict adaptation effect (e.g. Mayr et al., 2003). This result highlights the potential role of task differences in the conflict adaptation effect. However, it is difficult to reconcile such task differences within present cognitive control models that consider response conflict irrespective of its source.

In terms of the ERP data, the amplitude of the P1 component did show a significant main effect of hemisphere with larger amplitudes over the right than the left hemisphere. This result is unclear and was not replicated in Experiment 1. Like Experiment 1, P1 amplitude was affected by relevant stimulus dimension with higher amplitudes when the face was relevant compared to when the text was relevant. However, P1 amplitude was not affected by compatibility sequence or relevant stimulus dimension.

Similarly to the P1, N170 amplitude was not influenced by the compatibility sequence or relevant stimulus dimension. Thus, the results from the present experiment and also those from Experiment 1 cannot provide any evidence that, after the detection of conflict, attention is biased toward task-relevant stimulus features. This is based on the result that N170 amplitude was not modulated by the relevance of face stimuli and the conflict experienced on the

previous trial, despite clear interference and adaptation effects in behaviour, albeit, only for response alternations in Experiment 2.

4.4 General Discussion

Both Experiment 1 and 2 investigated the role of attention toward task relevant and task irrelevant stimulus features after the detection of conflict. This was done by investigating the conflict adaptation effect in overt behaviour and by measuring the N170 amplitude to a stimulus containing a face under conditions where the face served as the target and where the face served as the distracter. The only difference between Experiments 1 and 2 was the task used with Experiment 1 using a gender classification task whereas Experiment 2 used a profession classification task. It was predicted that a classification based on profession would be more difficult, and thus, produce longer RTs. This was the case with overall RT being approximately 120 ms greater for the profession classification than the gender classification. It was also predicted that the more difficult task would produce a higher level of conflict and as a result a greater level of conflict adjustment. Looking only at the comparisons between compatible and incompatible trials, the interference effect in Experiment 1 was 49 ms. This compared to 66 ms in Experiment 2. Thus, it appears that the use of a profession classification task produces more interference in behaviour. However, the increased interference between compatible and incompatible trials for the profession classification task did not result in increased conflict adaptation effects. Again, considering compatible and incompatible trials only, the conflict adaptation effect in Experiment 1 was 20 ms. While the same conflict adaptation effect in Experiment 2 was 35 ms, this was specific to response alternations, with

response repetitions giving a negative adaptation effect of 32 ms. It is difficult to reconcile these results. What this result does highlight is the fact that task type or task difficulty can influence the conflict adaptation effect in terms of repetitions/alternations even when identical experimental parameters are used. This result is difficult to reconcile within current models of cognitive control (e.g. Botvinick et al. 1999; Botvinick et al., 2001) as such models view the detection of conflict as being the main determinant of subsequent control processes. Such a model of cognitive control is blind as to the source of conflict and thus, cannot explain the difference observed here when a different task is used within the same paradigm, nor the differences observed across different paradigms (e.g. Flanker task – Mayr et al., 2003; see also Experimental Chapter 2; Prime-target paradigm – Kunde & Wühr, 2006; Stroop task – Kerns et al., 2004) in terms of the influence of response repetition and alternations. Nieuwenhuis et al. (2006) suggested that the Flanker task may differ from other conflict paradigms due to the small stimulus set size, and as a result may not be suited to the study of sequential conflict adaptation effects. However, much evidence for the model of cognitive control has developed from brain imaging studies using the Flanker task (e.g. Botvinick et al., 1999). In addition, the two experiments reported here demonstrate that discrepancies can exist regarding the influence of response sequence on the conflict adaptation effect dependent upon task using a paradigm with increased stimulus set size. Thus, fully understanding exactly why the influence of response sequence is important in some cases and not in others in terms of the conflict adaptation effect is an important area for the development of models of cognitive control.

The ERP data from both Experiments 1 and 2 provide no evidence for the proposal that after the detection of conflict, attention becomes more focused toward the task-relevant stimulus feature. This is based on the finding that N170 amplitude was unaffected by the conflict on the previous trial and a face stimulus's relevance to current behaviour. There are a number of possible reasons for this and will be discussed in turn but basically fall into two classes. First, attentional allocation toward task-relevant features does occur, but this attentional allocation is not detectable in N170 amplitude. Second, attention may not be influenced by conflict and thus, attentional allocation toward task relevant features of future trials does not occur.

Considering the first class of explanation, is attentional allocation detectable in N170 amplitude? Models of face perception are strongly influenced by modularity accounts (e.g. Bruce & Young, 1986). Within such a model, identification of a face proceeds in a sequential fashion from perceptual/structural encoding of the stimulus to the retrieval of a stored representation (termed Face Recognition Units or FRUs). This is followed by an identity specific or Person Identity Nodes (PIN) and semantic information about that person (Semantic Information Units or SIUs) and finally the naming of the face (Name Idenntification Units, NIUs). While the precise details of such models are not important for the present purpose, what is important to note is that the flow of information is unidirectional within such a model. As the N170 has been proposed to represent the structural encoding of a face (e.g. Sagiv & Bentin, 2001), such a model of face perception assumes that the N170 is cognitively impenetrable. However, whether the N170 can be modulated by attention is controversial. Cauquil, Edmonds and Taylor (2000) assessed the effect of directed attention to

faces and found that N170 amplitude was unaffected by the face stimuli's status as target or non-target. In contrast, Holmes et al. (2003) (see also Eimer, 2000, see 1.4.8.1) did show an enhanced N170 amplitude to faces when they were attended to versus ignored. It is possible that the use of different spatial locations for the target and non-target items within the Holmes et al. study resulted in an attention effect that is not evident when both the face item and the competing item are presented at the same spatial location. However, Liu and Kanwisher (2000), as reported in Downing et al. (2001), demonstrated attentional effects on N170 amplitude when both the relevant and irrelevant stimulus dimensions (face and house in this instance) were presented at the same spatial location. Thus, it is unclear whether the lack of any modulation on N170 amplitude in the current experiments is due to the cognitively impenetrability of the component or the lack of any attentional modulation toward the relevant target as the result of previous conflict. This highlights a potential area for future research, namely, establishing the exact nature of the effects of attention on N170 amplitude across different paradigms where relevant and irrelevant stimuli are presented at both different spatial locations and also at the same spatial location. A potential limitation of the present experiments was the lack of a control experiment where attention effects on N170 were established using similar experimental procedures. However, such a finding should be evident when considering the main effect of relevant stimulus dimension. For example, if attention does affect N170 amplitude, it should be enhanced when responding according to the face as compared to when responding according to the text irrespective of conflict sequence. This was evident for Experiment 1 but not for Experiment 2, thus any definite conclusion is difficult. In addition, relevant stimulus dimension demonstrated a significant main effect on

P1 amplitude in both Experiments. P1 amplitude is not proposed to show any specificity for a face stimulus over any other category of stimuli.

The second class of explanations posit that top-down control does not result in increased attentional allocation toward future relevant targets after the detection of conflict. If this is the case, how can the results of Egner and Hirsch (2005) be explained? To recap briefly, they demonstrated increased activation within the FFA after the detection of conflict when a face stimulus was relevant. They suggest that attentional top-down signals may enhance pre-stimulus activity within brain areas related to the processing of task relevant stimuli. However, as mentioned previously, this suggestion is not fully supported from their results. Their results show that for incompatible trials, FFA activation is higher when the previous trial was incompatible compared to when the previous trial was compatible. This is consistent with target amplification following the detection of conflict. When considering congruent trials, FFA activation is higher when the previous trial is compatible compared to when the previous trial is incompatible. As participants cannot predict stimulus sequence, explanations solely based on an increase in baseline activity when conflict is detected would predict additive effects rather than the interaction observed (see Figure 4.3). That is, when trial N-1 is incompatible, this triggers control adjustments in terms of biasing baseline activity. Hence, if the fMRI BOLD response is measuring only this activity change, then it should be independent from the event in trial N. A possible explanation regarding the lack of modulation in N170 amplitude in the present experiments and the modulation of activity within the FFA measured via the BOLD response in Egner and Hirsch (2005) concerns differences in the temporal resolution of the techniques used. EEG signals generated by neural activity can

provide a temporal resolution in the scale of milliseconds, whereas fMRI on the other hand relies on slow hemodynamic changes and thus, can only provide a temporal resolution in the scale of several seconds. Furey et al. (2006) demonstrate that the responses measured within the FFA via fMRI and the N170 response (or in this case the M170) can be dissociated by the effect of attention. They used double exposure stimuli of faces and houses similar to those used by Kanwisher and colleagues (see 1.4.8.1). Participants were required to attend to either the face stimulus or the house stimulus within a block of trials and were required to indicate whether a repetition of the attended-to stimulus occurred. Their fMRI results showed that when attention was directed to houses within the double-exposure trials, the face-selective response within the FFA was suppressed. In contrast, their MEG results showed that attention had no effect on the face-selective M170 response. Furey et al. suggest that the M170 reflects a rapid feed-forward phase of processing, whereas, the hemodynamic signal within the FFA reflects later responses that are modulated by feed-back connections. This conclusion is consistent with previous research comparing attentional effects on the C1 component via ERPs and attention effects within visual area V1 using fMRI (e.g. Martinez et al., 1999; see 1.4.7).

To conclude the discussion of the ERP data, two main possibilities for the lack of any effect dependent upon previous trial conflict have been proposed. The first assumes that attention is directed toward the task-relevant item after conflict detection but that this attentional biasing toward the relevant stimulus dimension (the face in this instance) is not detectable in amplitude modulations of the N170. The second assumes that attention is not directed toward task relevant features in advance of stimulus presentation. Here it is proposed that the effects within the

FFA observed by Egner and Hirsch (2005) are the result of later feed-back connections.

4.5 Chapter Summary

To summarise the present chapter, two pictorial Stroop tasks were conducted. Stimulus and response conflict was manipulated as was the relevant stimulus dimension to which participants responded. It was investigated whether, after the detection of conflict, attention is directed toward the task-relevant stimulus feature. This was done by using the N170 component as a dependent measure of face processing. Behavioural data indicated that the task was effective in producing interference and that this interference was reduced after conflict consistent with the proposal that the detection of conflict results in the recruitment of control mechanisms. Analysis of the conflict adaptation effect after stimulus and response conflict indicated that it was the detection of response conflict that resulted in conflict adaptation effects. However, the conflict adaptation effect was influenced by response sequence in the second experiment, thus highlighting potential influences of task difficulty. The ERP data offered no evidence that, after the detection of conflict, attention is directed toward the task relevant stimulus feature. Further research is needed in order to determine the cognitive penetrability of the N170 component. In addition, further research is needed to determine whether the attentional effects within the FFA observed by Egner and Hirsch (2005) are the result of baseline increases in activity that occur prior to stimulus presentation as proposed by the authors, or the result of feedback connections that occur later after the presentation of the stimulus.

Chapter 5. General Discussion

5.1 Overview

This thesis utilised a cognitive electrophysiological approach to the study of executive control processes. Questions addressed include the mental operations that are modulated by executive control processes and the mechanisms underlying control-related processing adjustments. More specifically, Chapter 2 investigated whether the processes of task-set reconfiguration – a proposed stage of information processing when one switches between cognitive tasks – creates a bottleneck for all subsequent processing, delaying even the earliest of processing stages (e.g. perceptual stages). Chapters 3 and 4 investigated control-related adjustments in behaviour after the detection of conflict within behavioural interference tasks. Chapter 3 used a Flanker paradigm while Chapter 4 used an adapted version of the Stoop task and examined the possible role of attention in resolving conflict by biasing task relevant stimulus features. Within the Flanker Task, such attentional modulation dependent upon conflict was spatial in nature (i.e. attending to the central target location), whereas for the Stroop task, both the relevant and irrelevant stimulus dimensions were presented at the same spatial location.

Before discussing the results in a wider context, a brief overview of the main findings will be provided. As highlighted earlier, the rationale of the Experiments reported in Chapter 2 was driven by the study of Oriet and Jolicoeur (2003) who claimed that the processes of task-set reconfiguration constituted a hard bottleneck delaying even perceptual processing. This claim was based on their finding of an additive interaction between a manipulation of stimulus contrast and decreasing RSI. From this they proposed a sequential model of task-

switching where the process of task-set reconfiguration takes place before stimulus processing, response selection and response execution. Chapter 2 (Exps. 1 & 2) used an identical alternating runs paradigm (Rogers and Monsell, 1995), as used by Oriet and Jolicoeur, with the addition of ERP measures. The results from the experiments reported in Chapter 2 do not offer support to the claim of Oriet and Jolicoeur, and instead, question whether the proposed stage of reconfiguration is specific to task switch trials. This is based on the finding of and underadditive effect of stimulus contrast and decreasing RSI that was independent of trial type (RT – Exp 2, RT + P1/N1 latencies – Exp 2). Chapters 3 and 4 demonstrated behavioural adjustment effects after the detection of conflict with these behavioural adjustments being specific to response repetitions within the Flanker task (Chapter 3) and specific to response alternations within the adapted Stroop task (Chapter 4). Despite clear behavioural adjustment after the detection of conflict, there was no evidence in the ERP data that such adjustments are the result of increased attention toward the task-relevant stimulus feature. These results question previous research that have shown increased attentional allocation to task-relevant stimulus features after the detection of conflict (Flanker task – Scerif et al. (2006); modified Stroop task – Egner & Hirsch (2005)). In the case of the Flanker task, there was a discrepancy between the results of Scerif et al and those reported in Chapter 3. Thus, the results from Chapter 3 question the robustness of the findings of Scerif et al. and indicate that further research is needed to determine whether control is manifested as an attentional bias toward the central target location within the flanker array. In the case of the Stroop task, a potential explanation for the discrepancy lies in the research methods used (e.g. Egner and Hirsch (2005) measured the BOLD effect within the FFA using fMRI,

while Chapter 4 adopted ERP methodology utilising N170 amplitude as a measure of face processing). These methods (fMRI & ERPs) differ greatly in the temporal resolution offered. Thus, it is possible that the increased activity observed within the FFA to face targets after conflict reflects later responses that are modulated by feed-back connections, whereas the N170 reflects a rapid feed-forward phase of processing (e.g. Furey et al., 2006). Indeed, such discrepancies between fMRI results and ERP results have been observed in attentional investigations of the C1 component (e.g. Martinez et al., 1999). There was also a discrepancy between the behavioural conflict adaptation effects within the Flanker task and the modified Stroop task. Within the Flanker task, the observed behavioural adjustments were specific to response repetition trials, and thus, question whether a top-down control explanation that relies on conflict detection and resultant increased control is necessary. Instead, the results are consistent with explanations that posit that behavioural adjustments within the Flanker task are the result of a confound resulting from unequal proportions of stimulus and response repetitions between different trial sequences (e.g. Mayr et al., 2003). However, within the Stroop task, such behavioural adjustments were specific to response alternation trials, and in addition, indicated that it was the occurrence of response conflict that determined subsequent behavioural adjustments.

5.2 Task Switching and Executive Control

As highlighted in the introduction, a proposed endogenous, intentional reconfiguration process involved in task switching has been the focus of much research as it may provide a window for the study of higher-order functions of executive control (Rogers & Monsell, 1995). However, debate exists regarding

the extent to which switch costs reflect an endogenous control process. Much of this debate centres on the 'residual cost' found in task switching experiments. Specifically, when preparation is long enough to, theoretically, allow full preparation, the switch cost is not entirely limited. Proponents of a task-set reconfiguration view of switch costs have postulated that endogenous control requires stimulus presentation in order to complete reconfiguration, a so-called exogenous component (e.g. Rogers & Monsell, 1995). Alternatively, others (e.g. Allport et al., 1994; Altmann, 2002) have rejected the notion of endogenous reconfiguration, and instead, attributed switch costs to the competition between relevant and irrelevant task-sets, with the implementation of a new task-set requiring the inhibition of the previous task-set. This has been termed the 'task-set inertia' (TSI) hypothesis (Allport et al., 1994). Both explanations receive a large volume of empirical support, and thus, it is generally accepted that a combination of endogenous reconfiguration and TSI provide the most convincing explanations of the data (Monsell, 2003).

The experiments reported in Chapter 2 were not designed to distinguish between control and interference (or encoding) accounts of task switching, but instead, assumed a task-set reconfiguration process a priori and investigated whether such a process constituted a hard bottleneck delaying even the earliest of processing (e.g. perceptual stages) as proposed by Oriet and Jolicoeur (2003). However, several findings from the experiments reported have implications for models of task switching. First, underadditivity of a contrast manipulation with decreasing RSI was observed in RT (Exps. 2 & 3) and peak P1/N1 latencies (Exps. 1 & 2) independent of whether the trial involved a task switch or a task repetition. Thus, while the switch cost was reduced with increasing preparation

time, the observed underadditivity cannot be attributed to a process of task-set reconfiguration that is specific to task switch trials. From this, the question as to what causes the underadditivity of contrast at short RSIs independent of trial type remains open. Gilbert (2005) suggested a model of task switching where the processes of task-set reconfiguration, perceptual processing and response selection take place in parallel and demonstrated that the pattern of data observed by Oriet and Jolicouer can be replicated. However, the results from experiments reported in Chapter 2 produced underadditive effects of contrast and RSI, a finding that cannot be accommodated within the model of Gilbert (2005). Speculatively, some form of response monitoring that occurs on both task repetition and task switch trials may produce the underadditivity of contrast observed. Indeed, this may be consistent with the proposal of an extended selection bottleneck hypothesis within the PRP paradigm (see Welford, 1952). Welford proposed that after the execution of R1, monitoring of the response requires the retrieval of S1 and R1 codes. Jentzsch, Leuthold, and Ulrich (2007) report data that is consistent with response selection monitoring hypothesis for the residual component within the PRP paradigm. The residual component within the PRP paradigm refers to the portion of the RT cost when R1 is executed before the presentation of S2. Thus, although R1 has been executed, a central bottleneck stage is still occupied for a period and that this is the result of continued monitoring of R1. It is a possibility that such a monitoring process is involved in both task repetition and switch trials and that this produces the underadditive effect of contrast at the short RSI independent of trial type observed in Chapter 2. Such a monitoring process may occupy central resources for a longer period in task switch trials. This may explain why, although not significant, there was more

underadditivity observed on task switch trials than on task repetition trials (Chapter 2, Epxs. 1 & 2).

The LRP data from Chapter 2 (Exp 2.) indicated that task switching affected a processing stage prior to response selection. This is consistent with previous results reporting effects of task switching on the S-LRP interval (e.g. Hsieh & Yu, 2003). Hsieh and Yu suggested that response selection was prolonged due to a carry-over of interference effects from the previous task, whereas task preparation influenced the duration of processes prior to response selection on both task repeat and task repetition trials (see also, Koch, 2005). Indeed, such a result is consistent with the model of task switching proposed by Meiran (2000) (see also Meiran, Chorev, and Sapir, 2000) who suggested a two-component model of task switching. First, an endogenous control component that reduces the switch cost with increased preparation time based on stimulus-sets. Second, a response-set reconfiguration process that is completed after response selection. Meiran et al. argue that it is this response-set reconfiguration process that is responsible for the residual aspect of the switch cost.

From the above, it appears that switch costs reflect processing difficulties from a number of sources. First, preparation may influence the duration of early processes on both switch trials and repeat trials. Indeed, RTs to both switch and repeat trials are reduced as preparation time increases (N.B. at very long RSI intervals, RTs may increase due to a loss of preparation). Second, with longer RSIs, there is less interference from the previous task set. Importantly, task switch procedures involving univalent stimuli (stimuli with which only a single task can be performed) often show reduced switch costs or no switch costs at all (e.g. Rogers & Monsell, 1995, Exp 4.). This is consistent with the TSI hypothesis as

univalent stimuli will produce no interference across tasks. However, Rogers & Monsell (1995, Exp 4.) still observed a small residual cost that remained even at the longest RSI level (1200 ms). Thus, it appears that the residual cost is unaffected by preparation and is attributed to an exogenous component of reconfiguration that can only be completed after stimulus presentation (Rogers & Monsell, 1995). In addition, Rogers and Monsell (1995, Exp 6., see also Chapter 2 Exp. 3) demonstrated that within a four trial run sequence, the performance benefit for repetition trials was specific to the first repetition with the remaining residual component of the switch task remaining relatively constant across subsequent task repetitions. This is inconsistent with the TSI hypothesis as it assumes that interference will persist over many intervening trials (Rogers & Monsell, 1995). Thus, the third component is independent of task preparation and also interference from the previous task set.

Future research needs to identify the relative contribution from each source and also the circumstances where each source makes the largest contribution. As highlighted by Logan (2003), different paradigms have been used to assess switch costs yet the conclusions drawn tend to be general in nature. For example, how does the switch cost measured via the alternating runs paradigm compare to the switch cost measured within a task cueing paradigm? Within the alternating runs paradigm, the task sequence is predictable while in the task cueing paradigm, the task is indicated by a cue presented prior to stimulus onset. It is possible that within the task cueing paradigm, after the execution of a response, participants adopt a task-set that is more akin to cue-encoding rather than the task-set required for the experimental task. Indeed, this is consistent with the results of Logan and Bundesen (2003) who demonstrated that there was a

large switch cost when the cue changed yet indicated a task repetition. Thus, they propose that the switch cost observed within task cueing paradigms reflects a benefit from cue repetition rather than a benefit from repeating a task.

Most task switching experiments involve both bivalent stimuli and bivalent responses. Meiran (2000) suggested that the preparation effect (indexed by either CTI or RSI) reflects a stimulus-set biasing stage and is only required with bivalent stimuli and hence, with univalent stimuli, the switching cost should reflect the residual component only. Alternatively, with univalent response, there should be no residual component. Future research should carefully manipulate combinations of univalent and bivalent stimuli and responses.

5.3 Conflict Adjustment within Interference Tasks

The discrepancy between the conflict adaptation effects observed within the Flanker task (Chapter 3) and the modified Stroop task (Chapter 4) are consistent with previous reports. For example, Mayr et al. (2003) (see also, Nieuwenhuis et al., 2006) report results demonstrating conflict adaptation effects specific to response repetitions within the Flanker task, whereas, conflict adaptation effects independent of response sequence have been reported within the Stroop task (e.g. Kerns et al., 2004). Such a discrepancy highlights the importance of task differences in explaining conflict adaptation effects. However, such task differences are difficult to reconcile within conflict control models (e.g. Botvinick et al., 2001), as it is the simple detection of conflict irrespective of source that determines adjustments within such models. Thus, explaining why such a discrepancy is found between different interference tasks is an important future direction for models of cognitive control. What seems to be important is the

number of stimuli used within the experimental set-up. Within a standard Flanker paradigm, there are only four possible stimulus arrays, and thus, the occurrence of stimulus repetitions is high. Indeed, within a modified Flanker paradigm that increased the stimulus set size by using the digits 1-9, it has been shown that conflict adaptation effects are evident when repetition trials are removed (Ullsperger et al., 2005, Exp. 2). Ullsperger et al. argue that, within the analysis of Mayr et al. the conflict adjustment effect may have been masked by the influence of negative priming. For example, Stadler and Hogan (1996) demonstrated that RTs are elevated for incompatible stimuli following incompatible stimuli that involve a reserve of target and flanker items (e.g. < < > < < → > > < > >). Such an influence of negative priming is unlikely when stimulus elements are not repeated due to increased stimulus set size (Ullsperger et al., 2005). Ullsperger et al. also demonstrated conflict adaptation effects within a standard flanker paradigm (Exp 1.) and argue that the influence of negative priming was reduced in this instance due to the longer inter-stimulus interval and brief stimulus presentation times when compared to the experimental procedure used by Mayr et al.

In the second experiment reported by Mayr et al. (2003), it was demonstrated that conflict adaptation effects were removed when the flanker and target arrows alternated in a trial-by-trial manner across x and y dimensions. Within such a set-up, there was no instance of negative priming. However, conflict adaptation was evident when considering trial n-2 and trial n, a finding Mayr et al. attribute to a memory-based priming account. Ullsperger et al. suggest that such a set-up may have been treated as a switch between two independent tasks, and argue that it is unclear whether the conflict monitoring model would

predict top-down control modulations across the two tasks. However, conflict adjustment effects have been observed across different congruency tasks. For example, Kunde and Wühr (2006) demonstrated conflict adaptation effects within a prime-target paradigm combined with spatial Simon effects.

In terms of behavioural conflict adaptation effects, future research needs to establish when the relative contributions of bottom-up priming effects and top-down control are important. This is especially true in the case of the standard Flanker task involving a small number of stimulus combinations. For example, does the Flanker task represent a special case where bottom-up priming effects override top-down control mechanisms?

5.4 Concluding Remarks

In summary, this thesis utilised a cognitive electrophysiological approach to the study of executive control processes. The first experimental chapter investigated whether the process of task-set reconfiguration constitutes a hard bottleneck delaying even early perceptual processing as previously suggested (e.g. Oriet & Jolicoeur, 2003). No evidence for this claim was provided by the results. The second and third experimental chapters investigated the conflict adaptation effect within two different interference paradigms (Flanker task and modified Stroop task, respectively). Despite behavioural adaptation effects, albeit, only for response repetitions within the Flanker task, the ERP results showed no evidence that the processing of the relevant stimulus dimension is enhanced after the detection of conflict.

References

Ach, N. (1910). *Über den Willensakt und das Temperament.* Leipzig: Quelle & Meyer.

Ach, N. (1935). Analyse des Willens. In E. Abderhalden (Ed.), *Handbuch der biologischen Arbeitmethoden* (Vol. VI). Berlin: Urban & Schwarzenberg.

Allison, T., Ginter, H., McCarthy, G., Nobre, A.C., Puce, A., Luby, M. & Spencer, D.D. (1994). Face recognition in human extrastriate cortex. *Journal of Neurophysiology, 71*, 821-825.

Allport, A., Styles, E.A., & Hsieh, S. (1994). Shifting international set: Exploring the dynamic control of tasks. In C. Umilta & M. Moscovitch (Eds.), *Attention and performance XV,* p 421- 452. Cambridge, MA: MIT Press.

Altmann, E.M. (2002). Functional decay of memory for tasks. *Psychological Research*, *66*, 287- 297.

American Electroencephalographic Society (1994). Guideline nine: guidelines on evoked potentials. *Journal of Clinical Neurophysiology*, *11*, 40–73.

Atkinson, R. C., & Shiffrin, R.M. (1968). Human memory: a proposed system and its control processes. In K.W. Spence (Ed.), *The Psychology of Learning and Motivation: Advances in Research and Theory*, Vol. 2, p 89-195. New York: Academic Press.

Baas, J. M. P., Kenemans, J. L., & Mangun, G. R. (2002). Selective attention to spatial frequency: an ERP and source localization analysis. *Clinical Neurophysiology, 113*(11), 1840-1854.

Baddeley, A. D., & Hitch, G.J. (1974). Working memory. In G.A. Bower (Ed.), *Recent Advances in Learning and Motivation*, Vol. 8, p 47-89. New York: Academic Press.

Berg, P., & Scherg, M. (1994). A multiple source approach to the correction of eye artifacts. *Electroencephalography & Clinical Neurophysiology*, *90*, 229-241.

Botvinick, M.M., Nystrom, L. E., Fissell, K., Carter, C. S., & Cohen, J. D. (1999). Conflict monitoring versus selection-for-action in anterior cingulate cortex. *Nature, 402*(6758), 179-181.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*(3), 624-652.

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: an update. *Trends in Cognitive Sciences, 8*(12), 539-546.

Bruce, V., & Young, A. (1986). Understanding face recognition. *British Journal of Psychology, 77*(3), 305.

Burton, A., Bruce, V., & Johnston, R.A. (1990). Understanding face recognition with an interactive activation model. *British Journal of Psychology, 81*(3), 361.

Cabeza, R., & Nyberg, L. (2000). Imaging cognition II: An empirical review of 275 PET and fMRI studies. *Journal of Cognitive Neuroscience, 12***,** 1-47.

Carter, C. S., Braver, T. S., Barch, D. M., Botvinick, M. M., Noll, D., & Cohen, J. D. (1998). Anterior cingulate cortex, error detection, and the on-line monitoring of performance. *Science, 280,* 747-749.

Casey, B. J., Thomas, K. M., Welsh, T. F., Badgaiyan, R. D., Eccard, C. H., Jennings, J. R., & Crone, E.A. (2000). Dissociation of response conflict, attentional selection, and expectancy with functional magnetic resonance imaging. *Proceedings of the National Academy of Sciences, 97*(15), 8728-8733.

Cauquil, A. S., Edmonds, G. E., & Taylor, M. J. (2000). Is the face-sensitive N170 the only ERP not affected by selective attention? *Neuroreport, 11*(10), 2167-2171.

Clark, V. P., & Hillyard, S. A. (1996). Spatial selective attention effects early extrastriate but not striate components of the visual evoked potential. *Journal of Cognitive Neuroscience, 8(5),* 387-402.

Clark, V. P., Fan, S., & Hillyard, S. A. (1995). Identification of early visual evoked potential generators by retinotopic and topographic analyses. *Human Brain Mapping*, *2*, 170-187.

Coles, M. G. H. (1989). Modern Mind Brain Reading: Psychophysiology, physiology, and cognition. *Psychophysiology, 26*, 251-269.

Coles, M.G.H., Gratton, G., & Fabiani, M. (1990). Event-related brain potentials. In J.T. Cacioppo & L.G. Tassinary (Eds.), *Principles of Psychophysiology: Physical, social, and inferential elements*. Cambridge, UK: Cambridge University Press.

Dahaene, S., Posner, M. I., & Tucker, D. M. (1994). Localization of a neural system for error detection and compensation. *Psychological Science, 5,* 303-305.

De Jong, R. (2000). An intention-activation account of residual switch costs. In S. Monsell & J. Driver (Eds.), *Control of Cognitive Processes: Attention and Performance XVIII*, MIT Press, p 357-376.

Deutsch, J. A., & Deutsch, D. (1963). Attention: Some theoretical considerations.

Psychological Review, *70*, 80-90.

Donchin, E. (1981). Surprise!... Surprise? *Psychophysiology, 18*(5), 493-513.

Donders, F. C. (1969). On the speed of mental processes. *Acta Psychologica, 30*, 412-431.

Downing, P., Liu, J., & Kanwisher, N. (2001). Testing cognitive models of visual attention with fMRI and MEG. *Neuropsychologia, 39*(12), 1329-1342.

Egner, T., & Hirsch, J. (2005). Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. *Nature Neuroscience, 8*(12), 1784-1790.

Eimer, M. (2000). Effects of face inversion on the structural encoding and recognition of faces: Evidence from event-related brain potentials. *Cognitive Brain Research, 10*(1-2), 145-158.

Eimer, M., & Coles, M.G.H. (2003). *The lateralized readiness potential. The Bereitschaftspotential* (p 229-248). New York: Kluwer/Plenum.

Epstein, R., Harris, A., Stanley, D. & Kanwisher, N. (1999). The parahippocampal place area: recognition, navigation, or encoding? *Neuron, 23*, 115-125.

Epstein, R. & Kanwisher, N. (1998). A cortical representation of the local visual environment. *Nature, 392*, 598-601.

Eriksen, C. W. (1995). The flanker task and response competition: A useful tool for investigating a variety of cognitive problems. *Visual Cognition, 2,* 101-118.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception and Psychophysics, 16,* 143-149.

Eriksen, C. W., & Schultz, D. W. (1979). Information processing in visual search: A continuous flow conception and experimental results. *Perception and Psychophysics, 25,* 248-263.

Farah, M.J., Wilson, K.D., Drain, M., & Tanaka, J.N. (1998). What is "special" about face perception? *Psychological Review, 105*, 482-498.

Fera, P., Jolicoeur, P., & Besner, D. (1994). Evidence against early selection: Stimulus quality effects in previewed displays. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 259-275.

Furey, M. L., Tanskanen, T., Beauchamp, M. S., Avikainen, S., Uutela, K., Hari, R., & Haxby, J.V. (2006). Dissociation of face-selective cortical responses by attention. *Proceedings of the National Academy of Sciences, 103*(4), 1065-1070.

Gandhi, S.P., Heeger, D.J., & Boynton, G.M. (1999). Spatial attention affects brain activity in human primary visual cortex. *Proceedings of the National Academy of Sciences*, 96, 3314-3319.

Gazzaniga, M.S., Ivry, R.B., & Mangun, G.R. (2002). Cognitive Neuroscience – the biology of the mind. WW Norton & Company: New York.

Gehring, W. J., Goss, B., Coles, M. G. H., Meyer, D. E., & Donchin, E. (1993). A neural system for detection and compensation. *Psychological Science, 4*(6), 385-390.

Gilbert, S. J. (2005). Does task-set reconfiguration create cognitive slack? *Journal of Experimental Psychology - Human Perception and Performance, 31*(1), 92-100.

Gilbert, S. J., & Shallice, T. (2002). Task Switching: A PDP Model. *Cognitive Psychology, 44*(3), 297-337.

Goldman-Rakic, P. S. (1987). Circuitry of the prefrontal cortex and the regulation of behavior by representational memory. *Handbook of Physiology,* 5(1, 9), 373417

Gonzalez, C. M. G., Clark, V. P., Fan, S., Luck, S. J., & Hillyard, S. A. (1994). Sources of attention-sensitive visual event-related potentials. *Brain Topography, 7*(1), 41-51.

Gratton, G., Coles, M.G.H., & Donchin, E. (1992). Optimizing the use of information: strategic control of activation of responses. *Journal of Experimental Psychology, 121,* 480- 506.

Gratton, G., Coles, M. G. H., Sirevaag, E. J., Eriksen, C. W., & Donchin, E. (1988). Pre- and post- stimulus activation of response channels: A psychophysiological analysis. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 331-344.

Halgren, E., Raij, T., Marinkovic, K., Jousmaki, V., & Hari, R. (2000). Cognitive Response Profile of the Human Fusiform Face Area as Determined by MEG. *Cerebral Cortex, 10*(1), 69-81.

Hillyard, S.A. & Picton, T.W. (1987). Electrophysiology of cognition. In V.B. Mountcastle, F. Plum, & S.R. Geiger (Eds.), *Handbook of Physiology: Section 1. The nervous system: Vol V. Higher functions of the brain*, *2*, p 519-584. Bethesda, MD: American Physiological Society.

Hillyard, S. A., Luck, S. J., & Mangun, G. R. (1994). The cuing of attention to visual field locations: Analysis with ERP recordings. In H. J. Heinze, T. F. Munte, & G. R. Mangun (Eds.), *Cognitive electrophysiology: Event-related brain potentials in basic and clinical research,* p 1-25. Cambridge, MA: Birkhausen Boston.

Hohnsbein, J., Falkenstein, M., & Hoorman, J. (1989). Error processing in visual and auditory choice reaction time tasks. *Journal of Psychophysiology, 3*, 32.

Holmes, A., Vuilleumier, P., & Eimer, M. (2003). The processing of emotional facial expression is gated by spatial attention: evidence from event-related brain potentials. *Cognitive Brain Research, 16*(2), 174-184.

Hommel, B. (1998). Event files: Evidence for automatic integration of stimulus-response episodes. *Visual Cognition, 5*, 183-216.

Hommel, B., Proctor, R., & Vu, K.P. (2004). A feature-integration account of sequential effects in the Simon task. *Psychological Research, 68*(1), 1-17.

Hommel, B., Ridderinkhof, R. K., & Theeuwes, J. (2002). Cognitive control of attention and action: Issues and trends. *Psychological Research, 66*, 215-219.

Hommel, B. & Prinz, W. (1997). *Theoretical issues in stimulus-response compatibility.* North-Holland.

Hopfield, J. J. (1982). Neural networks and physical systems with emergent collective computational abilities. *Proceedings of the National Academy of Sciences, 79,* 2554-2558.

Hsieh, S. & Yu, Y. (2003). Switching between simple response-sets: inferences from the lateralized readiness potential. *Cognitive Brain Research, 17 (2)*, 228-237.

James, W. (1890). *The principles of Psychology*. New York: Dover Publications.

Jaskowski, P., Pruszewicz, A., & Swidzinski, P. (1990). VEP latency and some properties of simple motor reaction time distribution. *Psychological Research, 52,* 28–34.

Jeffreys, A.D. (1996). Evoked potential studies of face and object processing. *Visual Cognition 3*, 1-38.

Jeffreys, D., & Axford, J. (1972). Source locations of pattern-specific components of human visual evoked potentials. I. Component of striate cortical origin. *Experimental Brain Research, 16*(1), 1-21.

Jentzsch, I., Leuthold, H., & Ulrich, R. (2007). Decomposing sources of response slowing in the PRP paradigm. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 610–626.

Jersild, A. T. (1927). Mental set and shift. *Archives of Psychology,* Whole No. 89.

Johannes, S., Munte, T. F., Heinze, H. J., & Mangun, G. R. (1995). Luminance

and spatial attention effects on early visual processing. *Brain Research: Cognitive brain Research, 2*(3), 189-205.

Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. In J.B. Long & A.D. Baddeley (Eds.), *Attention and performance IX, p 187-203*. Hillsdale, NJ: Erlbaum.

Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The Fusiform Face Area: A Module in Human Extrastriate Cortex Specialized for Face Perception. *Journal of Neuroscience, 17*(11), 4302-4311.

Kanwisher, N., & Wojciulik, E. (2000). Visual attention: insights from brain imaging. *Nature reviews neuroscience, 1*, 91–100.

Karayanidis, F., Coltheart, M., Michie, P.T., & Murphy, K. (2003). Electrophysiological correlates of anticipatory and poststimulus components of task switching. *Psychophysiology, 40*, 329-348.

Kastner, S., & Ungerleider, L. G. (2001). The neural basis of biased competition in human visual cortex. *Neuropsychologia, 39*(12), 1263-1276.

Kastner, S., DeWeerd, P., Desimone, R., & Ungerleider, L. G. (1998). Mechanisms of directed attention in the human extrastriate cortex as revealed by functional MRI. *Science*, *282*, 108-111.

Kerns, J. G., Cohen, J. D., MacDonald, A. W., Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior Cingulate conflict monitoring and adjustments in control. *Science, 303*(5660), 1023-1026.

Koch, I. (2005). Sequential task predictability in task switching. *Psychonomic Bulletin & Review, 12*, 107-112.

Kopp, B., Mattler, U., Goertz, R., & Rist, F. (1996). N2, P3 and the lateralized readiness potential in a nogo task involving selective response priming. *Electroencephalography and Clinical Neurophysiology, 99*(1), 19-27.

Kornhuber, H.H., & Deecke, L. (1965). Hirnpotentialänderungen bei Willkürbewegungen und passiven Bewegungen des Menschen: Bereitschaftspotential und reafferente Potentiale. *Pflügers Archic für fie gesamte psychologie, 284*, 1-17.

Kunde, W., & Wühr, P. (2006). Sequential modulations of correspondence effects across spatial dimensions and tasks. *Memory & Cognition, 34*(2), 356-367.

Kutas, M., & Donchin, E. (1980). Preparation to respond as manifested by movement-related brain potentials. *Brain Research, 202*, 95-115.

Leuthold, H., Sommer, W., & Ulrich, R. (1996). Partial advance information and response preparation: inferences from the lateralized readiness potential. *Journal of Experimental Psychology-General, 125*(3), 307-323.

Lien, M.C., Ruthruff, E., Remington, R. W., & Johnston, J. C. (2005). On the limits of advance preparation for a task switch: Do people prepare all the task some of the time or some of the task all the time? *Journal of Experimental Psychology: Human Perception & Performance*, *31*, 299-315.

Liu, J., & Kanwisher, N. (2000). Covert visual attention modulates face-specific activity at 160 msec: An MEG study. Poster presented at the annual meeting of the Society for Cognitive Neuroscience, San Francisco.

Liu, J., Higuchi, M., Marantz, A., & Kanwisher, N. (2000). The selectivity of the occipitotemporal M170 for faces. *Neuroreport, 11*, 337-341.

Logan, G. D. (2003). Executive control of thought and action: In search of the wild homunculus. *Current Directions in Psychological Science, 12*(2), 45-48.

Logan, G. D., & Zbrodoff, N. J. (1979). When it helps to be misled: Facilitative effects of increasing the frequency of conflicting stimuli in a Stroop-like task. *Memory and Cognition,* 7, 166-174.

Luck, S. J. (2005a). *An Introduction to the Event-Related Potential Technique*. MIT Press, Cambridge.

Luck, S. J. (2005b). The operation of attention—millisecond by millisecond—over the first half second. In H. Ogmen & B. G. Breitmeyer (Eds.), *The first half second: The microgenesis and temporal dynamics of unconscious and conscious visual processes,* p 187-206. Cambridge, MA: MIT Press.

Luck, S. J. (1998). Sources of Dual-Task Interference: Evidence From Human Electrophysiology. *Psychological Science, 9*(3), 223-227.

Luck, S. J., & Hillyard, S.A. (1995). The role of attention in feature detection and conjunction discrimination: an electrophysiological analysis. *International Journal of Neuroscience, 80*(1-4), 281-297.

Luck, S. J., Woodman, G. F., & Vogel, E. K. (2000). Event-related potential studies of attention. *Trends in Cognitive Sciences, 4*(11), 432-440.

Luria, R., & Meiran, N. (2005). Increased control demand results in serial processing: Evidence from dual-task performance. *Psychological Science, 16(10)*, 833-840.

MacLeod, C. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109*, 163–203.

Mangun, G.R. (1995). Neural mechanisms of visual selective attention. *Psychophysiology, 32*, 4–18

Mangun, G. R., Hansen, J. C. & Hillyard, S. A. (1987). The spatial orienting of attention: Sensory facilitation or response bias? In R. Johnson Jr., J. W. Rohrbaugh & R. Parasuraman (Eds.), *Current trends in event-related potentials research* (*EEG Suppl*. 40), 118–124. Amsterdam: Elsevier.

Mangun, G. R., & Hillyard, S. A. (1991). Modulations of Sensory-Evoked Brain Potentials Indicate Changes in Perceptual Processing during Visual Spatial Priming. *Journal of Experimental Psychology-Human Perception and Performance, 17*(4), 1057-1074.

Mangun, G. R., Hillyard, S. A., & Luck, S. J. (1993). Electrocortical substrates of visual selective attention. In D. E. Meyer & S. Kornblum (Eds.), *Attention and performance XIV: Synergies in experimental psychology, artificial intelligence, and cognitive neuroscience,* p 219-243. Cambridge, MA: MIT Press.

Martinez, A., Anllo-Vento, L., Sereno, M.I., Frank, L.R., Buxton, R.B., Dubowitz, D.J., Wong, E.C., Hinrichs, H., Heinze, H.J., & Hillyard, S.A. (1999). Involvement of striate and extrastriate visual cortical areas in spatial attention. *Nature Neuroscience, 2*(4), 364.

Martinez, A., Di Russo, F., Anllo-Vento, L., & Hillyard, S. A. (2001). Electrophysiological analysis of cortical mechanisms of selective attention to high and low spatial frequencies. *Clinical Neurophysiology, 112*(11), 1980-1998.

Mattler, U. (2003). Priming of mental operations by masked stimuli. *Perception & Psychophysics, 65*, 167-187.

Mayr, U., Awh, E., & Laurey, P. (2003). Conflict adaptation effects in the absence of executive control. *Nature Neuroscience, 6*(5), 450.

McClelland, J.L. (1979). On the time relations of mental processes: An examination of systems of processes in cascade. *Psychological Review, 86*, 287-330.

Meiran, N., Chorev, Z., & Sapir, A. (2000). Component Processes in Task Switching. *Cognitive Psychology, 41*(3), 211-253.

Meyer, D.E., Osman, A.M., Irwin, D.E., & Yantis, S. (1988). Modern mental chronometry. *Biological Psychology, 26*, 3-67.

Miller, J. (1982). Discrete versus continuous models of human information processing: In search of partial output. *Journal of Experimental Psychology: Human Perception and Performance, 8*, 273-296.

Miller, J., Patterson, T., & Ulrich, R. (1998). Jackknife-based method for measuring LRP onset latency differences. *Psychophysiology, 35*(1), 99-115.

Monchi, O., Petrides, M., Petre, V., Worsley, K., & Dagher, A. (2001). Wisconsin Card Sorting Revisited: Distinct Neural Circuits Participating in Different Stages of the Task Identified by Event-Related Functional Magnetic Resonance Imaging. *Journal of Neuroscience, 21*(19), 7733-7741.

Monsell, S., & Driver, J. (2000). Banishing the control homunculus. In S. Monsell & J. Driver (Eds.), Control of cognitive processes: Attention and Performance XVIII, p 3-32. Cambridge MA: MIT Press.

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences, 7*(3), 134-140.

Müller, H. J. F., & John, M. (1987). Sensitivity and criterion effects in the spatial cuing of visual attention. *Perception & Psychophysics. , 42*(4), 383-399.

Müller, H. J., & Rabbitt, P. M. A. (1989). Reflexive and voluntary orienting of visual attention: Time course and activation and resistance to interruption. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 315-330.

Näätänen, R., & Picton, T. (1987). The N1 Wave of the Human Electric and Magnetic Response to Sound: A Review and an Analysis of the Component Structure. *Psychophysiology, 24*(4), 375-425.

Newell, A. (1980). Reasoning, Problem-Solving, and Decision Processes. In R. Nickerson (Ed.), *Attention and Performance VIII*. Hillsdale, N.J.: Erlbaum.

Nieuwenhuis, S., Stins, J.F., Posthuma, D., Polderman, T.J.C., Boomsma, D.I., de Geus, E.J. (2006). Accounting for sequential trial effects in the flanker task: Conflict adaptation or associative priming? *Memory and Cognition, 34*(6), 1260-1272.

Norman, W. & Shallice, T. (1986) Attention to action. In R. J. Davidson, G. E. Schwartz & D. Shapiro (Eds.), *Consciousness and self- regulation: Advances in research and theory, vol. 4,*. Plenum.

Notebaert, W., Gevers, W., Verbruggen, F., & Liefdoghe, B. (2006). Top-down and bottom-up sequential modulations of congruency effects. *Psychonomic Bulletin & Review, 13*(1), 112-117.

Notebaert, W., Soetens, E., & Melis, A. (2001). Sequential analysis of a Simon task – evidence for an attention-shift account. *Psychological Research, 65*(3), 170-184.

Notebaert, W., & Verguts, T. (2008). Cognitive control acts locally. *Cognition, 106*(2), 1071-1080.

O'Craven, K. M., Downing, P. E., & Kanwisher, N. (1999). fMRI evidence for objects as the units of attentional selection. *Nature, 401*(6753), 584.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsycholoia, 9,* 97-113.

Oriet, C., & Jolicoeur, P. (2003). Absence of perceptual processing during reconfiguration of task set. *Journal of Experimental Psychology-Human Perception and Performance, 29*(5), 1036-1049.

Osman, A., & Moore, C.M. (1993). The locus of dual-task interference: Psychological refractory effects on movement-related brain potentials. *Journal of ExperimentalPsychology: Human Perception and Performance, 19,*1292–1312.

Osman, A., Moore, C. M., & Ulrich, R. (1995). Bisecting RT with lateralized readiness potentials: Precue effects after LRP onset. *Acta Psychologica, 90*(1-3), 111-127.

Pachella, R. G. (1974). *The interpretation of reaction time in information processing research. Human information processing: Tutorial in performance and recognition.* Hillsdale, NJ: Erlbaum.

Pardo, J. V., Pardo, P. J., Janer, K. W., & Rachel, M. E. (1990). The anterior cingulate cortex mediates processing selection in the Stroop attention conflict paradigm. *Proceedings of the National Academy of Science*, *87*, 256–259.

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin, 116,* 220–244.

Pashler, H., & Johnston, J.C. (1989). Chronometric evidence for central postponement in temporally overlapping tasks. *Quarterly Journal of Experimental Psychology, 41A,*19–45.

Picton, T. W., Lins, O. G., & Scherg, M. (1995). The recording and analysis of event-related potentials. In J. Grafman (Ed.), *Handbook of neuropsychology, Vol. 10*, p 3-73. Amsterdam: Elsevier.

Posner, M.I., Nissen, M.J. & Ogden, C. (1978). Attended and unattended processing, modes: The role of set for spatial location. In H. L. Picks & I. J. Saltzman (Eds.), *Modes of perceiving and processing information,* p 137-157. Hillsdale, NJ: Erlbaum.

Posner, M. I. (1978). *Chronometric Explorations of Mind*: Englewood Heights, NJ: Erlbaum.

Posner, M. I. (1980). Orienting of attention. *Journal of Experimental Psychology, 32*, 3-21.

Posner, M.I., & Di Girolamo, G.J. (1998). Executive attention: conflict, target

detection and cognitive control. In R. Parasuraman (Ed.), *The Attentive Brain*, p 401-423, MIT Press.

Posner, M.I., & Cohen, Y. (1984). Components of Visual Orienting. In H. Bouma & D.G. Bouwhuis (Eds.), *Attention and Performance,* vol. 10, p 531-556. Hilldale, N.J.: Erlbaum.

Rabbitt, P.M.A. (2002). Consciousness is slower than you think. *The Quarterly Journal of Experimental Psychology A, 55*, 1081-1092.

Rabbitt, P.M.A., & Vyas, S. (1981). Processing a display even after you make a response to it. How perceptual errors can be corrected. *The Quarterly Journal of Experimental Psychology Section A, 33*(3), 223 - 239.

Rabbitt, P. M. A. (1966). Error Correction Time without External Error Signals. *Nature, 212*(5060), 438-438.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124,* 207-231.

Sagiv, N., & Bentin, S. (2001). Structural Encoding of Human and Schematic Faces: Holistic and Part-Based Processes. *Journal of Cognitive Neuroscience, 13*(7), 937-951.

Sanders, A. F., & Lamers, J. M. (2002). The Eriksen flanker effect revisited. *Acta Psychologica, 109*(1), 41-56.

Scerif, G., Worden, M. S., Davidson, M., Seiger, L., & Casey, B. J. (2006). Context modulates early stimulus processing when resolving stimulus-response conflict. *Journal of Cognitive Neuroscience, 18*(5), 781-792.

Shallice, T. (1988). *From Neuropsychology to Mental Structure.* MIT Press, Cambridge, MA.

Shaw, M. (1984). Division of attention among spatial locations: A fundamental difference between detection of letters and detection of luminance increments. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X: Control of language processes,* p 109-121. Hillsdale, NJ: Erlbaum.

Shallice, T. (1994). Multiple Levels of Control Processes. In C. Umilta & M. Moscovitch (Eds.), Attention and performance XV, p 395-420. Cambridge, MA: MIT Press.

Simon, J. R. (1969). Reactions toward the source of stimulation. *Journal of Experimental Psychology, 81*, 174–176.

Smulders, F. T. Y., Kok, A., Kenemans, J. L., & Bashore, T. R. (1995). The

temporal selectivity of additive factor effects on the reaction process revealed in ERP component latencies. *Acta Psychologica, 90*, 97– 109.

Somers, D. C., Dale, A. M., Seiffert, A. E., & Tootell, R. B. H. (1999). Functional MRI reveals spatially specific attentional modulation in human primary visual cortex. *Proceedings of the National Academy of Sciences, 96*(4), 1663-1668.

Sperling, G. (1984). A unified theory of attention and signal detection. In R. D. Parasuraman, (Ed.), *Varieties of attention*: New York: Academic Press.

Sperling, G. & Dosher, B. A. (1986). Strategy and optimization in human information processing. In K. R. Boff, L. Kaufman, & J. P. Thomas, (Eds.), *Handbook of perception and human performance, Vol.1 Sensory processes and perception* (Chap. 2). New York: Wiley.

Stadler, M.A., & Hogan, M.E. (1996). Varieties of positive and negative priming. *Psychonomic Bulletin and Review, 3*, 87-90.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. *Acta Psychologica, 30*, 276-315.

Sternberg, S. (2001). Separate modifiability, mental modules, and the use of pure and composite measures to reveal them. *Acta Psychologica, 106*(1-2), 147-246.

Stroop J.R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643-662.

Stürmer, B., Leuthold, H., Soetens, E., Schröter, H., & Sommer, W. (2002). Control over location-based response activation in the Simon task: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology-Human Perception and Performance, 28*(6), 1345-1363.

Ullsperger, M., Bylsma, L. M., & Botvinick, M. M. (2005). The conflict adaptation effect: It's not just priming. *Cognitive Affective & Behavioral Neuroscience, 5*(4), 467-472.

Ulrich, R. & Miller, J. (1994). Effects of truncation on reaction time analysis. *Journal of Experimental Psychology – General,* 123, 34-80.

Ulrich, R., & Miller, J. (2001). Using the jackknife-based scoring method for measuring LRP onset effects in factorial designs. *Psychophysiology, 38*(5), 816-827.

Vaughan, H. G. Jr., Costa, L. D., & Gilden, L. (1966). The functional relation of visual evoked response and reaction time to stimulus intensity. *Vision Research*, *6*, 654-656.

van Veen, V., & Carter, C. S. (2002). The anterior cingulate as a conflict monitor:

fMRI and ERP studies. *Physiology & Behavior, 77*(4-5), 477-482.

van Veen, V., Cohen, J. D., Botvinick, M. M., Stenger, V. A., & Carter, C. S. (2001). Anterior cingulate cortex, conflict monitoring, and levels of processing. *Neuroimage, 14*(6), 1302-1308.

Verbruggen, F., Notebaert, W., Liefooghe, B., & Vandierendonck, A. (2006). Stimulus- and response-conflict-induced cognitive control in the flanker task. *Psychonomic Bulletin & Review, 13*(2), 328-333.

Vidal, F., Hasbroucq, T., Grapperon, J., & Bonnet, M. (2000). Is the ‘error negativity' specific to errors? *Biological Psychology, 51*(2-3), 109-128.

Vogel, E. K., & Luck, S. J. (2000). The visual N1 component as an index of a discrimination process. *Psychophysiology, 37,* 190–203.

Wojciulik, E., Kanwisher, N., & Driver, J. (1998). Covert visual attention modulates face-specific activity in the human fusiform gyrus: fMRI study. *Journal of Neurophysiology, 79*(3), 1574-1578.

Wylie, G.R., Javitt, D.C. & Foxe, J.J. (2003). Task switching: a high-density electrical mapping study. *Neuroimage, 20*, 2322-2342.

Wylie, G. R., Javitt, D. C., & Foxe, J. J. (2004). Don't think of a white bear: An fMRI investigation of the effects of sequential instructional sets on cortical activity in a task-switching paradigm. *Human Brain Mapping, 21*, 279-297.

Yeung, N., Botvinick, M.M., & Cohen, J. (2004). The neural basis of error detection: Conflcit monitoring and the error-related negativity. *Psychological Review, 111*, 931-959.

Yeung, N., & Monsell, S. (2003). The effects of recent practice on task switching. *Journal of Experimental Psychology - Human Perception and Performance, 29*(5), 919-936.