Event-related potential studies of prefrontal cortex contributions to episodic retrieval

Damian Cruse

DECLARATION

This work has not previously been accepted in substance for any degree and is not concurrently submitted in candidature for any degree.

Signed ....D. Crusse.................. (candidate)

Date ..16/05/10....

STATEMENT 1

This thesis is being submitted in partial fulfilment of the requirements for the degree of PhD.

Signed ....D. Crusse.................. (candidate)

Date ...16/05/10..

STATEMENT 2

This thesis is the result of my own independent work/investigation, except where otherwise stated. Other sources are acknowledged by explicit references.

Signed ....D. Crusse.................. (candidate)

Date ...16/05/10...

STATEMENT 3

I hereby give consent for my thesis, if accepted, to be available for photocopying and for inter-library loan, and for the title and summary to be made available to outside organisations.

Signed ....D. Crusse.................. (candidate)

Date ..16/05/10

Abstract

Although the prefrontal cortex (PFC) is known to play roles in episodic memory retrieval, the specific processes it supports are not fully understood. The high temporal resolution of the event-related potential (ERP) technique provides one fruitful avenue for investigations of these processes. However, the PFC-supported retrieval operations that may be indexed by ERPs are currently under-specified. The work contained in this thesis is concerned with providing a more specific characterisation of PFC-supported processes that operate during episodic retrieval than is available currently. To this end, Experiments One to Three were designed in order to assess the likely functional significance of one known modulation which has been identified in ERP studies of episodic retrieval – the right-frontal ERP old/new effect. This effect is widely assumed to reflect activity generated within the PFC. Experiments Four and Five extended this work to related issues which arose as a result of the outcomes of the initial experiments.

All five experiments reported in this thesis employed source memory tasks in which participants studied a list of words presented in one of two contexts (or sources). These words were presented visually in one of two colours in Experiments One, Two, Three, and Five (Visual condition), and were presented auditorily in a male/female voice in Experiments Four and Five (Auditory condition). At test, in all experiments, all studied words were presented visually in white letters intermixed with unstudied (new) words. For words judged to have been encountered previously (old words), a second judgment was required. In Experiments One and Two, this was a binary decision regarding the source in which the word had been previously presented (study colour). In Experiments Three, Four, and Five, a high/low source confidence rating was also made.

For the right-frontal ERP old/new effect, strong evidence was provided in Experiments One and Two to rule out the potential contributions of three aspects of task design that may have contributed to disparate and seemingly contradictory findings in the published literature. These were: the presence/absence of copy cues at test, response requirements at test, and the difficulty of the retrieval task. Experiment Three was designed in order to test directly a "number of decisions account" for the

right-frontal old/new effect (Dobbins & Han, 2006; Hayama, Johnson, & Rugg, 2008), and provided strong evidence inconsistent with such an account. A serendipitous finding in this study was evidence for a left-frontal ERP old/new effect that was functionally and electrophysiologically dissociable from the right-frontal old/new effect, and which differentiated between high and low confidence correct source judgments. There was no evidence for this effect in Experiment Four, however, when auditory (male/female voice) rather than visual (pink/yellow letters) source information was to be retrieved at test, suggesting the content-specificity of this frontally distributed ERP effect. This possibility was tested directly in Experiment Five in which versions of Experiments Three and Four were completed within-participants. Two separable frontal old/new effects were observed. These effects differed in their scalp distributions as a function of the forms of episodic content that were retrieved (i.e. visual vs. auditory source).

The scalp distributions of the frontal old/new effects across Experiments Three to Five also varied according to whether the data from the first or the second halves of retrieval phases were analysed. These qualitative changes in neural activity according to time on task are interpreted in terms of processes involved in the resolution of interference, which presumably increases during the course of a retrieval task. The implications of this finding for conclusions made on the basis of averaged measures of neural activity across the entirety of a retrieval task are also discussed. In combination, the data reported in this thesis provide evidence that ERPs are sensitive to multiple neurally, functionally, and temporally distinct PFC-supported processes which operate during episodic retrieval, and offer insights into the roles played by PFC during episodic retrieval.

Acknowledgments

My thanks go first to my supervisor, Dr. Ed Wilding, for his constructive guidance and support throughout the last three years. Thanks also go to those others in the my lab group who are both colleagues and friends, in particular, Emma Bridger, Rachael Elward, Hilary Watson, and Belle Yick, along with many other post-graduate friends at Cardiff, without whom this would not have run so smoothly nor been nearly as enjoyable. Finally, my thanks go to those friends and family who will never read this, but who have kept my feet on the ground when my head was elsewhere.

Table of Contents

List of Figures

List of Tables

Chapter One : Introduction

1.1 Introduction

Our capability as humans to retrieve detailed information about a particular prior experience or event from amongst countless others with similar features is a remarkable cognitive feat. Such selective remembering requires that control be exerted over retrieval to ensure the desired veridical memory is recovered. These control processes are likely to operate at multiple loci throughout retrieval – prior to, during, and subsequent to retrieval – and are thought to be supported by the prefrontal cortex (PFC). However, the majority of support for this view stems from neuropsychological and haemodynamic brain imaging studies (Mitchell & Johnson, 2009), both of which lack sufficiently high temporal resolution to determine the specific time-points throughout retrieval at which particular processes operate (Friedman & Johnson, 2000). In the experiments described in this thesis, a real-time measure of neural activity – event-related potentials (ERPs) – was employed in order to investigate the retrieval processes supported by the PFC which operate during and following retrieval.

1.2 Long-term Memory

It is generally agreed that long-term memory can be separated into a number of functionally distinct types of memory. At the highest level of separation, long-term memory can be divided into conscious memory for facts and events and non-conscious memory that is none the less capable of influencing behaviour, such as skills and conditioned responses. This dichotomy has been referred to as a distinction between *explicit* and *implicit* memory (Schacter, 1987) or between *declarative* and *non-declarative* memory (Squire & Zola-Morgan, 1991). Tulving (1972; 1983) fractionated explicit memory further into *semantic* and *episodic* memory. Semantic memory encapsulates memory for facts, important historical dates, and general knowledge of the world. Episodic memory 'receives and stores information about temporally dated episodes or events, and temporal–spatial relationships among these events' (Tulving, 1972). It is memory for the 'what, where, and when' of personally experienced events (Nyberg, McIntosh, Cabeza, Habib, & Houle, 1996) and is also considered to constitute (Nelson, 1993), or form one aspect of (Conway, 2001), *autobiographical memory*, or those events which describe an individual's life story.

Retrieval from episodic memory – the focus of the work in this thesis – is considered to be accompanied by *autonoetic* or conscious awareness of retrieval (Tulving, 1985) and is often measured with *recognition memory tasks* in which participants are required to match a retrieval cue to a memory trace in order to determine whether it has been previously experienced or not. Another class of memory task employed to this end are *source memory tasks* in which participants are also required to retrieve or identify an aspect of the context (or source) in which an event (or item) was previously experienced. Source here, and throughout this thesis, refers to aspects of the spatial, temporal, cognitive, or perceptual characteristics of the original event.

According to dual-process theories (for a review, see Yonelinas, 2002), recognition memory judgments (i.e. those requiring a judgment of an event's prior occurrence) can be supported by two distinct forms of information – *recollection* and *familiarity*. Recollection involves the retrieval of specific contextual (or source) details of the original event, whereas familiarity simply entails a feeling of prior experience without the recovery of such accompanying contextual details – i.e. familiarity can occur in the absence of recollection. Both recollection and familiarity may provide information diagnostic to correct judgments in a recognition memory task since a judgment of the old/new status of the item is all that is required. Correctly assigning an item to its context at study in source memory tasks, however, generally requires a contribution from recollection (although see Section 1.3.3.4 below for arguments regarding the contribution of familiarity under some circumstances). There are several frameworks which contain specifications for how recollection occurs, and how recovered information is processed in service of task demands. The emphasis across frameworks is focused on different stages of retrieval, with some emphasising processes engaged prior to the act of retrieval to a greater degree than others (cf. Burgess & Shallice, 1996; Rugg & Wilding, 2000). The principal frameworks are outlined below.

1.2.1 The General Abstract Processing System (GAPS)

A framework for how episodic memories are formed and retrieved was outlined by Tulving (1983). This GAPS framework describes the act of remembering as a result of interactions between events, processes, and cognitive states at both encoding and retrieval. During encoding, the cognitive operations engaged at the time of the event along with its perceptual features combine to form the memory trace, or *engram* (Semon, 1921). For retrieval to occur, an individual must enter into a cognitive set called *retrieval mode* which biases encountered stimuli to be treated as cues for retrieval rather than simply as features of the environment. Information from the retrieval cue then interacts with information from the engram, in a process termed *ecphory* (Semon, 1921), which then leads to the state of *ecphoric information* which forms the basis of the recollective experience.

The process of ecphory may operate recursively, combining aspects of the ecphoric information with other stored episodic information in order to achieve a recollective state which meets the goals of remembering. The relationship between the contents of the recollective experience and the original perceived event was considered by Tulving (1983) to be one of similarity only, in that it is determined by multiple intermediate processes and events – e.g. the way in which the event was encoded, the nature of the retrieval cue – and that variations in the ways in which these operate may result in distortions of memory.

1.2.2 Processes engaged throughout and/or following retrieval

On the basis of a detailed analysis of the autobiographical recollections of healthy participants and considerations of the ways in which distortions of memory occur, Burgess and Shallice (1996) proposed a model of the involvement in episodic memory retrieval of control processes which operate iteratively and under some degree of strategic control. According to their model, *descriptor processes* specify the retrieval cues which satisfy the demands of the retrieval task. The contents of retrieval are subsequently subjected to two forms of monitoring processes. The first of these – *editor processes* – are considered to iteratively check that the retrieved elements of memory match other elements which have been recovered as part of the retrieval attempt, and are relevant to the requirements of the task as instantiated by the descriptor processes. The second of these processes – *mediator processes* – evaluates the plausibility or adequacy of the recovered information for the purposes of the retrieval task. Burgess and Shallice (1996) considered the distortions of memory reported by confabulators (Parkin, 1997) to result from the failure of these PFC-supported retrieval monitoring processes.

A similar emphasis on processes involved in the monitoring and evaluation of the products of retrieval is evident in the source-monitoring framework (SMF) put forward by Johnson, Hashtroudi, and Lindsay (1993). According to the SMF the attribution of a memory's source – i.e. who it was that told you a particular piece of information, or the location in which a conversation took place – results from the engagement of decision processes which evaluate differences across activated memory records. These records include aspects such as the perceptual features, affective information, and cognitive operations which were engaged at the time the event was encoded. For example, the memory records activated for a perceived event will include a greater amount of perceptual information than those activated for an imagined event. As a result, source-monitoring decision processes may therefore encourage attributing an event as having been imagined rather than perceived when lower activation of perceptual records occurs relative to other records associated with cognitive operations, for example.

The view that the products of retrieval will be subjected to monitoring and evaluation processes is also included in the constructive memory framework (CMF) proposed by Schacter, Norman, and Koutstaal (1998). The aspects of this model concerned with the processes engaged during retrieval describe the need for a good retrieval *focus*, similar to the descriptor processes of Burgess and Shallice (1996), which provides a more refined description of the episode which is to be retrieved. The pattern of activation which produces a match with the retrieval cue is then subjected to decision processes, similar to the SMF (M. K. Johnson et al., 1993), to determine whether the retrieved information constitutes a veridical memory. If the memory is determined to be a 'real' memory, further post-retrieval monitoring and verification processes determine whether the contents of the memory pertain to the information required by the retrieval task.

In summary, these models all propose that memory retrieval involves controlled processing which operates iteratively throughout a retrieval attempt to monitor and evaluate the products of retrieval in order to achieve the goals of retrieval. Before discussing the brain regions thought to support control processes in memory retrieval, the following section will briefly describe the two broad types of account for the forms of information which support recognition memory judgments. This is introduced here because the processes described will be referred to later in this thesis. In addition, the following description of criterion placement and the use of multiple criteria provide important background for the ways in which some of the empirical work in this thesis is interpreted.

1.2.3 Theories of Recognition Memory

These can be broadly divided into two types of account – signal-detection models (e.g. Green & Swets, 1966; Murdock, 1965) and dual-process models (e.g. Jacoby, 1991; Mandler, 1980) mentioned briefly above. Signal-detection models of item recognition memory represent the 'memory strength' associated with studied and unstudied items as two Gaussian (normal) distributions which overlap in decision space due to the variability in strength for both classes of item (see Figure 1.1, overleaf). An old/new decision is made by placing a decision criterion along the *x*-axis whereby items with a memory strength exceeding (or, to the right of, in Figure 1.1) the criterion are judged to have been studied (old), and those with lower memory strength relative to the criterion are judged not to have been previously studied (new). Source memory judgments have also been modelled in this way (see Slotnick & Dodson, 2005). Confidence ratings are considered to be made by judging an item's memory strength relative to a number of other decision criteria (n-1 criteria for an n-point confidence scale, Parks, Yonelinas, & John, 2008).

Dual-process models, on the other hand, assume that two forms of information underlie recognition memory. The first of these, familiarity, is considered to be a continuous quality of memory strength, similar to that described by signal-detection models above, which provides an individual with a sense of knowing that an item has been previously encountered. The second, recollection, provides the individual with detailed contextual information of a previous event. This is considered by some (e.g.

Yonelinas, 1994) to be a threshold process such that some items in a recognition memory task will not be associated with recollection. Conversely, all test items in a recognition memory task, whether old or new, are associated with familiarity, the level of which may be judged against a decision criteria in order to reach an old/new decision. Correct judgments of source/context in tasks which require the retrieval of a specific aspect of an item's study context are considered to be made on the basis of recollection alone (for further discussion of this point see Section 1.3.3.4). More recently, hybrid models have combined the assumptions of both signal-detection and dual-process models in proposing that recognition memory judgments can be made on the basis of a single continuously distributed memory strength variable which comprises the additive combination of both familiarity and recollection (e.g. Rotello, Macmillan, Hicks, & Hautus, 2006; Wixted, 2007).

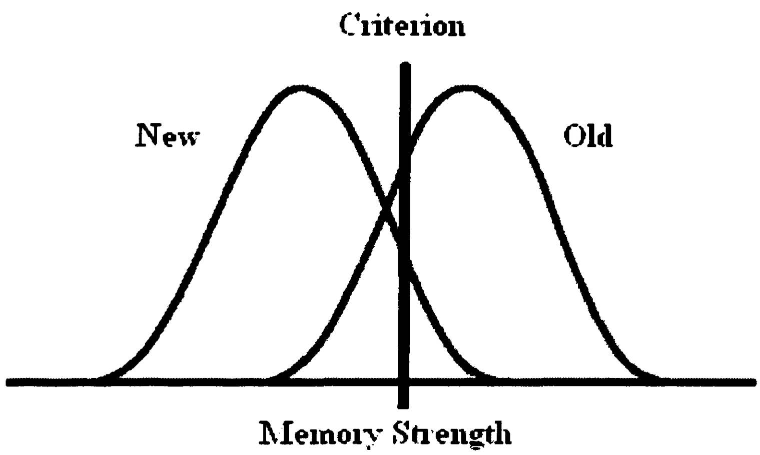


Figure 1.1: Signal-detection theory as applied to recognition memory judgments. Items with memory strength falling to the right of the criterion are judged to be old, while those to the left are judged to be new.

1.2.4 Retrieval Monitoring and Theories of Recognition Memory

The preceding considerations are relevant to the work in this thesis for at least two reasons. First, because ERPs index familiarity as well as (and more importantly here) recollection. Second, because one of the principal classes of control operation considered in this thesis with respect to the functional significance of ERP modulations, as well as the roles played by regions of the prefrontal cortex, is retrieval monitoring. This concept has been criticised as being somewhat ill-defined, but one way of operationalising monitoring is to consider it in relation to criterion setting. An item presented in the test phase of an old/new recognition memory task is considered to be associated with monitoring to a greater extent when its old/new status is relatively unclear. In terms of models of memory in which criteria are included, this represents items that fall close to decision criteria (Burgess & Shallice, 1996; Henson, Rugg, Shallice, & Dolan, 2000). That is, the degree to which monitoring is engaged is negatively proportional to its distance from a criterion. The implications of this consideration for averaged measures of neural activity that are acquired in brain imaging studies are returned to in subsequent sections.

1.3 The PFC and Episodic Memory Control Processes

Moscovitch (1992) described the PFC as 'working-with-memory' by supporting the operation of strategic processes both at encoding and retrieval. These processes, or 'problem-solving routines' (Moscovitch & Melo, 1997), include, at retrieval, the monitoring, evaluation, and verification of recovered information, as well as the placement of this information in the correct temporal-spatial context relative to other events. For Moscovitch and Melo (1997, p. 1030), 'to be effective and purposeful, memory begins and ends with the frontal lobes'. The following sections discuss converging data from a variety of research techniques that link the PFC to the strategic processes that are engaged at the time of retrieval.

1.3.1 Neuropsychological Data

Patients with PFC damage demonstrate selective episodic memory impairments which are more pronounced under conditions requiring the retrieval of contextual details of an event than under those requiring simple judgments about prior occurrence (for a review, see Stuss, Eskes, & Foster, 1994). For example, Janowsky, Shimamura, and Squire (1989) asked frontal lobe patients to remember a set of facts before testing them on their memory for these facts 6-8 days later. Half of the facts included in the test phase had not been learned in the previous study phase. Compared to both age-matched and young controls, the patients' recall of learned facts was unimpaired. However, when asked to identify the source of the learning, frontal lobe patients were considerably more like to make a false attribution – i.e. attributing correctly recalled facts learned in the study phase to an extra-experimental source. Similarly, Johnson, O'Connor, and Cantor (1997) reported unimpaired old/new recognition of spoken words in patients with frontal lobe damage. When required to retrieve the voice of the speaker (male/female) however, frontal patients were significantly less likely to make a correct source attribution than controls.

These selective deficits in the retrieval/selection of accurate source information have been attributed to the failure of PFC-supported control processes during retrieval (Burgess & Shallice, 1996; Janowsky et al., 1989). However, it is difficult on the basis of lesion studies alone to separate the impact of frontal lobe damage at encoding from its impact at retrieval. Haemodynamic imaging methods have enabled this separation, identifying multiple regions of PFC that are engaged during encoding as well as retrieval from episodic memory. The focus below is on PFC regions that are active during retrieval tasks.

1.3.2 Haemodynamic Imaging Data

Neuroimaging studies employing functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) have demonstrated activations in multiple regions of both left and right PFC during episodic memory retrieval (Fletcher & Henson, 2001; Rugg & Henson, 2003). As with the neuropsychological research discussed in the previous section, one focus in these studies that have linked the PFC to the control of retrieval, has been on comparisons of neural activity during tasks which require the explicit retrieval of the source of an event with those that require a simple judgment of its old/new status. In one fMRI study, Ranganath, Johnson, and D'Esposito (2000) made such a comparison. Participants studied pictures of objects which were then presented at test intermixed with new objects. Half of the pictures of old objects were enlarged at test, and half were reduced in size. During the old/new recognition task, participants were to ignore the size of the test item and simply identify its old/new status. During the source recognition task, participants indicated whether old items were presented in a larger/smaller size than at study. A region of left anterior PFC was reliably more active during the source recognition task than the old/new recognition task, linking the processes supported by this region of PFC to the monitoring and evaluation of specific memory characteristics. Raye, Johnson, Mitchell, Nolde, and D'Esposito (2000) contrasted activity in the PFC during an old/new recognition task with an *exclusion task* (Jacoby, 1991) in which items studied in only one of two contexts are responded to on one key (targets) while all other items are responded to with another key (non-targets). Again, regions of left PFC were more active during the tasks which required identification of source information relative to those which required old/new recognition. A similar pattern of activation in left PFC has also been shown for other forms of source information including spatial location (Rugg, Fletcher, Chua, & Dolan, 1999) and stimulus type (picture/word: Nolde, Johnson, & D'Esposito, 1998).

These results have been interpreted in terms of the SMF (Johnson et al., 1993) by suggesting that left PFC supports *systematic* processes which are engaged when the reflective demands of the task increase, such as when contextual/source information is required or when more detailed evaluations of retrieval are required (Nolde, Johnson, & D'Esposito, 1998). Right PFC, on the other hand, has been linked to relatively simple and quick processes which are sufficient for less demanding memory tasks, referred to as *heuristic* processes (for a review, see Nolde, Johnson, & Raye, 1998).

However, not all published data points fit with this systematic-heuristic characterisation of left-right PFC activity during retrieval. An alternate account highlights the role of the *right* PFC in completing tasks with greater monitoring demands. In an fMRI study, Henson, Shallice, and Dolan (1999) presented participants with words at study in two separate 6-item lists in which half of the words were presented above/below the midline of the display screen. In the memory test phases, participants completed either an *inclusion task* which required a simple judgment of prior occurrence (old/new) or an *exclusion task.* A region of right dorsal mid-lateral PFC was more active during the exclusion task than the inclusion task. In so far as the demands of the exclusion task require greater monitoring of the products of retrieval than the inclusion task due to the requirement to identify the source in which an item was presented, this region of right PFC was implicated in supporting monitoring processes (cf. Wilding & Rugg, 1997b, for a related ERP finding). Rugg, Henson, and Robb (2003) also contrasted the activity associated with an inclusion and exclusion task for words presented in red/green letters at study. The right dorso-lateral PFC was more active for old words than new words in both tasks, and this old/new effect was larger in the exclusion task, an outcome consistent with the findings of Henson and colleagues (Henson, Shallice et al., 1999) and a monitoring account for this region of right PFC.

In further support of this account for right PFC, Henson, Rugg, Shallice, Josephs, and Dolan (1999) employed the *Remember/Know* procedure (R/K; Tulving, 1985) when testing participants' memory for words which had been encoded in a lexical decision (word/non-word) task at study. Activity in right lateral and medial PFC was greater for correct K judgments, considered to reflect decisions made on the basis of familiarity, than correct R judgments made on the basis of recollection. Henson, Rugg and colleagues (1999) argued that the memory strengths for items attracting K responses are likely to fall closer to an old/new criterion (see Section 1.2.4) and that the requirements to engage in monitoring are highest when this is the case. In a separate study, Henson and others (2000) asked participants to make high/low confidence judgments in an old/new recognition task for studied words which had been semantically encoded (pleasant/unpleasant) and found that activity in right dorso-lateral PFC was greater for correct low confidence responses relative to correct high confidence responses. The authors argued that the memory strength of items attracting low confidence judgments would fall closer to the old/new response criterion than items attracting high confidence judgments, and would therefore be associated with a greater level of monitoring, consistent with this account for regions of right PFC.

These two characterisations of PFC activity are seemingly in opposition. The systematic/heuristic (Nolde, Johnson, & Raye, 1998) characterisation would predict greater activity in left PFC during the retrieval of contextual information, whereas the post-retrieval monitoring (Henson et al., 2000; Henson, Rugg et al., 1999) characterisation would predict that these tasks require more monitoring than old/new recognition tasks and therefore greater activity in right PFC. In an attempt to adjudicate between these accounts, Dobbins, Simons, and Schacter (2004) contrasted an item recognition task with a judgment of frequency (JOF) task using fMRI. Participants studied pictures of objects which were presented either two or six times each. In the test phase, half of the items were identically presented pictures from the study phase and half were pictures of different exemplars of a studied object. Participants were cued trial-by-trial to make either a JOF (i.e. seen two or six times at study) or item recognition judgment (same/different exemplar). Dobbins and colleagues (2004) argued that a JOF can be accomplished on the basis of an assessment of the level of an item's familiarity, such that items presented six times in the study phase will be more familiar than those presented twice. Regions of right dorso-lateral and fronto-polar PFC were more active during JOFs than item memory judgments, leading the authors to propose that right PFC is involved in the close monitoring of familiarity levels. Greater activation was also found in left PFC for JOFs relative to item judgments only when the test item was a different exemplar of the studied item, suggesting that regions of left PFC are involved in recollecting the specific attributes of an item (Ranganath, 2004). Together, these results highlight the functional heterogeneity of both left and right PFC.

Further evidence for multiple dissociable PFC-supported retrieval control processes has also been provided by Ranganath, Heller, and Wilding (2007) who presented their participants with words spoken in a male/female voice at study. At test, old and new words were presented with half of the old words spoken in a different voice and half spoken in the same voice as at study. Ranganath and colleagues (2007) contrasted PFC activity during old/new recognition (general task) and source recognition (specific task) and found enhanced activation during the specific task in right anterior and dorso-lateral PFC for both studied and unstudied test items, which was interpreted as reflecting differential processing of all test items between the tasks, perhaps in pursuit of task-appropriate information. Bilateral inferior frontal regions of PFC were also more active during the specific task, but only for studied items. This result was interpreted as reflecting the greater engagement of post-retrieval monitoring processes in the specific task since only previously studied items would be associated with retrieval.

It is evident from the above data points that multiple regions of PFC support dissociable control processes which operate during episodic memory retrieval. In addition to the studies described above, there are others in which the focus has been on identifying control processes that are engaged in advance of retrieval (for example, retrieval mode discussed in Section 1.2.1), and which may be engaged throughout the time in which retrieval is required. While claims about the engagement of these kinds of sustained processes have been made on the basis of PET data (Lepage, Ghaffar, Nyberg, & Tulving, 2000; Tulving, Kapur, Craik, Moscovitch, & Houle, 1994; Wheeler, Stuss, & Tulving, 1997), arguably a stronger basis for making claims about these kinds of operations stems from fMRI studies in which the haemodynamic signal has been decomposed into sustained and transient components (see in particular Donaldson, Peterson, Ollinger, & Bucker, 2001). A complementary line of research employing ERPs has also implicated the PFC in supporting such sustained control processes (Duzel et al., 1999; Duzel, Picton et al., 2001). The focus in this thesis, however, is on those processes that are engaged when a retrieval cue is presented, and the post-cue stages at which they operate. In this regard, the temporal acuity of haemodynamic imaging methods is not sufficient to accurately make claims about the specific post-stimulus time periods at which particular memory control processes operate. Greater temporal resolution can be achieved using electrophysiological measures of neural activity.

1.3.3 Electrophysiological Data

The event-related potential (ERP) technique provides the high temporal resolution lacking in haemodynamic methods, along with an index of recollection, known as the *left-parietal old/new effect*, which has a well documented time-course and scalp distribution. This makes ERPs a useful tool in identifying the time-course of the engagement of PFC-supported processes relative to the recovery of episodic information – i.e. those that are set in train before retrieval, and those that are engaged during and/or as a result of retrieval – significantly contributing to an understanding of the functional roles of these processes (see in particular J. D. Johnson, Minton, & Rugg, 2008; Yick & Wilding, 2008). The utility of ERPs in the study of episodic retrieval processes was emphasised by Rugg, Otten, & Henson (2002) who described two methodological factors which they considered to be crucial to the investigation of neural correlates of such processes. First, it is necessary to be able to separate the neural activity associated with successful and unsuccessful retrieval. Second, it is important to be able to identify those items for which recollection of contextual details from the study episode has occurred. Clearly, blocked PET and fMRI designs are limited in this regard. Source memory ERP studies, however, successfully meet both of these criteria, since the correct completion of a source memory task requires recollection and ERPs can be easily separated by both item type and the responses with which they are associated.

Studies employing event-related fMRI are also capable of meeting these criteria and provide some degree of temporal resolution, particularly in terms of the relative timing/order of the engagement of retrieval processes. For example, Simons, Gilbert, Owen, Fletcher, and Burgess (2005) contrasted activity in the PFC during a context memory task which required the retrieval of one of two different aspects of an items study context and demonstrated that different regions of PFC were more active at different time points. Activity in lateral anterior PFC peaked around 4 seconds after presentation of the cue, and activity in medial anterior PFC peaked 6 seconds later. Evidently, the event-related fMRI technique provides an indication of the relative order in which PFC-supported processes are most active in retrieval tasks, but concerns remain about local variation in the time course of the haemodynamic response. In addition, and unlike ERPs, this technique lacks an index of the time-point at which recollection occurs and therefore provides a challenge in identifying the specific locus during retrieval – i.e. prior to, during, or following recollection – at which a particular process operates. It has also been noted by Rugg (1998) that neural activity identified by event-related fMRI, as with all haemodynamic methods, requires a detectable change in the metabolic demands of a brain region with an extended time-course, i.e. regional blood flow. ERPs, however, are not limited by these particular preconditions (although see Chapter Two for the preconditions of a scalp-detectable ERP) and may therefore be sensitive to PFC-supported processes which are not detectable with event-related fMRI (Rugg, 1998).

The following sections discuss the current evidence for PFC-generated activity in ERP studies of memory retrieval which is considered to reflect processes engaged during and/or as a result of retrieval – i.e. late in a retrieval attempt. First, however, there is a description of the left-parietal ERP old/new effect which is considered to index recollection.

1.3.3.1 The Left-Parietal Old/New Effect

This effect, maximal at left-parietal scalp sites, onsets at around 500ms post-stimulus, lasts for several hundred milliseconds and comprises more positive-going ERPs for correct old judgments (hits) than for correct new judgments (correct rejections). A large body of evidence has tied this effect to the recollection component of dual-process models of recognition memory. Smith (1993) demonstrated that the magnitude of the old/new effect was largest for items rated as being consciously remembered compared with those items eliciting a feeling of familiarity (although see Spencer, Abad, & Donchin, 2000, for a critique of this particular finding). Similarly, in Remember/Know paradigms the magnitude of the left-parietal old/new effect has been shown to be larger for items attracting an R judgment (Duarte, Ranganath, Winward, Hayward, & Knight, 2004; Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997). The magnitude of the effect has also been shown to be sensitive to 'depth of processing' manipulations, such that it is larger during the recognition of words encoded in relatively more *deep* encoding tasks, such as visual imagery or the incorporation of a word into a meaningful sentence, than in relatively more *shallow* tasks, such as whether the first and last letter are in alphabetical order or the number of Es in the word (Paller & Kutas, 1992; Rugg, Allan, & Birch, 2000). In so far as deep encoding promotes recollection to a greater extent than does shallow encoding, this result is consistent with a recollection account for the left-parietal old/new effect. This interpretation, however, is predicated on assumptions regarding the selective effects of depth of processing manipulations on recollection (Yonelinas, 2002).

Stronger evidence linking the left-parietal old/new effect to recollection has come from studies employing source memory paradigms. In two experiments, Wilding, Doyle and Rugg (1995) demonstrated reliable left-parietal effects only for items attracting correct judgments of source. Items receiving correct old responses but incorrect contextual judgments elicited ERPs indistinguishable from those associated with new items at left-parietal sites (see also, Wilding & Rugg, 1996). If recollection is defined as the retrieval of contextual information from an event, these results strongly tie the effect to recollection.

Behavioural data analysed using receiver operating characteristics (ROCs) have demonstrated that recollection is disproportionately impaired relative to familiarity when attention is divided at study relative to when it is not (Yonelinas, 2001). Consistent with a recollection account for the left-parietal old/new effect, Curran (2004) observed that the magnitude of this effect is reduced following divided attention at study, while the FN400, a putative index of familiarity (Curran, 2000; although there is currently debate with regard to this, see for example Paller, Voss, & Boehm, 2007), remained unchanged relative to when attention was not divided at study. Curran (2004) also showed that left-parietal ERPs become more positive with increasing confidence in the recognition of old items, but not new items which would not have been associated with recollection.

Studies of patient groups have also provided ERP data consistent with this account. For example, the left-parietal old/new effect has been shown to be absent in a group of patients suffering from Alzheimer's disease who, in a source memory task, were able to accurately identify an item's prior occurrence but were unable to recover the contextual information (the colour of visually presented words at study) associated with the item at above chance levels (Tendolkar et al., 1999). Comparable results have also been observed for an amnesic patient (Duzel, Vargha-Khadem, Heinze, & Mishkin, 2001) and hypoxic brain injury patients (Mecklinger, von Cramon, & Matthes-von Cramon, 1998) in old/new recognition tasks. An attenuation of the magnitude of the left-parietal old/new effect has also been reported in older adults relative to younger adults in old/new recognition memory tasks (e.g. Ally, Simons, McKeever, Peers, & Budson, 2008; Joyce, Paller, McIsaac, & Kutas, 1998; Morcom & Rugg, 2004). Coupled with the observed selective impairment of recollection obtained from ROC analyses of data from recognition memory tasks (e.g. Howard, Bessette-Symons, Zhang, & Hoyer, 2006; Prull, Dawes, Martin, Rosenberg, & Light, 2006) these data provide further support for a recollection account for the left-parietal old/new effect.

Critically, the regular time-course of this effect, from 500-800ms post-stimulus, allows us to use the time of onset of processes believed to be supported by the PFC relative to this effect to inform our understanding of their functional roles. The next section will review late frontal old/new effects (i.e. from around 500ms onward) which have been reported in episodic retrieval tasks and which are considered to reflect activity generated within the PFC.

1.3.3.2 Late Frontal Old/New Effects

Event-related potential studies of episodic retrieval have revealed, under some circumstances, a *late right-frontal old/new effect.* The effect comprises a greater positivity for items correctly identified as old relative to those correctly identified as new which onsets around 400ms and lasts for up to 1000ms (e.g. Wilding & Rugg, 1996, 1997a). The frontal distribution of this effect and the fact that it is larger in tasks requiring the explicit retrieval of contextual (source) information relative to those requiring old/new recognition memory judgments (Johansson, Stenberg, Lindberg, & Rosen, 2002; M. K. Johnson, Kounios, & Nolde, 1997; Senkfor & Van Petten, 1998; Van Petten, Senkfor, & Newberg, 2000), and the above described link of such tasks to activity in the PFC, implicates this scalp-recorded activity with generators in the PFC.

In one of the first reports of the late frontal ERP old/new effect, Wilding and Rugg (1996, see also M. K. Johnson, Kounios, & Nolde, 1996) presented participants with words spoken in a male or female voice at study. At test, studied words were presented visually, intermixed with unstudied words. For each test word, participants made an initial old/new judgement followed by a male/female judgment for words judged to be old. The ERP data revealed a right-lateralised late frontal old/new effect for correct source judgments only, leading the authors to suggest that the effect indexes processes necessary for forming successfully a representation of a prior episode. In a subsequent study, Wilding and Rugg (1997b) employed an exclusion task at test following the presentation of words spoken in male/female voices at study. A reliable late right-frontal old/new effect was evident for items designated as targets only. In so far as non-targets will also have been associated with successful retrieval, this result suggests that the effect is not an obligatory correlate of successful recollection.

Senkfor and Van Petten (1998) proposed that the effect indexes the engagement of a source *retrieval search.* In that study, participants were again presented with an equal number of words at study spoken in a male/female voice. At test, all studied words were presented again in either the same or different voice as spoken at study, and were interspersed with previously unstudied spoken words. In a source-recognition task, participants made a 3-way decision between *old-same voice/old-different* *voice/new*. Bilateral frontally-distributed old/new effects, on-setting around 400ms post-stimulus and continuing through to the end of the epoch, did not vary in magnitude as a function of the accuracy of source judgments. Since both accurate and inaccurate source judgments will have been associated with a source retrieval attempt/search, this pattern of results supports the retrieval search interpretation. Similar results were reported by Van Petten, Senkfor, and Newberg (2000) who presented participants with line drawings at study in one cell of a 3x3 grid. Again, in a source-recognition task the participants made a 3-way decision at test between *old-same location/old-different location/new items*. Bilateral frontally-distributed effects onset around 300ms post-stimulus, continued through to the end of the recording epoch, and did not differ in magnitude according to source accuracy.

Evidently, the reliably larger late frontal old/new effect associated with correct source judgments relative to incorrect source judgments reported by Wilding and Rugg (1996) does not fit within a retrieval search account. The above described neuropsychological and fMRI/PET data linking the PFC to post-retrieval monitoring and evaluation processes has led some authors to interpret the late frontal ERP old/new effect in terms of these processes (Friedman & Johnson, 2000; Mecklinger, 2000; Rugg et al., 2002). As described above, the late frontal ERP old/new effect is larger in tasks which require the retrieval of source information relative to those which only require a judgment of an item's prior occurrence (Johansson et al., 2002; M. K. Johnson, Kounios et al., 1997; Senkfor & Van Petten, 1998; Van Petten et al., 2000), a result which is consistent with a post-retrieval monitoring and evaluation account for this electrophysiological effect since it is assumed that a judgment of study source will require more monitoring of the products of retrieval than an old/new decision (cf. Henson, Shallice et al., 1999). This finding, however, is also consistent with a retrieval search account if a source search is not typically engaged in old/new recognition memory tasks.

Data consistent with a post-retrieval monitoring account were found in an old/new recognition task for which a depth of processing manipulation was employed at study. A late frontal old/new effect was reliably right-lateralised and larger for items which had been subjected to shallow encoding (Rugg et al., 2000). In so far as greater monitoring is required when the quality of retrieved information is low, as in the case of the shallow encoding condition, this result provides support for a monitoring interpretation of the right-frontal old/new effect (see also Mecklinger, 2000). Further support was provided by Ullsperger, Mecklinger, and Muller (2000) who employed a directed forgetting paradigm in which participants were cued trial-by-trial at study to either remember or forget the previously presented word. At test both to-be-remembered (TBR) and to-be-forgotten (TBF) words were presented along with previously unseen words. Participants were required to make an old/new decision for each item, and to not consider whether the words were previously TBR or TBF. The late right-frontal old/new effect was reliably larger for TBF words relative to TBR words, a result which was interpreted as reflecting the greater requirement of evaluation processes for TBF words which are considered to be associated with a lower quality of retrieved information (Ullsperger et al., 2000).

Wilding (1999) presented participants with words spoken in either a male or female voice to which they were cued trial-by-trial to make one of two encoding judgments – active/passive or pleasant/unpleasant. For old words at test, participants were required to retrieve either the gender of the study speaker or the kind of study task which was performed. Collapsed across the retrieval of voice and task, reliable right-frontal old/new effects were observed for both correct and incorrect source judgments. These were larger for correct source judgments, consistent with the results of Wilding and Rugg (1996) described above. When the ERPs associated with correct source judgments were separated according to the form of source information which was retrieved (voice or encoding task), the late right-frontal old/new effect was reliable in both cases but larger in the case of the retrieval of task information. This result can be interpreted as reflecting a common set of post-retrieval processes which are engaged to differing degrees by the requirements to retrieve the different forms of source information.

It is clear from the above that the late frontal ERP old/new effect has not behaved in a predictably consistent way across source memory studies. Studies investigating the effects of age on retrieval processing have also reported somewhat inconsistent patterns of late frontal ERPs. For example, Trott and colleagues (Trott, Friedman, Ritter, Fabiani, & Snodgrass, 1999) contrasted the ERPs recorded during a source memory task between older and younger adults (see also Trott, Friedman, Ritter, &

Fabiani, 1997). All participants studied sentences containing two nouns presented in two temporally distinct lists. At test, old/new judgments were made for each of two sequentially presented nouns. For those judged to be old, a binary source (list 1/list 2) judgment was required. In keeping with the recollection deficit seen in older adults (discussed above, Section 1.3.3.1), source accuracy was impaired for these participants relative to younger adults. As for the electrophysiology, a reliable right-frontal old/new effect was evident in the younger adults' data, but absent from the older adults'. This result was interpreted as reflecting a deficit in a PFC-supported search for source information in the older adults, which contributed to their relatively poorer source accuracy.

Mark and Rugg (1998) also compared ERPs in a source memory task between older and younger adults. At study, participants heard words spoken in a male/female voice. At test, participants made an initial old/new judgment followed by a male/female source judgment (as in Wilding & Rugg, 1996). Unlike the results of Trott and others (Trott et al., 1997; Trott et al., 1999), however, Mark and Rugg (1998) observed reliable right-frontal old/new effects for both age groups which did not differ from one another. In an attempt to accommodate these two patterns of data within a search account, Trott and colleagues (1999) argued that the contextual detail associated with temporal source employed in their studies was not as rich as that associated with voice gender, which was employed in the study by Mark and Rugg (1998). This may have put older adults at a selectively greater disadvantage when engaging in a search for this form of source information. Mark and Rugg (1998), on the other hand, argued that the relatively lower source memory performance in the study reported by Trott and colleagues (1997) – 71.5% vs. 55% respectively – led to fewer trials for which recollection had occurred contributing to the older adults' source judgment response categories, and therefore to the absence of reliable right-frontal effects for this participant group. In an effort to rule out this possibility and improve the low source performance in older adults, Wegesin, Friedman, Varughese, & Stern (2002) modified the study procedure used by Trott and others (Trott et al., 1997; Trott et al., 1999) to involve a more elaborative encoding task as well as shorter and self-paced study lists. This effort succeeded in increasing the source performance of older adults to 67%. Again, however, a reliable right-frontal old/new effect was only evident for younger adults[1].

In another source memory study, Swick, Senkfor, and Van Petten (2006) had older and younger adult participants study words, each presented twice, in a male/female voice to which a male/female judgment was made. At test, words were presented visually and participants made an old/new judgment followed by a male/female judgment (as in Mark & Rugg, 1998, above). Interestingly, younger adults ERPs did not contain a reliable late frontal old/new effect. Swick and colleagues (2006) argued that the task employed in their study relative to that employed by Mark and Rugg (1998) was far easier for younger adults, as demonstrated by the extremely high source accuracy (97% vs. 78% respectively), and therefore allowed them to form a strong link between the word and its speaker which did not require the engagement of a secondary search process which they considered to be indexed by the right-frontal old/new effect (see Kuo & Van Petten, 2006, for a similar result). Older adults in that study demonstrated impaired source accuracy relative to the younger adults, consistent with the above described studies. Late frontal ERPs for the older adults were reliably more negative-going for correct source judgments than correct rejections of new items (i.e. an upside-down old/new effect) from around 600ms post-stimulus which was interpreted as reflecting the recruitment of qualitatively distinct regions of PFC in older adults in order to successfully perform the task (for evidence from fMRI studies of qualitatively different PFC engagement in older and younger adults, see, for example, Cabeza, Anderson, Locantore, & McIntosh, 2002).

These findings with older adults emphasise that the story of late frontal ERPs in source memory tasks is an inconsistent one. One possibility is that, given the neuroanatomical and functional heterogeneity of the PFC that has been documented in lesion and haemodynamic imaging studies in numerous cognitive domains (Fletcher & Henson, 2001; Ranganath, 2004; Ranganath & Knight, 2003; Stuss et al., 1994), multiple PFC-supported processes engaged during source retrieval may be detectable

[1] It is clear that this approach replaced one confound with another potential confound relating to differences in encoding task. However, the very low proportion of correct source judgments made by the older adults in the initial study (55%, where 50% is chance) suggests that source judgments for these adults were associated with very low levels of recollection. The important contribution of the re-designed study of Wegesin and others (2002) is that this contrast was made between occasions in which an acceptably high level of recollection had occurred for both age-groups.

at the scalp, and that not entirely the same old/new effects have been observed across the memory literature. Informal inspection of variations in the locations of the scalp maxima and degrees of laterality of late frontal old/new effects across studies provide general support for this view (compare, for example, Johansson & Mecklinger, 2003; Senkfor & Van Petten, 1998; Tendolkar & Rugg, 1998; Trott et al., 1997; Trott et al., 1999).

The work contained in this thesis is concerned with investigating the functional roles of frontally-distributed old/new effects in source memory tasks which onset late in retrieval – i.e. from 500ms post-stimulus. The following sections discuss some important aspects of these effects which are unclear from the published literature, and which provide starting points for an attempt to provide a more specific characterisation of the specific processes which are indexed by ERPs.

1.3.3.3 The Degree of Lateralisation – Multiple Late Frontal Effects?

Typically, the late frontal old/new effect observed in source memory tasks is referred to as the *right-frontal* ERP old/new effect (Friedman & Johnson, 2000; Rugg et al., 2002). However, the degree to which late frontal old/new effects are right-lateralised varies across source memory studies. Late frontal old/new effects in some studies are distributed bilaterally across frontal sites (Kuo & Van Petten, 2006; Senkfor & Van Petten, 1998; Vallesi & Shallice, 2006; Van Petten et al., 2000) while others report effects which are reliably right-lateralised (Johansson et al., 2002; Wilding, 1999; Wilding & Rugg, 1996, 1997a, 1997b).

One aspect of the tasks employed in these studies which differs alongside the degree to which late frontal effects are right-lateralised is the accuracy with which 'old' judgments were made. Those studies in which late frontal old/new effects are bilaterally distributed employed tasks for which hit-rates were at ceiling (~95%; Kuo & Van Petten, 2006; Senkfor & Van Petten, 1998; Van Petten et al., 2000), while those in which late frontal effects are reliably right-lateralised had relatively lower hit-rates (~65%; Wilding, 1999; Wilding & Rugg, 1996, 1997a, 1997b). This apparent correspondence between task difficulty and the laterality of late frontal effects provides one starting point which may contribute to an understanding of these disparities.

Given the neuroanatomical and functional heterogeneity of the PFC that has been observed in studies of patient groups and in studies employing haemodynamic imaging techniques (Fletcher & Henson, 2001; Ranganath, 2004; Ranganath & Knight, 2003; Stuss, Eskes, & Foster, 1994) it is somewhat surprising that few tasks requiring source memory retrieval have identified multiple frontally-supported processes. Two neurally and functionally dissociable frontal ERP old/new effects have, however, been reported in a word recognition memory task by Woodruff, Hayama, and Rugg (2006) however. At test, Woodruff and colleagues (2006) employed the same 5-button response procedure as that employed in a similar fMRI study by Yonelinas, Otten, Shaw, and Rugg (2005). Participants were instructed to signal 'R', or Remember, when something specific about the study episode could be recollected. In the absence of recollection, participants were required to make either a high/low confidence old judgment or a high/low confidence new judgment. A late right-frontal old/new effect (800-1900ms) was evident in the contrast of both recollected 'R' responses and high confidence old responses with the high confidence new response category. A contrast of the recollected 'R' response category with the high confidence old category revealed an effect topographically dissociable from the right-frontal old/new effect with a midline frontal/fronto-polar maximum. Together these data provide evidence for two neurally and functionally dissociable late frontal old/new effects – a right-frontal old/new effect associated with all old judgments, and a midline frontal effect associated with items assigned a recollected response only. One of the goals in this thesis is to deploy designs where it will be possible to follow up this finding, and more generally provide detailed examinations of the sensitivity of ERPs to retrieval processes supported by the PFC.

1.3.3.4 Retrieval Cues and Response Requirements

Across the published data there is also a reasonably consistent correspondence between the use of copy cues at test and whether late frontal old/new effects will vary with the accuracy of source judgments. Copy cues are verbatim re-presentations of studied items. Studies reporting frontal effects which did not vary with the accuracy of source judgments (Senkfor & Van Petten, 1998; Van Petten et al., 2000) made use of test stimuli for which a proportion were copy cues of studied stimuli to which a three-way *same/different/new* judgment was required. Those studies for which frontal

ERPs were predictive of the accuracy of source judgments (Wilding, 1999; Wilding & Rugg, 1996) did not make use of copy cues at test and required participants to make a judgment on the old/new status of the item before a delayed binary source judgment. Hence, two consistent differences across these studies are the presence/absence of copy cues and the response requirements at test.

The nature of the two types of response options (three-way versus two-stage) may lead participants to adopt different retrieval strategies in each case, which could result in at least some of the apparent disparities in the literature. Friedman and Johnson (2000) argued that the sequential nature of the two-stage response requirement encourages participants to adopt a serial processing strategy such that the retrieval/search of source information occurs after an old/new decision has been made, and outside the bounds of the recording epoch. Senkfor and Van Petten (1998), however, argued that old/new and source judgments are also made sequentially when three-way same/different/new response options are used. In the second experiment reported in that paper, their participants completed an old/new recognition task followed by a source task which included no new items and simply required a same/different judgment. Frontal ERPs associated with correct source judgments were more positive than those associated with correct old and new judgments from the preceding old/new recognition task. Importantly, this difference onset later than the left-parietal index of recollection, supporting the claim that participants delayed source memory processes until the item had been recognised as old, even when no explicit old/new decision was required. The use of same/different response options, however, can only be employed in tasks for which a proportion of test stimuli are exact copy cues of study stimuli and which may allow participants to make a source judgment based upon a relative feeling of familiarity for the item, rather than based solely upon recollection. This argument is expanded on below (for a similar argument, see Ranganath & Paller, 2000).

One account for the disparate findings for the relative amplitudes of correct and incorrect late frontal ERP old/new effects is that these effects index processes which operate on any form of information that may be diagnostic for a source judgment. When test stimuli do not include copy cues, recollection of study context is the only form of information diagnostic for the source judgment. When a proportion of test stimuli are copy cues, however, the relative levels of familiarity of test items will also be diagnostic for the source judgment. The potential contribution of familiarity to source judgments under some circumstances has been highlighted in previous source memory studies (see, for example, Diana, Yonelinas, & Ranganath, 2008; Ranganath & Paller, 2000), has been employed to explain the recognition memory advantage of holding modality constant between study and test exposures (Kelley, Jacoby, & Hollingshead, 1989), and has been used in explanations of curvilinear source recognition receiver operating characteristic (ROC) curves under some circumstances (Yonelinas, 1999) (for an alternative view, see Qin, Raye, Johnson, & Mitchell, 2001). The key assumption here is that copy-cues generate higher levels of familiarity than do non-copy-cues.

By this argument, all old items in a study using a proportion of copy cues will be associated with information which is diagnostic for the source judgment, and will therefore engage the processes indexed by the late frontal old/new effect to the same extent for all items. When no copy cues are used at test, however, only items for which recollection has occurred (i.e. correct source judgments) will be associated with the processes indexed by the late frontal old/new effect. This argument is able to reconcile the variations in frontal ERPs across the previously described source memory studies. A test of this argument provides a starting point which may contribute to our understanding of late frontal old/new effects.

Tulving (1983) also highlighted the importance of the presence or absence of copy cues when instigating memory retrieval. Source memory tasks in which copy cues are presented at test may be considered to be source-recognition tasks, while those in which no copy cues are presented may be considered source-recall tasks. In describing his Synergistic Ecphory Model (SEM), Tulving (1983) noted that in addition to differences in the nature of the retrieval cues, the processes involved in retrieval differ across recognition and recall tasks in terms of the *conversion* of ecphoric information into behaviour (see Section 1.2.1 above). Behaviour here refers to the response required by the task i.e. a recognition or recall judgment. In Tulving's words, the processes associated with retrieval in recognition and recall tasks differ in terms of their *'post-ecphoric processes'* (Tulving, 1983, p. 302). With reference to the SEM, Moscovitch (1989) described retrieval in a recall task as requiring the individual to initiate multiple and iterative ecphoric processes whereby the products of each process become the retrieval information for the next until the individual is satisfied that the products of their retrieval match the requirements of the task (for a similar view see Burgess & Shallice, 1996, discussed in Section 1.2.2). In recognition tasks, however, the requirement for such iterative processes is considered to be reduced. This emphasis on the impact of the retrieval cues employed in a memory task on the processes engaged late in a retrieval judgment is consistent with the above view that this aspect of task design may contribute to changes in retrieval processes detectable at the scalp.

1.3.3.5 The Contents of Retrieval

Across source memory ERP studies reporting late frontal old/new effects, the retrieval of a variety of source information from the study episode has been required, including the voice in which words were spoken (Senkfor & Van Petten, 1998; Vallesi & Shallice, 2006; Wilding, 1999; Wilding & Rugg, 1996, 1997a, 1997b), the spatial location of line drawings (Van Petten et al., 2000), the colour of line drawings (Cycowicz, Friedman, & Snodgrass, 2001; Kuo & Van Petten, 2006, 2008) and the encoding task performed at study (Wilding, 1999). It is plausible that if PFC activity varies with the forms of episodic content which are retrieved, this may also impact on the frontally-distributed activity detectable in the EEG at the scalp.

Content-specific activations in PFC during episodic retrieval have been reported in studies employing haemodynamic imaging techniques. In an fMRI comparison of the retrieval of visually presented abstract words versus monochromatic textured patterns, the former exhibited greater left-lateralised activation during encoding and retrieval relative to the greater right-lateralised activation of the latter during encoding and retrieval (Wagner et al., 1998). Greater left-lateralised activation of a region of PFC has also been reported during the retrieval of object names versus more right-lateralised activation during the retrieval of unfamiliar faces (McDermott, Buckner, Petersen, Kelley, & Sanders, 1999). It has been observed in fMRI and PET studies that activation in PFC is lateralised according to the nature of the information to be retrieved/encoded, with left-PFC activation associated with the retrieval/encoding of verbal materials, and right-PFC activation associated with the retrieval/encoding of non-verbal, visuo-object materials (Badre & Wagner, 2007; Casasanto, 2003; Lee, Robbins, Pickard, & Owen, 2000).

As discussed above, in an ERP study, Wilding (1999) found reliable late right-frontal old/new effects which differed only quantitatively between the retrieval of two forms of content – voice information and the encoding task performed at study. This is one of only a small number of studies in which the ERP indices of retrieval of different contents have been contrasted directly (Kuo & Van Petten, 2008) Further investigation of the ways in which the forms of content to be retrieved effect the behaviour of late frontal old/new effects may provide insights into the functional roles of these PFC-supported processes, and speak to the seemingly disparate findings across ERP studies employing different forms of study materials and contents.

1.4 Concluding Remarks

In summary, the potential for ERP studies of episodic retrieval to contribute to an understanding of the retrieval operations supported by the PFC is well established. However, the processes that ERPs index in this regard remain under-specified. The focus in this thesis is on a more specific characterisation of the processes ERPs index during episodic retrieval than is available to date. How this will be operationalised for Experiment One will be discussed after a description of key methodological and practical considerations when using ERPs to address issues of this kind.

Chapter Two : Event-Related Potentials

2.1 Introduction

The human brain is composed of around 100 billion neurons, each communicating by means of small electro-chemical signals. Individually, the changes in voltage produced by these signals are too small to be recorded from a distance. When large populations of neurons fire simultaneously, however, they can produce a change in potential sufficient to be recorded at some distance. Berger (1929) demonstrated that when the output from a set of electrodes placed on the surface of the human scalp is passed through an amplifier, a pattern of variation in voltage over time is observed. This is known as the electroencephalogram (EEG). These potential changes are accepted to index electrical activity within the brain (see Coles & Rugg, 1995).

2.2 Electrogenesis

Each neuron transmits a signal through the flow of electrical current along and through its membrane. The electrical field generated by an individual neuron is too weak to be observed via scalp recording. The fields generated by many neurons within the same area of brain tissue, however, can combine to produce an electrical field large enough to be recorded at the scalp. Whether such summated fields are able to propagate to recording equipment at the scalp is dependent upon several factors.

First, the shape of the neuron is important. Regions where there is a net current outflow from a neuron's membrane are known as current 'sources', whilst regions with a net current inflow are known as current 'sinks'. If there is asymmetry in the shape of the neuron, such as in pyramidal neurons, these sources and sinks will be spatially separated, thereby creating a dipole – a pair of electrical charges of opposite polarity separated by some distance – which will generate an electrical field detectable outside the region of the neuron. In the case of radially symmetric neurons, however, such as stellate cells, the flow of current is such that dipole fields are generated around each dendrite which act in opposing directions. These opposing fields cancel one another out and are therefore not detectable outside the region of the neuron (Picton, Lins, & Scherg, 1995).

The alignment and activation of the neurons is also an important factor in the detection of these electrical fields at the scalp. The fields generated by a group of randomly oriented neurons will not summate to be detectable at the scalp as each is likely to have a neuronal counterpart generating an electrical field of equal magnitude in the opposite direction. The electrical fields of a group of asynchronously activated neurons will also cancel out and not be detectable at the scalp. What is required, therefore, for neural activity to be recorded at the scalp is an area of brain tissue composed of asymmetrical neurons (therefore generating an 'open field') arranged in a systematic fashion which are activated in a synchronised manner. The main structure of the brain satisfying these constraints is the neocortex, 70% of which consists of synchronously activated pyramidal cells arranged in a columnar fashion (Kutas & Dale, 1997). It is the neocortex that is believed to be the primary source of EEGs recorded at the scalp.

2.3 Recording an EEG

EEGs are recorded by connecting a willing participant to recording equipment through electrodes placed on the scalp. These electrodes are commonly arranged according to a selected montage which specifies the locations of electrodes on the scalp. Within the EEG literature, a montage of standardised locations is generally used which specifies locations of electrodes in terms of simple percentages (i.e. 10, 20, 50) along the lines linking the inion, nasion, and pre-auricular points. Within the widely used 10/20 system (Jasper, 1958), electrode locations are named by a combination of one or two letters indicating their general location on the scalp (FP = frontal pole; F = frontal; C = central; P = parietal; O = occipital; T = temporal) and a number or letter indicating their distance from the midline (odd numbers = left-hemisphere; even numbers = right-hemisphere; z = midline). For example, F8 refers to a frontal electrode over the right-hemisphere, Cz to a central electrode on the midline, and P5 to a posterior electrode over the left-hemisphere. Elasticised caps with electrode locations marked according to the 10/20 system help to maintain relatively constant locations across participants, and were used in the EEG recordings reported in this thesis.

For electrical activity to propagate from the scalp to the electrodes an electrolyte solution, typically a paste or gel, is applied to the scalp at electrode locations. To reduce the impedance from the electrode circuit the skin beneath the electrodes is often abraded. It is common practice to keep impedance below 5kOhms for these electrodes. There are electrodes available, however, which amplify the signal at the electrode site – active electrodes – and as a result do not require the restriction of impedance to these levels or the abrasion of the skin to the same degree. The EEG recordings in this thesis were made using such active electrodes.

In EEG multi-channel recording, each channel records the differences in voltage between that electrode site and a common electrode reference. EEG acquired in the experiments reported in this thesis made use of an online linked reference located midway between POz and PO3/PO4 respectively, and was then re-referenced computationally offline to the average of the mastoid signals.

The changes in voltage of a scalp recorded EEG are tiny, and as such the EEG signal needs to be amplified many thousands of times before it can be accurately measured. This means, however, that any non-brain electrical activity in the signal will also be amplified alongside it. To partly counteract this, the EEG signal is amplified by means of a differential amplifier which cancels out the ambient electrical noise common to all electrodes. The amplified signal will also contain low-frequency noise from skin potentials, caused by the participant sweating or moving. The EEG signal is therefore passed through a high-pass filter which attenuates low frequencies and passes high frequencies. Typically, these filters are set to between 0.01and 1Hz. The higher the frequency of the high-pass filter, the less drift in the signal from low-frequency noise, though filtering that is too aggressive can lead to distortion of the signal (Luck, 2005). EEG data is also typically passed through a low-pass filter which attenuates frequencies above a certain point. Most cognitive neuroscience experiments use a low-pass cut-off of between 30-100Hz. The experiments reported in the current thesis filtered the EEG signal to a bandwidth of 0.03-40Hz. This filter setting is sufficient to capture the frequency range in which EEG signals of interest occur while removing artefactual frequencies.

The amplified signal is then passed through an *analogue-to-digital converter* which converts the analogue voltage at a sequence of discrete time points, called samples, into a digital signal. The *sampling rate* refers to the frequency with which these samples are taken, and is determined by means of the Nyquist theorem which states that all information within an analogue signal can be captured digitally as long as the sampling rate is at least twice the highest frequency within the signal. Within this thesis, EEG was low-pass filtered to 40Hz with a sampling rate of 166Hz (or 6ms/point).

2.4 Extracting the ERP from the EEG

EEG activity segmented into epochs of equal length and time-locked to an event of interest, such as the onset of a stimulus, is known as an event-related potential (ERP). However, even after filtering, the EEG will still contain some electrical noise that is not generated by the brain. To separate the neural activity from the noise, the recorded activity from all trials within each condition is averaged. Background noise is expected to occur in a random fashion, whilst the brain activity elicited by the same experiment manipulation over multiple trials is not. Averaging will therefore lead the noise to cancel itself out, leaving only neurally-elicited activity in the ERP. The greater the number of trials which contribute to the average, the higher the signal-to-noise ratio (signal:noise hereafter).

However, as this technique requires the participant to complete many trials of each experimental condition to allow for averaging, EEG experiment designs can be lengthy and tedious for the participant. Averaging may also 'create' components that are not really of interest but rather are a result of bimodal variations in latency or amplitude across trials which have combined to form what appears to be a significant difference. It is also possible that a difference between two conditions comes about as a result of the proportion of trials in each condition for which the ERP component is evident, an issue which must be considered in forced-choice tasks where one condition may contain more 'guesses'.

Even after averaging, there can be other variations in the EEG signal which are not neural in origin, but rather a result of movement by the participant. These are referred to collectively as artefacts. The eye, when moved, acts like a dipole with a positive charge at one side and a negative charge at the other. Movements of the eye and eyelid cause this dipole to produce an electrical field which propagates across the scalp and will be recorded as part of the EEG (Lins, Picton, Berg, & Scherg, 1993). Such artefacts cannot be filtered out as they occur at the same frequencies as ERP features, but can be monitored by concurrent recording of the electro-oculogram (EOG).

To reduce the number of artefacts recorded, participants can be instructed to fixate a point in the stimulus display and/or to avoid eye movement during critical periods. However, such instructions could be considered a secondary task placed upon the participant that may interfere with performance on the primary task (Coles & Rugg, 1995). All trials containing artefacts could be discarded, although this is likely to significantly reduce the number of trials available for averaging and may result in the inappropriate rejection of trials in which prefrontal EEG activity has also been recorded in the EOG. A preferable solution is to employ an algorithm which is capable of correcting for the contribution of the blink artefact to all other EEG recording channels and therefore allows these trials to contribute to averaged EEG (Semlitsch, Anderer, Schuster, & Presslich, 1986). In the present studies, trials containing blink artefacts were corrected with such an algorithm. Saccadic eye movements were identified through offline visual inspection of the EOG and subsequently discarded.

Further artefacts include baseline drift, which is a linear increase or decrease in voltage across the recording epoch due to changes in electrode impedance from slight movements or sweating by the participant. A second artefact is analogue-to-digital converter saturation which occurs when the signal voltage exceeds the range of voltages passed by the amplifier and leads to the EEG signal "flat-lining" for a period. Trials containing these artefacts also need to be excluded from the average, generally on the basis of visual inspection (as in the experiments reported in this thesis), or via algorithms that have criteria which can be set for identification of these artefacts at given thresholds (for example, baseline drift exceeding ±80μV in this thesis).

2.5 Interpreting ERPs

An ERP consists of a series of positive peaks and negative troughs of voltage plotted against time. The simplest approach to interpreting an ERP would be to consider each peak and trough in the waveform as an ERP component defined in terms of its latency and polarity. The traditional nomenclature for ERP components defined in this way would name a positive peak with a latency of 100ms as P100, whilst a negative trough with latency of 400ms would be named N400. However, such a form of component definition refers to the typical latency of the component, something that is likely to vary with the age of participant or the strength of the signal (Picton et al., 1995). Such a means of component definition is also impeded by component overlap in the waveform, whereby the component observed at the scalp is the summation of electrical activity generated by multiple sources within the brain. Also, an ERP component observed at 200ms post-stimulus does not necessarily reflect the activity of a neural system at that time. It could equally be generated by two sources, one before 200ms and one after which both summate to activity recorded at 200ms.

Two main approaches are commonly adopted in the interpretation of ERP components, a physiological approach and a psychological approach. The physiological approach is concerned with identifying an ERP component in terms of its anatomical source. How the component relates to the psychological processes of the participant is not the main concern. The psychological, or functional, approach, however, defines ERP components in terms of the information processing operations with which they are correlated. By this definition, it is of no consequence that a component of scalp-recorded activity may reflect the activity of multiple neural sources as together they are considered to constitute an homogenous cognitive function, specified by the nature of the experiment manipulation.

In this thesis, the approach employed is to contrast the ERP waveforms associated with different experimental conditions and response categories. Through the use of inferential statistics it is possible to determine whether ERPs between experimental conditions differ reliably, and therefore indicate differences in the neural mechanisms engaged in these conditions. These differences can be described as qualitative or quantitative.

Qualitative differences refer to differences between the scalp distributions of ERPs across conditions, or across time-windows within the same condition, and are likely to reflect the contributions of different brain regions, or of identical brain regions with different levels of relative activation (Urbach & Kutas, 2002). Under the assumption of modularity of cognitive function within the brain, qualitative differences in ERPs are therefore interpreted as reflecting the engagement of distinct cognitive processes across conditions. Quantitative differences, on the other hand, describe occasions when ERP amplitudes differ reliably across conditions but are not accompanied by differences in scalp-distributions, suggesting a common set of neural generators in each condition (although this is of course a null result obtained using a measure that provides only a partial index of neural activity). Functionally, such differences in amplitude are therefore interpreted as the engagement of the same cognitive process, but to differing degrees across conditions.

Chapter Three : General Methods

3.1 Introduction

This chapter contains a description of the methods common to all the experiments reported in this thesis. Those experimental procedures specific to each experiment are described in the methods sections of the respective experimental chapters. The parameters for EEG acquisition and ERP extraction described below are identical across all experiments, as is the data processing and analysis approach.

3.2 Participants

Participants in all of the experiments were recruited from the undergraduate and postgraduate student populations at Cardiff University. All were native English speakers, right-handed, aged 18-30 years, and had normal or corrected to normal vision with no red/green colour-blindness. All participants also reported having no diagnosis of dyslexia or being prescribed psychotropic medication at the time of testing. The selection criteria for Experiments 4 and 5 also required participants to have normal or corrected to normal hearing. All participants gave informed consent prior to commencement of the experiment and received payment at a rate of £7.50 per hour upon completion. Ethical approval was obtained from the School of Psychology Ethics Committee, Cardiff University.

3.3 Experimental Materials

Stimuli in all experiments were low-frequency words (range 1-9 per million) taken from the MRC psycholinguistic database (Coltheart, 1981). All words were open-class and between 4 and 9 letters in length. In the test phases of all experiments, all words were presented in upper case white letters on a black background. Visual presentation of words was employed at study in Experiments 1, 2, 3, and the *Visual* condition of Experiment 5. Study words in Experiments 4 and the *Auditory* condition of Experiment 5 were presented auditorily via headphones. In the study phases of Experiments 1 and 2, half the words in each block were presented in red letters, and half in green letters. In the study phases of Experiments 3 and 5 (*Visual* condition only), half the words in each block were presented in pink letters, and half in yellow letters. All visual stimuli were presented centrally on a computer monitor located 1.2m directly in front of the participant and subtended maximum horizontal and vertical visual angles of 2.2° and 1.4° respectively. In the study phases of Experiments 4 and 5 (*Auditory* condition only) half the words in each block were spoken in a male voice and half in a female voice. All auditory stimuli were digitised at 16 KHz and had a mean length of 770 ms which did not differ between voice genders.

3.4 Experimental Procedures

In all experiments, participants were fitted with an electrode cap and seated in front of a computer monitor in a sound-attenuated room prior to receiving the specific task instructions. In all study phases, each trial began with the presentation of a fixation asterisk centrally for 500ms. After a gap of 200ms, during which the screen was blank, the study stimulus was presented. Visual stimuli, used in Experiments 1, 2, 3, and 5 (*Visual* condition only), were presented for 300ms. Following stimulus presentation, the screen went blank during which time the participant was required to make their study encoding response. For all experiments, this was a self-paced binary decision concerning the context in which the word was presented. In Experiments 1, 2, 3, and 5 (*Visual* condition only) the context was the colour in which the word was written, and in Experiments 4 and 5 (*Auditory* condition only) this was the voice of the speaker. The screen remained blank for a further 1000ms following the participant's response before the next trial began. At the end of each study phase, a message presented on screen for 5000ms informed the participants that the test phase was about to begin.

Test phases began immediately after this message. In the test phases of all experiments, participants were visually presented with all words which had been presented at study randomly intermixed with an equal number of words which were new to the experiment. In Experiments 1, 4, and 5, each test trial began with the presentation of an asterisk fixation point for 500ms. In Experiments 2 and 3, 90% of test trials in each block began with presentation of a fixation asterisk for 1500ms. The remaining 10% of test trials began with an asterisk that was visible for 500ms. The length of asterisk presentation was varied in this way to encourage the participant to remain alert in the pre-stimulus period, during which EEG was also acquired (results not reported in this thesis). For all experiments, a gap of 200ms followed the fixation asterisk before which the test stimulus was presented for 300ms. The screen then remained blank while the participant was required to make a self-paced old/new judgment for the test stimulus. Following this response the screen remained blank for 1000ms before the presentation of a question-mark signalled the requirement to make a second judgment for old items. For Experiments 1, 2, and 3 this was a binary decision regarding the context in which the item was presented at study. Experiments 4 and 5 required participants to also make a high/low confidence judgment in combination with this context discrimination. For test items judged to be new in the initial old/new discrimination, participants were instructed to press the new button again following the question-mark.

All responses were made using a button-box resting on the participant's lap. The experiments were designed so that the hands used for each of the old/new and context judgments (at study and test) were counterbalanced across participants. Participants were instructed to respond as quickly and accurately as possible, as well as to maintain central fixation. Upon completion of each study-test block, participants were able to take short breaks before proceeding to the next block.

3.5 Electrophysiological Recording Procedure

EEG was recorded from 32 silver/silver chloride electrodes housed in an elastic cap. They were located at midline sites (Fz, Cz, Pz, Oz) and left/right hemisphere locations (FP1/FP2, F7/F8, F5/F6, F3/F4, F1/F2, T7/T8, C5/C6, C3/C4, C1/C2, T5/T6, P5/P6, P3/P4, P1/P2, O1/O2: Jasper, 1958). Additional electrodes were placed on the mastoid processes. EEG was acquired at 2048Hz referenced to linked electrodes located midway between POz and PO3/PO4 respectively, time-locked to word presentation and filtered offline between 0.03 and 40Hz. The data were down-sampled to 166Hz (6ms/point), and re-referenced computationally off-line to the average of the mastoid signals into epochs of 1536ms (256 data points), each including a 102ms pre-stimulus baseline, relative to which all post-stimulus amplitudes were measured. EOG was recorded from above and below the right eye (vertical EOG: VEOG) and from the outer canthi (Horizontal: HEOG). Trials containing large EOG artefacts were rejected, as were trials containing analogue-to-digital saturation or baseline drift exceeding ±80μV. Other EOG blink artefacts were corrected using a linear regression estimate (Semlitsch, Anderer, Schuster, & Presslich, 1986). The averaged ERPs for each participant and for each category of interest were subjected to a 7-point (22Hz) binomially weighted smoothing filter prior to analysis. In order to achieve adequate signal:noise, only participants contributing a minimum of 16 artefact-free trials to each of the response categories of interest were included in the subsequent analyses.

3.6 Analysis Procedure

3.6.1 Behavioural Data

Analyses of task performance and reaction times (RTs) for all included participants were conducted using t-tests and repeated measures ANOVAs. Where necessary, analyses included the Greenhouse-Geisser correction for non-sphericity (Greenhouse & Geisser, 1959). Where appropriate, reliable main effects and interactions were followed up with post hoc comparisons, the details of which may be found in the relevant experiment chapter.

3.6.2 ERP Amplitudes

Averaged ERPs were analysed for 3 post-stimulus time windows: 500-800, 800-1100 and 1100-1400ms, selected on the basis of the time courses of ERP old/new effects identified in previous source memory studies[2] (Allan, Wilding, & Rugg, 1998;

---

[2] Electrophysiological data prior to 500ms are not analysed in the experiments reported in this thesis. This choice has been made for several reasons. First, the focus of this research is on the processes engaged either iteratively on the products of retrieval, or which are engaged subsequently. The timing of the left-parietal index of recollection, onsetting around 500ms post-stimulus, therefore identifies this time-point as a sensible one at which to begin analyses (see Section 1.3.3.1). Second, an early frontal old/new effect (300-500ms), the FN400, has been linked by some to the familiarity component of dual-process models of recognition memory (Curran, 2000; although see, Paller, Voss, & Boehm, 2007). The source memory tasks employed in this thesis, however, are not designed in order to provide any new insights into this particular interpretation. Large frontal effects with a similar time of onset that are typically observed in source memory tasks are also likely to overlap with this earlier frontal effect and make the separation of these effects challenging.

Mecklinger, 2000). For the initial analyses, the data from twenty electrode locations were grouped to form four clusters at anterior-right (FP2, F8, F6, F4, F2), anterior-left (FP1, F7, F5, F3, F1), posterior-right (O2, T6, P6, P4, P2), and posterior-left (O1, T5, P5, P3, P1) locations (see Figure 3.1, page 53). For each time window, initial global ANOVAs included the factors of response category (RC), the anterior/posterior dimension (AP), hemisphere (HM), and electrode site (ST). The details of the particular response categories included in these analyses are described in the relevant experiment chapters.

Where these global ANOVAs revealed reliable effects involving response category, they were followed up by all possible paired comparisons. Where these subsequent paired comparisons revealed a reliable interaction between response category and the anterior/posterior dimension, subsidiary analyses were conducted at anterior and posterior sites separately. As with the analyses of behavioural data, these included the Greenhouse-Geisser correction for non-sphericity where necessary (Greenhouse & Geisser, 1959).

3.6.3 ERP Topographic Distributions

As discussed in Chapter Two (Section 2.5), differences between the topographic distributions of ERP effects allow for claims to be made regarding the dissociation of the cognitive processes and neural generators engaged in the task. Analyses of the topographic distributions of effects in this thesis were conducted only when the amplitude analyses revealed reliable effects for each of the conditions of interest in the time-window of interest and for which the reliable differences between these conditions interacted with a scalp-location factor (anterior/posterior, hemisphere, or electrode site). Subtraction scores for the conditions meeting these criteria were then rescaled using the max-min method to remove differences between the amplitudes of the effects whilst maintaining differences between the shapes of the distributions (McCarthy & Wood, 1985). The subtraction scores were always calculated by subtracting the activity associated with correct rejections (a correct response to an unstudied test item) from the response category of interest. Comparisons of rescaled data for which the ANOVA retained reliable interactions between response category and scalp location indicate differences between the topographies of these effects.

3.7 Presentation of Statistical Outcomes

In all experiments the outcomes of the initial global analyses are reported in the text body, while the outcomes of subsequent ANOVAs are shown in table form at the end of the relevant results section. These analyses are reported with F-values and uncorrected degrees of freedom accompanied by their respective epsilon values when appropriate. While all reliable main effects or interactions involving the factor of response category (RC) and/or group (GP) are reported, for the most part discussion within the main text will focus on the highest order interactions. Behavioural data tables, topographic maps, and figures presenting ERPs from selected representative electrodes are presented alongside the text. At the end of each chapter, the ERP waveforms for all categories of interest are also presented from all electrodes in the recording montage. Unless otherwise stated, all topographic maps are computed on the difference scores obtained by subtracting the mean amplitudes associated with correct rejections from those associated with the response category of interest in the figure. Each map is scaled proportionately between the minimum and maximum amplitude values denoted in brackets below each map.

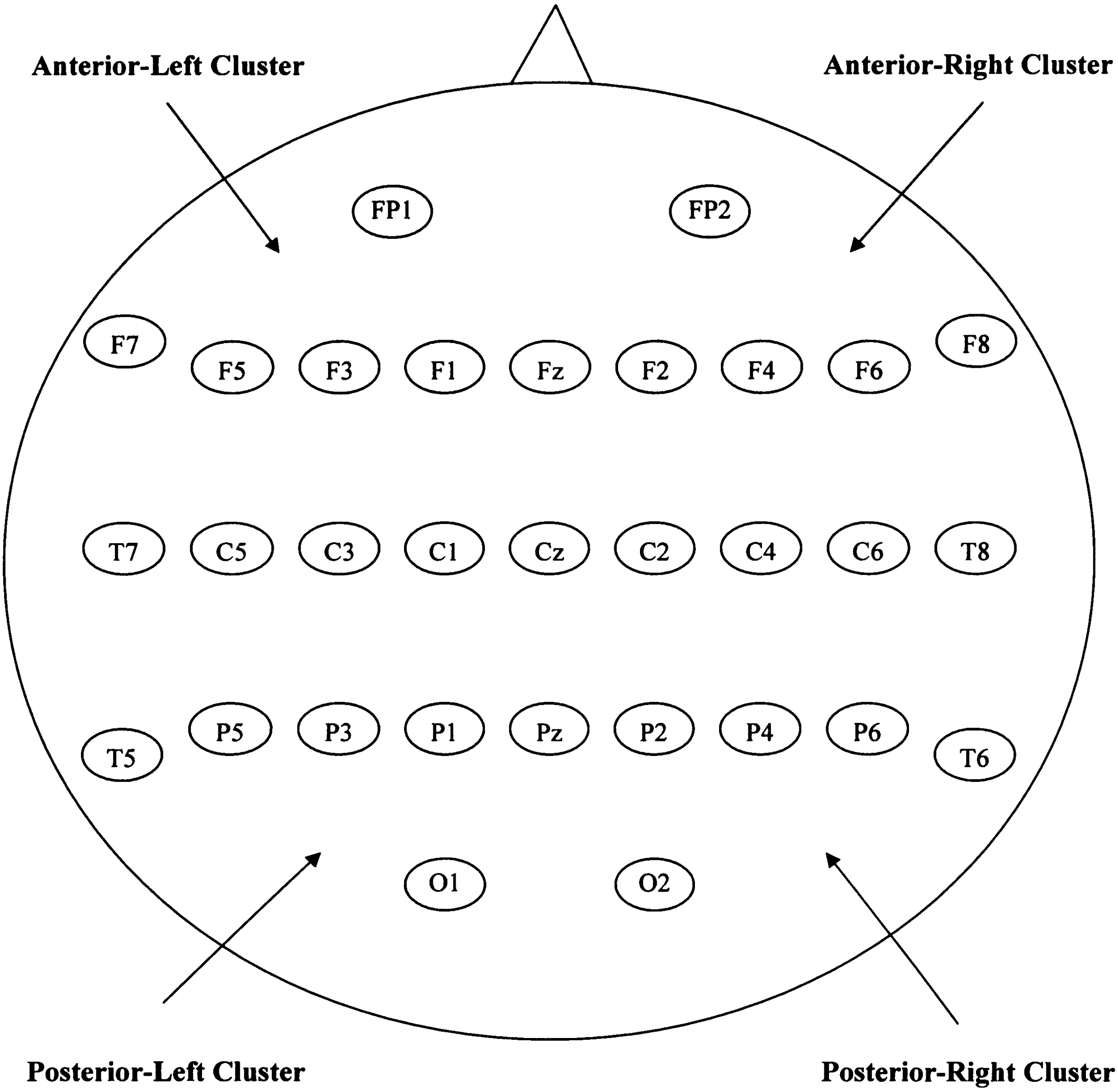


Figure 3.1: Approximate scalp locations of the 32 electrodes in the recording montage. Coloured locations denote the 20 electrode sites included in the analyses conducted in this thesis.

Chapter Four : Experiment One

4.1 Introduction

As discussed in Chapter One (Section 1.3.3.2), two broad accounts which have been offered for the functional significance of the right-frontal ERP old/new effect stem from observations of the relative magnitudes of this effect for correct and incorrect source judgments. A *retrieval search* account proposes that the effect reflects the engagement of a source retrieval attempt or search. Such an account is supported by data from studies in which frontal effects do not differ in magnitude according to the accuracy of source judgments, since a retrieval search is considered to be made under both conditions (e.g. Senkfor & Van Petten, 1998; Van Petten et al., 2000). A second account proposes that the effect indexes processes which operate on the products of retrieval in service of task goals – a *post-retrieval processes account* – and is supported by, among other data points, studies in which the magnitude of the right-frontal old/new effect is larger for correct source judgments than for incorrect ones (Wilding, 1999; Wilding & Rugg, 1996).

This seemingly unpredictable and inconsistent pattern of the relative magnitudes of frontal ERPs associated with correct and incorrect source judgments in studies employing similar paradigms encourages an appraisal of the ways in which the differences in the designs of these studies may contribute to the differences in ERP effects, and thus inform our understanding of the processes they reflect. Some of the critical differences and their potential impacts are discussed below.

Across the above described studies, there are several consistent differences in task stimuli and test requirements which may, in part, contribute to the behaviour of frontal effects. For example, for those studies in which frontal old/new effects do not predict the accuracy of source judgments (e.g. Senkfor & Van Petten, 1998; Van Petten et al., 2000), a proportion of the stimuli at test were exact copy cues of studied items, while for those studies in which frontal effects are sensitive to source accuracy (e.g. Wilding, 1999; Wilding & Rugg, 1996) test cues were consistently not copy cues. Similarly, in the studies where frontal effects do not predict source accuracy, the old/new and source judgments were made at the same time, for example, the three-way same voice/different voice/new judgement employed by Senkfor and Van Petten (1998), whereas those studies reported by Wilding and colleagues for which frontal effects are predictive of source accuracy (Wilding, 1999; Wilding & Rugg, 1996) employed a two-stage judgment of old/new status followed by a delayed source judgment. As discussed in Chapter One (Section 1.3.3.4), the presence or otherwise of copy cues and same/different response options at test may affect the types of processing with which source judgments are associated.

The account offered in Chapter One (Section 1.3.3.4) is that the right-frontal old/new effect indexes processes which operate on any form of information that may be diagnostic for a source judgment. When a proportion of test stimuli are exact copy cues of studied stimuli, both recollection and familiarity provide such diagnostic information since the relative level of familiarity associated with copy cues will be greater than that associated with those test stimuli which are not copy cues and can therefore inform a source judgment. Three-way same/different/new response options can also only be used in studies in which a proportion of test stimuli are copy cues, and may encourage the participant to make a source judgment based upon a relative feeling of familiarity, rather than solely upon recollection (for a similar argument see Ranganath & Paller, 2000). When no copy cues are present at test, however, recollection is the only form of information diagnostic for a source judgment since the level of familiarity diagnostic for a source judgment associated with each previously studied item will be equated. By this argument then, all old items in a study in which a proportion of test items are copy cues will be associated with information diagnostic for the source judgment, and will therefore engage the processes indexed by the right-frontal old/new effect to the same extent, resulting in effects of equivalent magnitude for correct and incorrect source judgments. When no copy cues are used at test, however, only items for which recollection has occurred will be associated with these processes. In so far as the majority of items associated with recollection will be assigned to the correct source, the processes indexed by the right-frontal old/new effect will be associated with these judgments to a greater extent than with incorrect source judgments resulting in right-frontal effects which differ in magnitude. This account therefore makes testable predictions regarding the relative magnitudes of the correct and incorrect source right-frontal old/new effects based upon the presence or otherwise of copy cues at test.

Another task effect which may contribute to the behaviour of frontal ERP effects is the accuracy with which old/new and source judgments are made. Across the literature there are several studies in which frontal old/new effects vary across conditions in which response accuracy also varies. For example, Kuo and Van Petten (2006) observed larger frontal old/new effects in one of a pair of source memory tasks with lower levels of source accuracy as a result of manipulating the encoding task. Wilding (1999) also demonstrated frontal old/new effects associated with correct source judgments which varied in magnitude between two conditions associated with different levels of source accuracy. In this case, however, late frontal effects were largest for the retrieval task eliciting the highest level of source-retrieval accuracy. The published data points also suggest a relationship between the degree of laterality of the late frontal old/new effect and the difficulty with which old judgments are made. For example, bilaterally distributed late frontal effects have been observed in tasks for which hit-rates were at ceiling (~95%; Kuo & Van Petten, 2006; Senkfor & Van Petten, 1998; Van Petten et al., 2000), while reliably right-lateralised late frontal effects observed in tasks with relatively lower hit-rates (~65%; Wilding, 1999; Wilding & Rugg, 1996, 1997a, 1997b). These differences, however, are confounded by the use of different encoding tasks and materials between conditions, making it difficult to disentangle the potential contribution of retrieval difficulty in isolation.

The potential relationship between the magnitude of and/or distribution of the late frontal old/new effect and the difficulty of retrieval is the primary focus in this experiment. While maintaining a constant encoding task, task difficulty was varied within participants in the current experiment by manipulating the number of to-be-remembered items between blocks. In the *Difficult* condition, participants studied three times as many words presented in red and green as in the *Easy* condition. At test, all studied (old) words were presented again and intermixed randomly with an equal number of unstudied (new) words. All words at test were presented in white, and participants made an old/new decision followed by a delayed red/green decision for old items. This design therefore allows an investigation of the effect of retrieval difficulty on the late-frontal ERP old/new effect. The ERPs associated with correct and incorrect source judgments can also be contrasted in this design allowing a test of the copy cue account for the relative magnitudes of these right-frontal old/new effects offered above. This account predicts a larger right-frontal old/new effect associated with correct source judgments relative to that associated with incorrect source judgments.

4.2 Methods

4.2.1 Participants

Twenty-five right-handed native English speakers took part in exchange for payment at a rate of £7.50/hour. All had normal or corrected to normal vision, no diagnosis of dyslexia, and gave informed consent prior to the experiment. Data from 9 participants were discarded for not contributing at least 16 artefact-free trials to the response categories of interest due to poor performance (6 participants) and excessive EOG artefact (3 participants). Of the remaining 16 participants (mean age 20 years, range 18-29 years), 14 were female.

4.2.2 Materials

Stimuli were 360 low-frequency words presented on a black background. All were open-class and ranged between four and nine letters in length.

4.2.3 Design and Procedure

The 360 words were randomly divided into 36 lists of 10 words and divided equally between the Easy and Difficult conditions. The 18 lists in the Easy condition were paired at random to form 9 list pairs. The lists in the Difficult condition were randomly grouped together in sets of three to form 6 word lists which were subsequently paired at random to form 3 list pairs. One of the word lists in each pair was assigned to be the study list. All words presented at study were presented again at test along with all words from the unstudied list to form one study-test block. The Easy condition comprised 9 study-test blocks (10 words at study per block, 20 at test), and the Difficult condition 3 study-test blocks (30 words at study, 60 at test).

Across participants all words appeared as both old and new stimuli, in both red and green, and in both Easy and Difficult conditions. The order of word presentation was randomised for each participant at study and test. Block order was arranged pseudo-randomly across participants such that within the overall total of 12 study-test blocks the 3 Difficult blocks appeared together in either positions 1-3, 4-6, 7-9, or 10-12.

This resulted in 32 complete task lists from which 16 were randomly selected to be completed by the participants.

Participants were fitted with an electrode cap prior to the experiment and were seated in a sound attenuated room 1.2m away from a computer monitor with their fingers on response keys. A short practice session preceded the experiment and participants were able to take short breaks between study-test blocks. Participants were instructed that, in each study phase, they would see words shown in red and green, and that their memories for the words and their colours would be assessed afterwards. For each study word, participants were instructed to press key pads using their index fingers to indicate word colour.

Each test phase began shortly after each study phase. Participants were informed that they would see words shown one at a time in white which were either from the immediately preceding study phase or were new to the experiment. They were asked to make an initial old/new judgment with their index fingers. For words judged to be old, participants were also asked to make a second judgment of the colour of the word when studied (red/green using index fingers). For words judged to be new, participants were instructed to press the new key again after the initial old/new judgment to proceed to the next trial. The hands used to make old/new judgments at test and red/green judgments at study were counterbalanced across participants.

Each study trial began with an asterisk that was displayed for 500ms, followed by a blank screen for 200ms, after which the word was displayed for 300ms. The next trial began 1000ms after a response was made. At test, each trial also began with an asterisk for 500ms, a blank screen for 200ms, and the word presented for 300ms. The screen remained blank for 1000ms after the initial old/new response before a question mark signalling that a context judgment was required was shown for 300ms. The screen then remained blank until 1000ms after the participant responded, at which point the next trial started.

4.2.4 Electrophysiological Recording Procedure

EEG was recorded from 32 silver/silver chloride electrodes housed in an elastic cap. They were located at midline sites (Fz, Cz, Pz, Oz) and left/right hemisphere locations (FP1/FP2, F7/F8, F5/F6, F3/F4, F1/F2, T7/T8, C5/C6, C3/C4, C1/C2, T5/T6, P5/P6, P3/P4, P1/P2, O1/O2: Jasper, 1958). Additional electrodes were placed on the mastoid processes. EEG was acquired at 2048Hz referenced to linked electrodes located midway between POz and PO3/PO4 respectively, time-locked to word presentation and filtered offline between 0.03-40Hz. The data were down-sampled to 166Hz (6ms/point), and re-referenced computationally off-line to the average of the mastoid signals into epochs of 1536ms (256 data points), each including a 102ms pre-stimulus baseline, relative to which all post-stimulus amplitudes were measured. EOG was recorded from above and below the right eye (vertical EOG: VEOG) and from the outer canthi (Horizontal: HEOG). Trials containing large EOG artefacts were rejected, as were trials containing signals that exceeded the amplifier range or baseline drift exceeding ±80μV. Other EOG blink artefacts were corrected using a linear regression estimate (Semlitsch, Anderer, Schuster, & Presslich, 1986). The averaged ERPs for each participant and for each category of interest were subjected to a 7-point (22Hz) binomially weighted smoothing filter prior to analysis. In order to achieve adequate signal:noise, only participants contributing a minimum of 16 artefact-free trials to each of the response categories of interest were included in the subsequent analyses.

4.3 Results

4.3.1 Behaviour

Table 4.1 (below) shows the probabilities of correct/incorrect judgments to old words, as well as the conditional probabilities of correct colour judgments. A pair of two-way ANOVAs conducted on the probabilities of a correct old judgment (hits hereafter) and the conditional probabilities of a correct source judgment (hit/hits hereafter) with factors of Study Colour (2 levels: Red, Green) and Condition (2 levels: Easy, Difficult) revealed only reliable main effects of Condition in both cases (Hits: $F(1,16) = 14.84$, $p<.001$; Hit/hits: $F(1,16) = 5.12$, $p<.05$). The absence of main effects or interactions involving study colour licensed subsequent analyses conducted on data collapsed across this factor in keeping with previous findings in similar studies where colour manipulations have been employed (Cycowicz et al., 2001; Wilding, Fraser, & Herron, 2005). Old/new discrimination (collapsed across source accuracy, p(hit) - p(false alarm), Snodgrass & Corwin, 1988) was significantly above chance in both conditions (Easy: $t(15) = 47.14$, $p<.001$; Difficult: $t(15) = 17.91$, $p<.001$) as was the conditional probability of a correct colour judgment (*p(source hit | hit)*; Easy: $t(15) = 14.40$, $p<.001$; Difficult: $t(15) = 9.75$, $p<.001$). Old/new discrimination was significantly more accurate in the Easy condition than the Difficult condition ($t(15) = 7.51$, $p<.001$) as was the conditional probability of a correct colour judgment ($t(15) = 3.88$, $p<.001$). Table 4.1 shows that the more accurate old/new discrimination in the Easy condition is a result of both an increased hit rate and reduced false alarm rate.

	Easy	**Difficult**	***Collapsed***
p(Hit)	0.85 (0.07)	0.69 (0.15)	*0.77 (0.14)*
p(FA)	0.05 (0.05)	0.09 (0.07)	*0.07 (0.06)*
p(Hit/Hit)	0.79 (0.08)	0.73 (0.09)	*0.76 (0.09)*

Table 4.1: Mean probabilities of identifying old words correctly (Hit) and incorrectly identifying new words (FA) across conditions as well as for the Easy and Difficult conditions separately. Also shown are the conditional probabilities of correct source judgments (hit/hit). Standard deviations are in brackets.

Mean reaction times (RTs) for the initial old/new judgments are shown in Table 4.2 (below). A two-way ANOVA on the RTs for words judged correctly to be old with factors of source accuracy and condition revealed no reliable effects or interactions. A second two-way ANOVA on the RTs for correct test judgments (collapsed across source accuracy) with factors of old/new status and condition revealed a reliable main effect of old/new status reflecting faster RTs for correct judgments to new items ($F(1,15) = 19.64$, $p<.001$). There was no main effect or interaction involving condition.

	Easy	**Difficult**	***Collapsed***
Hit	1045 (279)	1100 (275)	*1073 (276)*
CR	886 (187)	953 (193)	*919 (190)*
Hit/Hit	1026 (253)	1050 (204)	*1038 (227)*
Hit/Miss	1065 (309)	1150 (331)	*1107 (318)*

Table 4.2: Mean reaction times with standard deviations in brackets for correctly identifying old words (Hit), incorrectly identifying new words (FA), correct and incorrect source judgments (hit/hit; hit/miss) across conditions as well as for the Easy and Difficult conditions separately.

4.3.2 ERP Analyses

Two sets of ERP analyses were conducted. The first (N=16) was between the ERPs associated with correct rejections and hit/hits between the Easy and Difficult conditions. The mean numbers of epochs per participant per response category in the Easy condition were: correct rejections: 70 (range 44-73), hit/hits: 50 (29-69), and in the Difficult condition were: correct rejections: 62 (44-89), hit/hits: 36 (16-58). A second set of ERP analyses were conducted on the hit/hit and hit/miss (incorrect source judgment) data collapsed across the difficulty manipulation. The mean numbers of epochs per participant per response category for these analyses were: correct rejections: 132 (88-162), hit/hits: 86 (45-127), hit/misses: 25 (16-41).

The ERPs were analysed for 3 post-stimulus time windows: 500-800, 800-1100 and 1100-1400ms. These were selected on the basis of the time courses of ERP old/new effects identified in previous source memory studies (Wilding & Rugg, 1996, 1997a). The initial analyses included the data from twenty electrode locations grouped to form four clusters at anterior-right (FP2, F8, F6, F4, F2), anterior-left (FP1, F7, F5, F3, F1), posterior-right (O2, T6, P6, P4, P2), and posterior-left (O1, T5, P5, P3, P1) locations. These electrode locations were chosen to allow for known effects with different left/right lateralisation and anterior/posterior distributions to be investigated. For these time windows, initial global ANOVAs conducted in the analyses across the difficulty manipulation included the factors of difficulty (2 levels: Easy, Difficult), response category (2 levels: correct rejection, hit/hit), the anterior/posterior dimension (2 levels), hemisphere (2 levels), and electrode site (5 levels). Initial ANOVAs conducted in the analyses across source accuracy included the factors of response category (3 levels: correct rejection, hit/hit, hit/miss) along with the above location factors.

Where initial global ANOVAs revealed reliable effects involving response category, they were followed up by all possible paired comparisons, which were conducted separately at anterior and posterior sites when the initial analyses revealed interactions including response category and the anterior/posterior dimension. Where necessary, analyses included the Greenhouse-Geisser correction for non-sphericity (Greenhouse & Geisser, 1959). Uncorrected degrees of freedom and F-values are shown in the text and results tables, accompanied by their respective epsilon values when appropriate.

4.3.2.1 Difficulty of Retrieval

Figures 4.1 and 4.2 (pages 65 & 66) show that the ERPs associated with correct source judgments begin diverging from correct rejections in both the Easy and Difficult conditions at around 300ms post-stimulus. These old/new effects are largest at posterior sites from 500-800ms before shifting to a right-lateralised, frontally-distributed maximum that continues to the end of the epoch.

The initial global ANOVAs revealed no interactions involving the factors of difficulty and response category in any time-window, highlighting the lack of reliable differences in the ERPs between the Easy and Difficult conditions. The next section reports the outcomes of the analyses of the hit/hit and hit/miss old/new effects collapsed across the difficulty manipulation.

4.3.2.2 *Accuracy of colour judgments*

The ERPs associated with the hit/hit and hit/miss response categories, as shown in Figure 4.3 (page 67), begin diverging from those associated with correct rejections after approximately 300ms. These positive-going old/new effects are larger for the hit/hit than the hit/miss category at left-parietal locations from 500-1100ms. Positive-going frontal ERP old/new effects are broadly comparable for the two classes of hits throughout the recording epoch.

The initial global analyses revealed reliable response category by anterior/posterior dimension by site interactions in all time-windows (500-800ms: $F(8,120) = 5.35$, $p<.01$, $e = 0.39$; 800-1100ms: $F(8,120) = 3.84$, $p<.05$, $e = 0.43$; 1100-1400ms: $F(8,120) = 3.94$, $p<.05$, $e = 0.32$) as well as category by anterior/posterior dimension by hemisphere interactions from 800-1400ms (800-1100ms: $F(2,30) = 9.12$, $p<.01$, $e = 0.87$; 1100-1400ms: $F(2,30) = 19.05$, $p<.001$, $e = 0.71$). The outcomes of the subsequent paired contrasts at anterior and posterior sites separately can be seen in Table 4.3 (page73) and are described below.

At anterior sites, the category by site interactions for the hit/hit old/new effect from 500-800ms reflect the mid-lateral distribution of this effect, which becomes more broadly distributed across anterior sites from 800-1100ms, as reflected by the main effect of category in this time-window. The category by hemisphere interaction in the 1100-1400ms time-window reflects the right-lateralisation of this effect. The right-lateralisation and fronto-polar maximum of the hit/miss old/new effect from 800-1400ms is borne out by the category by hemisphere and category by site interactions in these time-windows. The category by site interactions for the comparison of hit/hit and hit/miss effects from 500-1100ms come about as a result of the larger positive-going hit/hit effect at superior sites. Hit/hit and hit/miss effects do not differ reliably in the late time-window (1100-1400ms) at anterior sites.

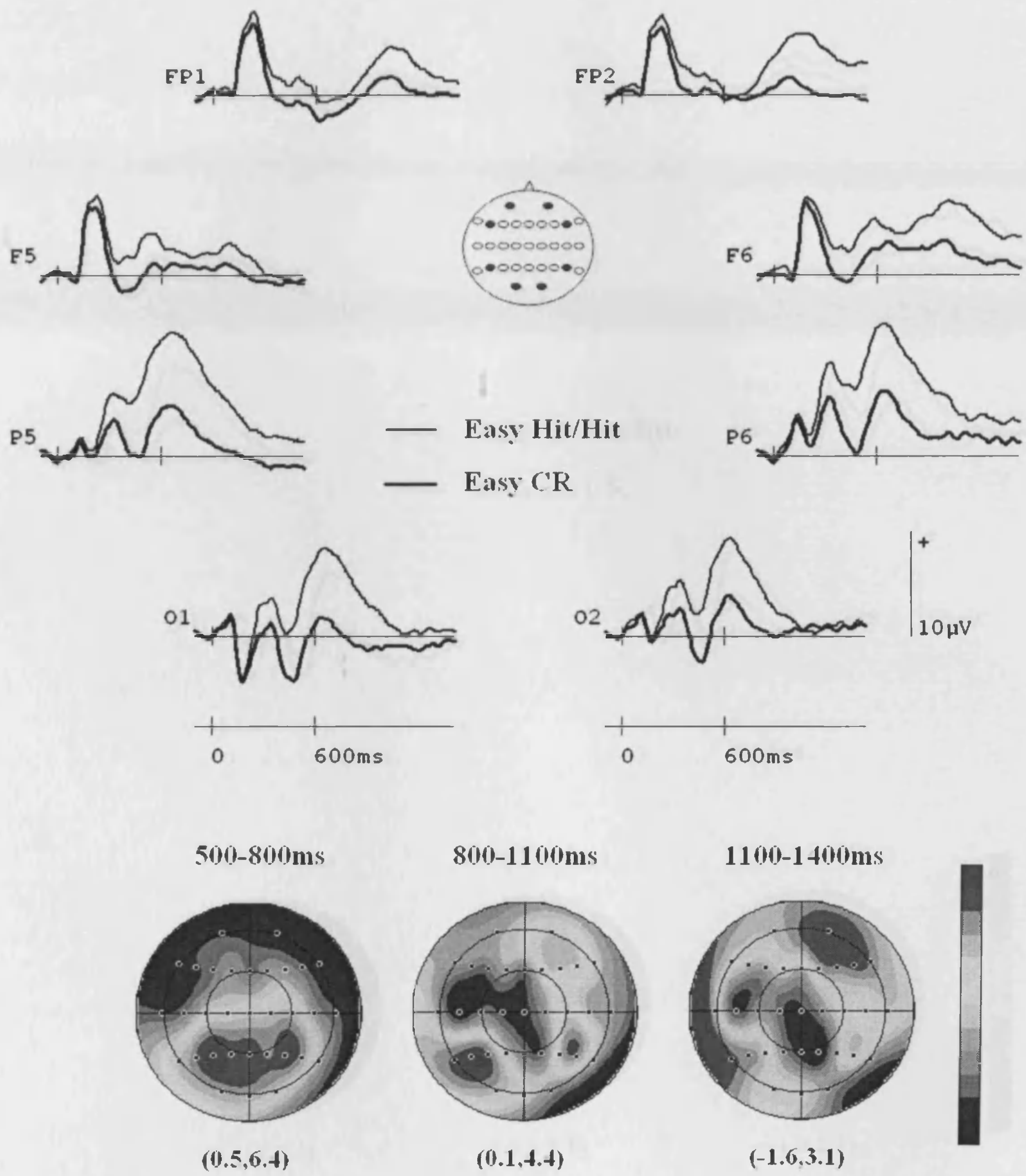


Figure 4.1: *Upper Panel*: Grand average ERPs associated with the hit/hit and correct rejection (CR) response categories in the Easy condition. Data are shown at fronto-polar (FP1/FP2), anterior (F5/F6), posterior (P5/P6), and occipital (O1/O2) sites. *Lower Panel*: Topographic maps showing the scalp distributions of the Easy hit/hit old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows. Voltage maps were computed on the difference scores obtained by subtracting the mean amplitudes associated with correct rejections from those associated with hit/hit. Each map is scaled proportionately between the minimum and maximum amplitude values denoted in brackets below each map.

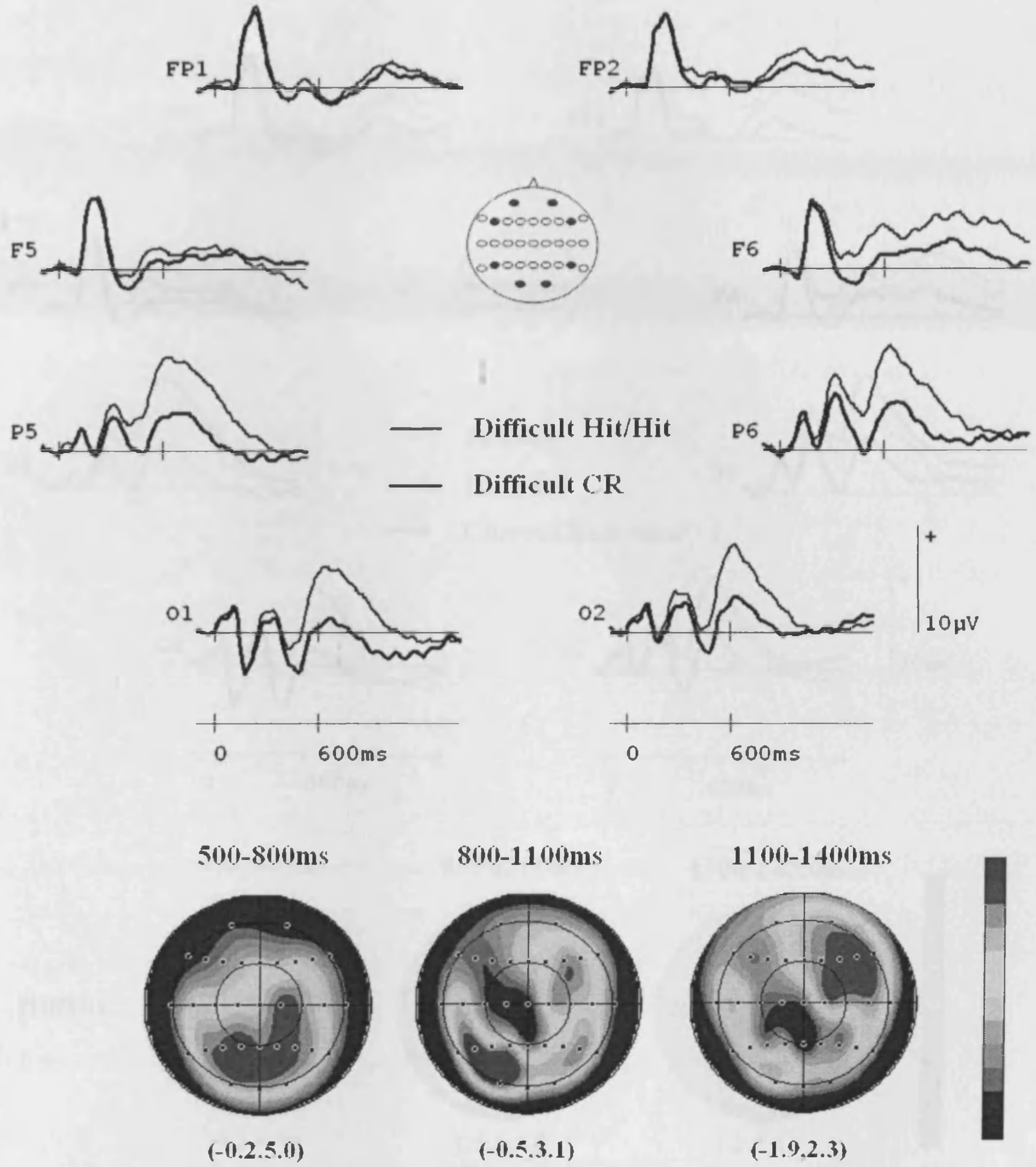


Figure 4.2: *Upper Panel*: Grand average ERPs associated with the hit/hit and correct rejection (CR) response categories in the Difficult condition. *Lower Panel*: Topographic maps showing the scalp distributions of the Difficult hit/hit old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows.

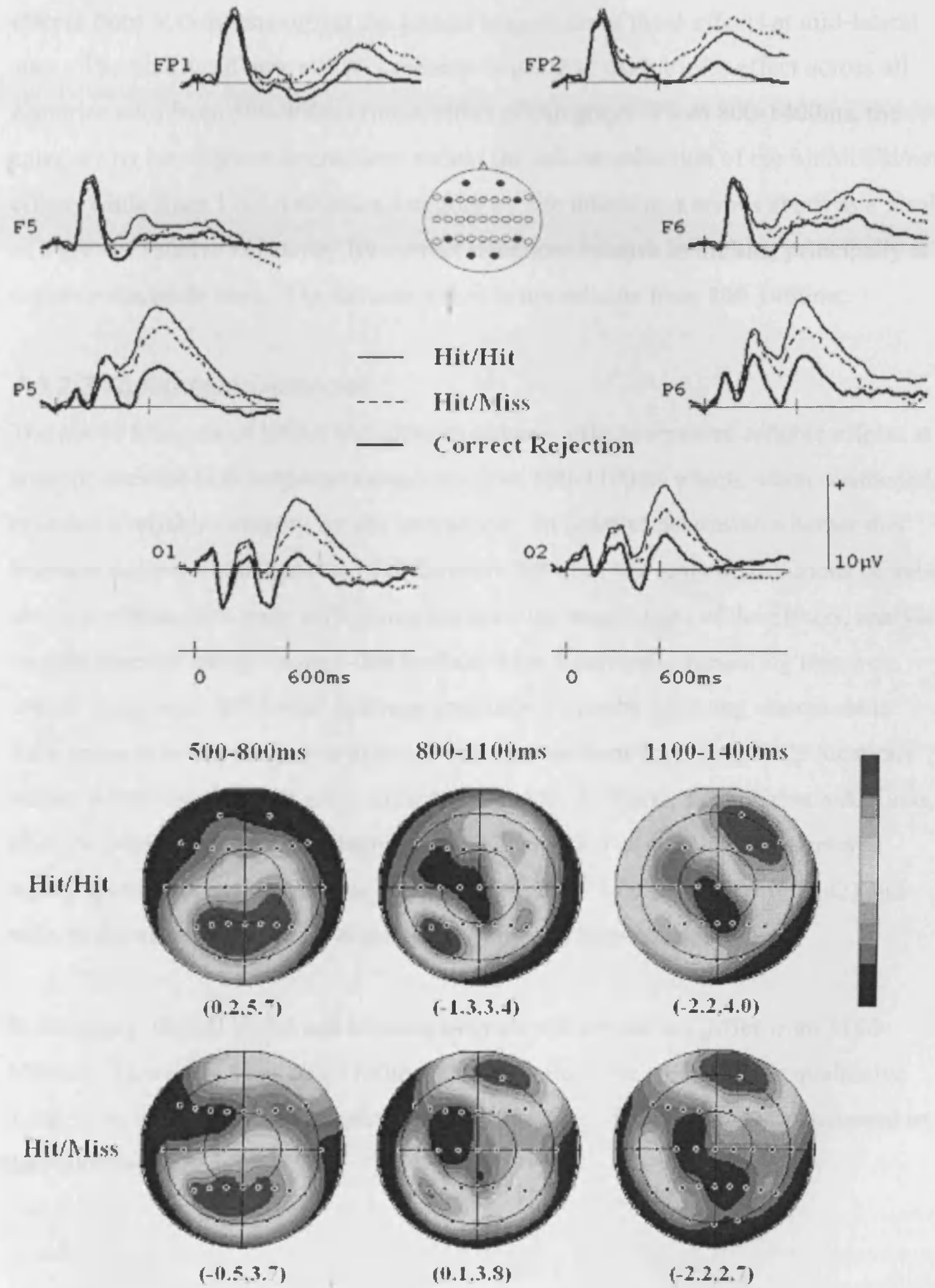


Figure 4.3: *Upper Panel*: Grand average ERPs associated with the hit/hit, hit/miss and correct rejection response categories (collapsed across Easy and Difficult conditions). *Lower Panel*: Topographic maps showing the scalp distributions of the hit/hit and hit/miss old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows.

At posterior sites, the category by site interactions for the hit/hit and hit/miss old/new effects from 500-800ms reflect the greater magnitude of these effects at mid-lateral sites. The hit/hit old/new effect is reliably larger than the hit/miss effect across all posterior sites from 500-800ms (main effect of category). From 800-1400ms, the category by hemisphere interactions reflect the left-lateralisation of the hit/hit old/new effect, while from 1100-1400ms a category by site interaction comes about as a result of a greater relative negativity for correct rejections relative to hit/hits, principally at superior electrode sites. The hit/miss effect is not reliable from 800-1400ms.

4.3.2.3 Topographic Analyses

The above analyses of hit/hit and hit/miss old/new effects revealed reliable effects at anterior sites for both response categories from 800-1100ms which, when contrasted, revealed a reliable category by site interaction. In order to determine whether this interaction came about because of differences between the scalp distributions of these old/new effects, or simply differences between the magnitudes of the effects, analyses on data rescaled using the max-min method were conducted. Rescaling removes overall amplitude differences between conditions, thereby licensing claims about differences between scalp distributions when interactions involving scalp locations remain when rescaled data are analysed (McCarthy & Wood, 1985; Urbach & Kutas, 2002; Wilding, 2006). The category by site interaction at anterior sites survived rescaling in the 800-1100ms time-window ($F(4,60) = 3.690$, $p<.05$, $e = 0.502$) and reflects the more fronto-polar distribution of the hit/miss old/new effect.

In summary, frontal hit/hit and hit/miss old/new effects did not differ from 1100-1400ms. However, from 800-1100ms post-stimulus there were reliable qualitative differences in the scalp topography of the two effects. These results are discussed in the following section.

4.4 Discussion

The lack of a consensual account for the processes indexed by the late-frontal ERP old/new effect encourages investigation of the aspects of task design which may contribute to the disparate findings within the literature. Several reports of a late-frontal ERP old/new effect have demonstrated variations in the magnitude of this effect between conditions employing different study encoding tasks and eliciting different levels of response accuracy at test (Kuo & Van Petten, 2006; Rugg et al., 2000; Wilding, 1999). To investigate the possibility that the observed variation in magnitude of this late-frontal effect is in part due to differences in the difficulty of task judgments, as indexed by response accuracy, in the current experiment task difficulty was manipulated within subjects while maintaining the same encoding task. This was done by manipulating the number of items to be learned in each study-test block in two conditions: Easy (10 study words in each list) and Difficult (30 study words in each list).

The lack of reliable differences between the ERPs obtained in the Easy and Difficult conditions throughout the recording epoch argues against the sole contribution of task difficulty to the magnitude of frontal ERPs. It was commented in the Introduction that the degree to which late frontal old/new effects are right-lateralised across published studies varies alongside the level of old/new response accuracy. Bilateral late frontal effects for hit/hits have been reported in source tasks eliciting high levels of response accuracy (hit-rates ~95%; Kuo & Van Petten, 2006; Senkfor & Van Petten, 1998; Van Petten et al., 2000), while the studies reporting right-lateralised late frontal effects (Wilding, 1999; Wilding & Rugg, 1996) made use of tasks eliciting lower levels of response accuracy (hit-rates ~65%). Visual inspection of Figures 4.1 and 4.2 (pages 65 & 66) reveals that the late frontal old/new effect (1100-1400ms) obtained in the Difficult condition has a more right-lateralised distribution than that obtained in the Easy condition. These apparent distributional differences are somewhat consistent with the pattern of effects across published studies. However, the lack of reliable differences across the difficulty manipulation in this experiment means that these observations can be made only tentatively at this point.

The current study also allowed for a comparison of ERPs associated with correct and incorrect source judgments collapsed across the Easy and Difficult conditions. As discussed in the Introduction, there are consistent differences between the task stimuli and test requirements in studies reporting late frontal effects which do or do not predict the accuracy of source judgments. For those studies in which frontal old/new effects do not vary with the accuracy of source judgments (Senkfor & Van Petten, 1998; Van Petten et al., 2000), a proportion of the test stimuli were direct copy cues of studied items while for those studies for which frontal effects predict source accuracy (Wilding, 1999; Wilding & Rugg, 1996) no copy cues were used at test. Similarly, frontal effects have not predicted source accuracy in studies employing a three-way judgment at test (e.g. same voice/different voice/new) whereas those studies employing a two-stage judgment of old/new status followed by a delayed source judgment at test have demonstrated frontal effects which vary as a function of source accuracy.

The presence in the current study of late-frontal old/new effects which did not vary with the accuracy of source judgments is relevant to the question of whether these task and stimulus-correspondence differences are part of the reason for some of the disparities in the published literature. The results suggest that the stimuli employed at test are not responsible for the disparate findings. This contrast, however, was made on data collapsed across a manipulation of task difficulty. A demonstration of this pattern of late-frontal effects in a study employing the same test stimuli and task requirements without a manipulation of difficulty would permit this claim to be made with fewer qualifications.

Earlier in the recording epoch (500-800ms), hit/hit and hit/miss responses (collapsed across the difficulty manipulation) were associated with a posterior mid-laterally distributed positivity relative to correct rejections. While not reliably left-lateralised, the time-course and distributions of the effects as shown in Figures 4.1, 4.2, and 4.3 (pages 65, 66, & 67) suggest that these are manifestations of the *left-parietal old/new effect* observed in many memory retrieval studies and which is tied strongly to recollection (Smith, 1993; Wilding, 2000; Wilding, Doyle, & Rugg, 1995). The current finding of reliable parietal old/new effects for both correct and incorrect source judgments which are larger for correct judgments is consistent with previous findings (Wilding & Rugg, 1996) and provides further support for the view that this effect indexes the quantity and/or quality of recollected information in a graded fashion (Vilberg, Moosavi, & Rugg, 2006; Wilding, 2000).

Frontal effects differed according to the accuracy of source judgments earlier in the epoch (500-800 and 800-1100ms), in that the hit/miss effect was distributed over fronto-polar sites to a greater degree than the hit/hit effect (see Figure 4.3, page 67). The reliable differences in rescaled data from 800-1100ms demonstrate that this is a qualitative difference in the distribution of ERPs. Topographical differences in the distribution of hit/hit and hit/miss effects have not been reported in previous source memory studies (although see Woodruff et al., 2006, discussed in Section 1.3.3.3). What could this difference reflect?

One possibility is that the differences come about as a result of variations in the magnitude of the left-parietal old/new effect, which is considerably larger for hit/hits in the 500-800ms time-window. The larger hit/hit left-parietal effect may have been recorded at some frontal electrode sites alongside the effect at fronto-polar sites which, when averaged, resulted in a somewhat less prefrontally distributed effect in the 800-1100ms time-window, relative to the hit/miss effect: as the hit/miss left-parietal effect is far smaller it will have projected to anterior electrodes to a lesser extent and so the effect's maximum remains at the right fronto-polar electrode. This possibility is supported by the lack of reliable differences in the latest time-window (1100-1400ms), by which time the left-parietal old/new effect had effectively terminated for both the hit/hit and hit/miss categories.

Alternatively, the differences between scalp topographies reflect differences in the neural generators of these effects such that items attracting correct or incorrect source judgments are associated with different cognitive processes (Rugg & Coles, 1995). Since these qualitative ERP differences occur in a time-window following the left-parietal index of recollection, they may reflect differential processing following the success or failure of recollection. As noted above, however, these differences are observed for data collapsed across a task difficulty manipulation, which makes it difficult to determine whether they come about as a result of differences in source accuracy, or are mediated by other task factors. Since this pattern has not been observed in previous studies employing source memory paradigms, the latter seems most likely. Replication of this pattern of results in the same paradigm without a manipulation of task difficulty would provide a stronger argument for differential processing as a function of source accuracy.

In summary, the results of the current study demonstrate that the magnitude of late-frontal ERP old/new effects is not determined solely by the difficulty of the retrieval task, although this may influence the extent to which these effects are right-lateralised. The observation of equivalent late-frontal effects for correct and incorrect source judgments also goes some way to ruling out the possible contribution of aspects of test stimuli and task responses to the behaviour of these effects. However, this is an outcome of analyses collapsed across a manipulation of task difficulty, and a replication of this pattern of ERPs in the same paradigm without this manipulation is necessary to successfully rule out their contribution. This also holds for the apparent differences between the scalp topographies of the hit/hit and hit/miss old/new effects in the 800-1100ms time-window. Experiment Two was designed to address this confound.

Table 4.3: Outcomes of the paired comparisons between the mean amplitudes associated with the hit/hit, hit/miss and correct rejection (CR) response categories collapsed across Easy and Difficult conditions for the 500-800, 800-1100, and 1100-1400ms epochs at anterior and posterior sites separately. Reporting criteria and nomenclature are as Table 4.3.

	500-800ms		**800-1100ms**		**1100-1400ms**	
	Anterior	**Posterior**	**Anterior**	**Posterior**	**Anterior**	**Posterior**
Hit/Hit vs. CR						
RC (1,15)	7.98 *	80.48 ***	10.28 **	9.81 **	9.27 **	ns.
RC x HM (1,15)	ns.	ns.	ns.	6.22 *	9.08 **	4.53 *
RC x ST (4,60)	4.80 * (0.41)	12.34 *** (0.62)	ns.	ns.	ns.	3.69 * (0.77)
Hit/Miss vs. CR						
RC (1,15)	ns.	10.01 **	ns.	ns.	ns.	ns.
RC x HM (1,15)	ns.	ns.	5.16 *	ns.	15.68 ***	ns.
RC x ST (4,60)	ns.	5.32 ** (0.67)	4.17 * (0.51)	ns.	6.08 ** (0.54)	ns.
Hit/Hit vs. Hit/Miss						
RC (1,15)	ns.	7.70 *	ns.	ns.	ns.	ns.
RC x ST (4,60)	8.42 ** (0.55)	ns.	4.54 * (0.49)	ns.	ns.	ns.

Figure 4.4: Grand average ERPs associated with the correct rejection and hit/hit response categories in the Easy condition. Data are shown for all 35 electrode sites from the recording montage.

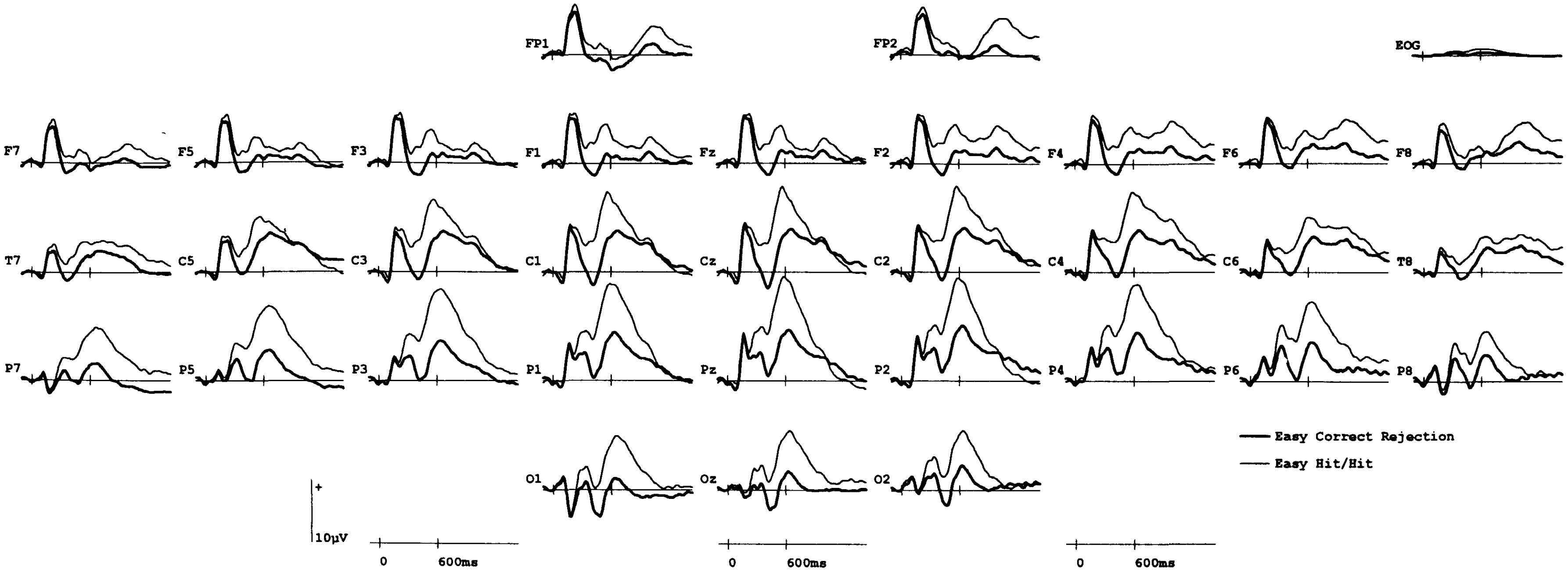


Figure 4.5: Grand average ERPs associated with the correct rejection and hit/hit response categories in the Difficult condition. Data are shown for all 35 electrode sites from the recording montage.

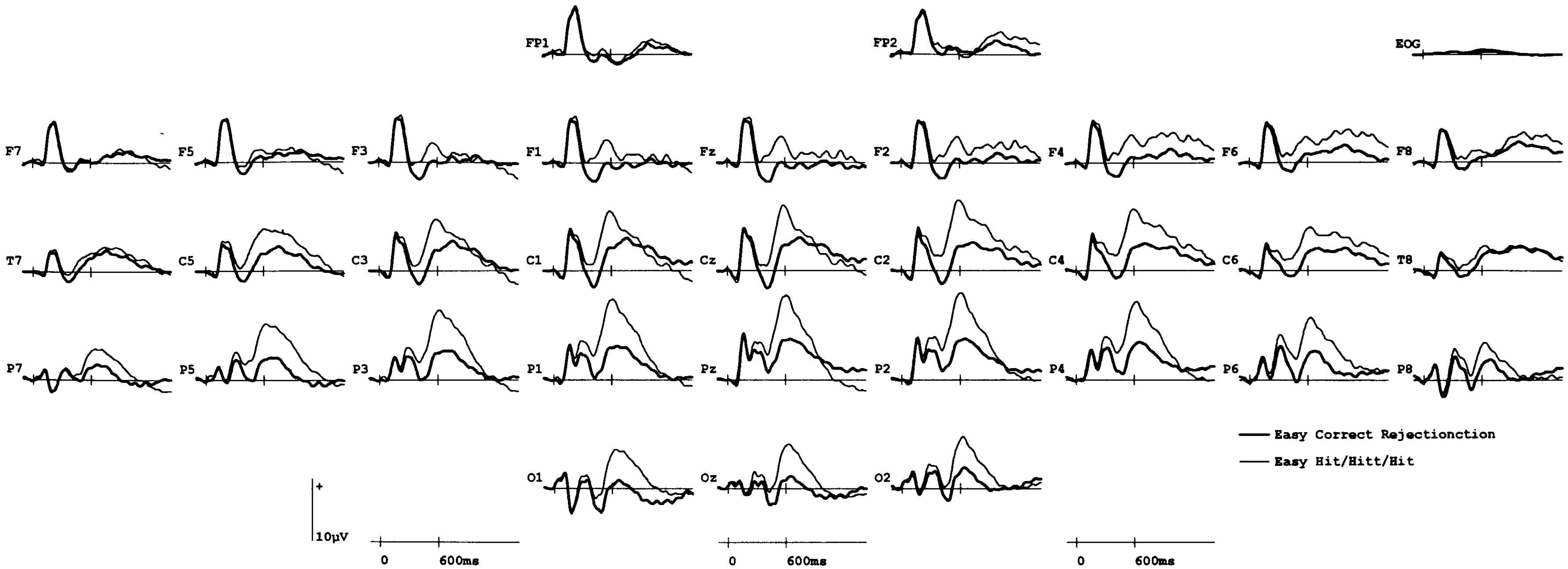
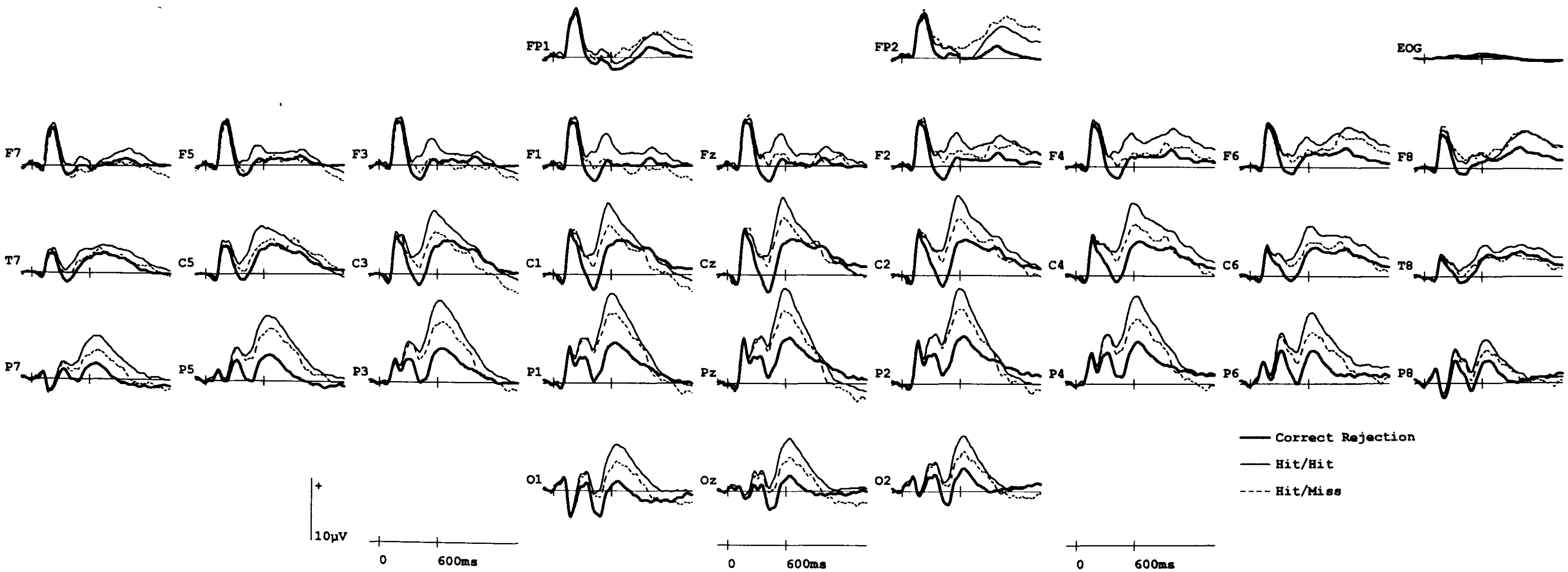


Figure 4.6: Grand average ERPs associated with the correct rejection, hit/hit, and hit/miss response categories (collapsed across the Easy and Difficult conditions). Data are shown for all 35 electrode sites from the recording montage. (The switch in relative positivity and negativity of the hit-miss waveforms across right and left-frontal electrodes here has been noted to possibly reflect greater eye movements in this condition. The included EOG channel data, however, demonstrate that this is unlikely to be the case, and that this pattern of scalp data reflects neurally-generated activity.)



Chapter Five : Experiment Two

5.1 Introduction

In Experiment One, late frontal ERP old/new effects did not differ as a function of the difficulty of retrieval, which argued against the contribution of this factor to the magnitude of these effects. Late frontal ERPs in Experiment One were also of equal magnitude in the cases of correct (hit/hit) and incorrect (hit/miss) source judgments. While this finding is consistent with some published data points (e.g. Senkfor & Van Petten, 1998; Van Petten et al., 2000), it is not consistent with all (e.g. Wilding, 1999; Wilding & Rugg, 1996).

As discussed in the Introduction of Experiment One, the task stimuli and test requirements used in published source memory studies vary in a consistent manner with the behaviour of late frontal hit/hit and hit/miss old/new effects. Previous studies reporting frontal effects which did not vary with the accuracy of source judgments (Senkfor & Van Petten, 1998; Van Petten et al., 2000) made use of test stimuli for which a proportion were exact copy cues of studied stimuli to which a three-way *same/different/new* judgment was required. Those studies for which frontal ERPs were predictive of the accuracy of source judgments (Wilding, 1999; Wilding & Rugg, 1996), however, did not make use of exact copy cues at test and required participants to make a judgment on the old/new status of the item before a delayed binary source judgment.

The account offered earlier in this thesis is that the disparate findings for the relative amplitudes of correct and incorrect source late frontal ERP old/new effects occurs because these effects index processes which operate on any form of information that may be diagnostic for a source judgment. When test stimuli do not include copy cues, recollection of study context is the only form of information diagnostic for the source judgment. When a proportion of test stimuli are copy cues, however, the relative levels of familiarity of test items will also be diagnostic for the source judgment. Therefore all old items in a study using a proportion of copy cues will be associated with information which is diagnostic for the source judgment and will engage the processes indexed by the late frontal old/new effect to the same extent, whether assigned to the correct source or not. When no copy cues are used at test, however, only items for which recollection has occurred (i.e. correct source judgments) will be associated with the processes indexed by the late frontal old/new effect.

The equivalent late frontal old/new effects for correct and incorrect source judgments observed in Experiment One do not fit with this account since no copy cues were used, and a two-stage response was required at test. Experiment One, however, also included a manipulation of task difficulty across which responses were collapsed to provide sufficiently high trial numbers for the incorrect source judgment ERPs. To rule out the possible confounding effect of collapsing across these conditions, the current experiment was a replication of the Difficult condition only from Experiment One, with the addition of more study-test blocks to allow sufficient trials in the incorrect source (hit/miss) response category. The failure to observe a reliable separation between the old/new effects associated with correct and incorrect source judgments when the difficulty confound is removed in the current experiment would present a strong challenge to this account, and to the contribution of these aspects of test stimuli and task requirements to late frontal ERPs.

5.2 Methods

5.2.1 Participants

Twenty right-handed native English speakers took part. Exclusion criteria for participants were as Experiment One, and are described in General Methods Section 3.2. Data from 4 participants were discarded because they did not contribute at least 16 artefact-free trials to the response categories of interest due to poor performance (3 participants) and excessive EOG artefact (1 participant). Of the remaining 16 participants (mean age 22 years, range 18-30 years), 12 were female.

5.2.2 Materials

Stimuli were 360 low-frequency words presented on a black background. All were open-class and ranged between four and nine letters in length.

5.2.3 Design and Procedure

The 360 words were divided randomly into 12 lists of 30 words which were paired at random to form 6 list pairs. One of the word lists in each pair was assigned to be the study list. All 30 words from the study list were presented again at test along with all words from the unstudied list to form one study-test block. A complete task list comprised 6 study-test blocks. An equal number of study words were shown in red/green. All test words were shown in white. The order of word presentation within each list was randomised for each participant at study and at test. Four complete task lists were created by rotating the study/test status and colour of words at study.

All experimental procedures were as experiment one, with the exception that there was no manipulation of list length in the current study. The timings of all stimuli were as experiment one, with the exception that at test 90% of trials in each block began with an asterisk that was visible for 1500ms and the remaining 10% of test trials began with an asterisk that was visible for 500ms. The length of asterisk presentation was varied in this way to encourage the participant to remain alert in the pre-stimulus period, during which EEG was also acquired (results not reported in this thesis).

5.2.4 Electrophysiological Recording Procedure

As Experiment One.

5.3 Results

5.3.1 Behaviour

Table 5.1 (below) shows the probabilities of correct and incorrect 'old' judgments separated according to the colour in which the word was presented at study (red/green), as well as the overall probabilities collapsed across this factor. As can be seen from Table 5.1, the conditional probability of a correct source judgment is significantly higher for items which were presented in red at study ($t(15) = 3.30$, $p<.01$). To determine whether this behavioural difference is reflected in the electrophysiological data, the ERPs associated with correct source judgments (hit/hits) were separated according to the colour of word presentation at study. The average numbers of trials per participant contributing to each of these hit/hit response categories were: red: 30 (range 16-49) and green: 31 (16-45). These ERPs were contrasted across the same time-windows and from the same electrode locations as used throughout this thesis (see Section 3.6.2 for the analysis strategy). There were no reliable differences between the ERPs associated with hit/hits separated according to their colour of presentation at study in any time-window. This result is taken as justification for all subsequent behavioural and ERP analyses to be conducted on data collapsed across the factor of study colour.

	Red	**Green**	**Overall**
p(Hit)	0.70 (0.11)	0.70 (0.12)	0.70 (0.11)
p(FA)	-	-	0.19 (0.12)
p(Hit/Hit)	0.74 (0.10)	0.59 (0.14)	0.67 (0.08)

Table 5.1: Mean probabilities of identifying old words correctly (Hit) and incorrectly identifying new words (FA). Data are shown separately for items presented in red and green at study, as well as for all items collapsed across this factor. Also shown are the conditional probabilities of correct source judgments (hit/hit). Standard deviations are in brackets.

As Table 5.1 shows, overall old/new discrimination was reliably greater than chance ($t(15) = 12.90, p<.001$), as was the conditional probability of a correct source judgment ($t(15) = 8.62, p<.001$). Mean RTs for the initial old/new judgments are shown in Table 5.2 (below). There is no reliable difference in reaction times between correct and incorrect source judgments. Correct rejections of new items were made significantly faster than correct old judgments (collapsed across source accuracy) ($t(15) = -2.30, p<.05$).

	Red	Green	Overall
Hit	1052 (305)	1122 (310)	1079 (271)
CR	-	-	940 (187)
Hit/Hit	1003 (199)	1139 (333)	1052 (220)
Hit/Miss	1101 (412)	1105 (286)	1106 (320)

Table 5.2: Mean reaction times with standard deviations in brackets for correctly identifying old words (Hit), incorrectly identifying old words (FA) and for correct and incorrect source judgments (hit/hit; hit/miss). Data are shown separately for items presented in red and green at study, as well as for all items collapsed across this factor.

5.3.2 ERP Analyses

The ERPs associated with correct rejections, hit/hits and hit/misses were submitted to the same analyses used in experiment one. The mean numbers of epochs per participant per response category were: correct rejections: 92 (range 61-136), hit/hits: 54 (26-85), hit/misses: 27 (17-37). The ERPs were analysed for 3 post-stimulus time windows: 500-800, 800-1100 and 1100-1400ms, used in Experiment One and other source memory studies (Wilding & Rugg, 1996, 1997a). Electrode locations submitted to analyses were as experiment one. Initial global ANOVAs conducted for each time-window included the factors of response category (3 levels: hit/hit, hit/miss, correct rejection), the anterior/posterior dimension (2 levels), hemisphere (2 levels), and electrode site (5 levels).

Where these initial global ANOVAs revealed reliable effects involving response category, all possible paired comparisons were conducted. When the initial analyses revealed interactions including response category and the anterior/posterior dimension, these paired comparisons were conducted at anterior and posterior sites separately. Where necessary, analyses included the Greenhouse-Geisser correction for non-sphericity (Greenhouse & Geisser, 1959). Uncorrected degrees of freedom and F-values are shown in the text and results tables, accompanied by their respective epsilon values when appropriate.

5.3.2.1 Accuracy of colour judgments

The ERPs associated with the hit/hit and hit/miss response categories, as shown in Figure 5.1 (page 85), begin diverging from those associated with correct rejections at around 400ms across the scalp. Both of these old/new effects are largest at posterior sites from 500-800ms where hit/hit ERPs are more positive than hit/miss ERPs. From around 800ms onward, both hit/hit and hit/miss old/new effects are maximal at right-frontal sites and are of equivalent magnitude.

The initial global analyses revealed reliable response category by anterior/posterior dimension by site interactions in all time-windows (500-800ms: $F(8,120) = 5.30$, $p<.001$, $e = 0.58$; 800-1100ms: $F(8,120) = 5.17$, $p<.001$, $e = 0.58$; 1100-1400ms: $F(8,120) = 2.74$, $p<.05$, $e = 0.56$), as well as a category by anterior/posterior dimension by hemisphere interaction from 1100-1400ms ($F(2,30) = 12.43$, $p<.001$). The outcomes of the subsequent paired contrasts at anterior and posterior sites separately can be seen in Table 5.3 (page 88).

At anterior sites, the hit/hit old/new effect moves from a distribution across both left- and right-superior sites from 500-800ms (as highlighted by the category by site interaction) to a right-lateralised distribution, as reflected by the category by hemisphere interaction from 1100-1400ms. The hit/miss old/new effect has a left fronto-polar maximum from 500-800ms as reflected by the category by hemisphere by site interaction in this time-period. From 800-1400ms this effect is right-lateralised (category by hemisphere interactions) with a fronto-polar maximum from 800-1100ms as reflected by the category by site interaction in this time-period. In the contrasts of the hit/hit and hit/miss old/new effects, the category by site interactions from 500-1100ms reflect the fronto-polar maximum of the hit/miss old/new effect relative to the lateral maximum of the hit/hit old/new effect. ERPs associated with hit/hit and hit/miss responses do not differ in the latest (1100-1400ms) epoch.

At posterior sites, both the hit/hit and hit/miss old/new effects are maximal at mid-lateral sites from 500-1100ms, as shown by the reliable category by site interactions, which changes to a greater negativity for both hit categories relative to correct rejections at superior sites from 1100-1400ms, as highlighted by the category by site interaction in this time-window. There are no reliable differences between these two categories of hit ERPs from 500-1400ms.

5.3.2.2 Topographic Analyses

The above analyses of hit/hit and hit/miss old/new effects revealed reliable effects at anterior sites for both response categories from 500-800ms which, when contrasted, revealed a reliable category by site interaction. After rescaling, there were no reliable interactions between response category and any scalp location factor in this time-period highlighting the fact that the category by site interaction in this time-period reflects differences in the magnitudes of the effects, rather than their distributions across the scalp.

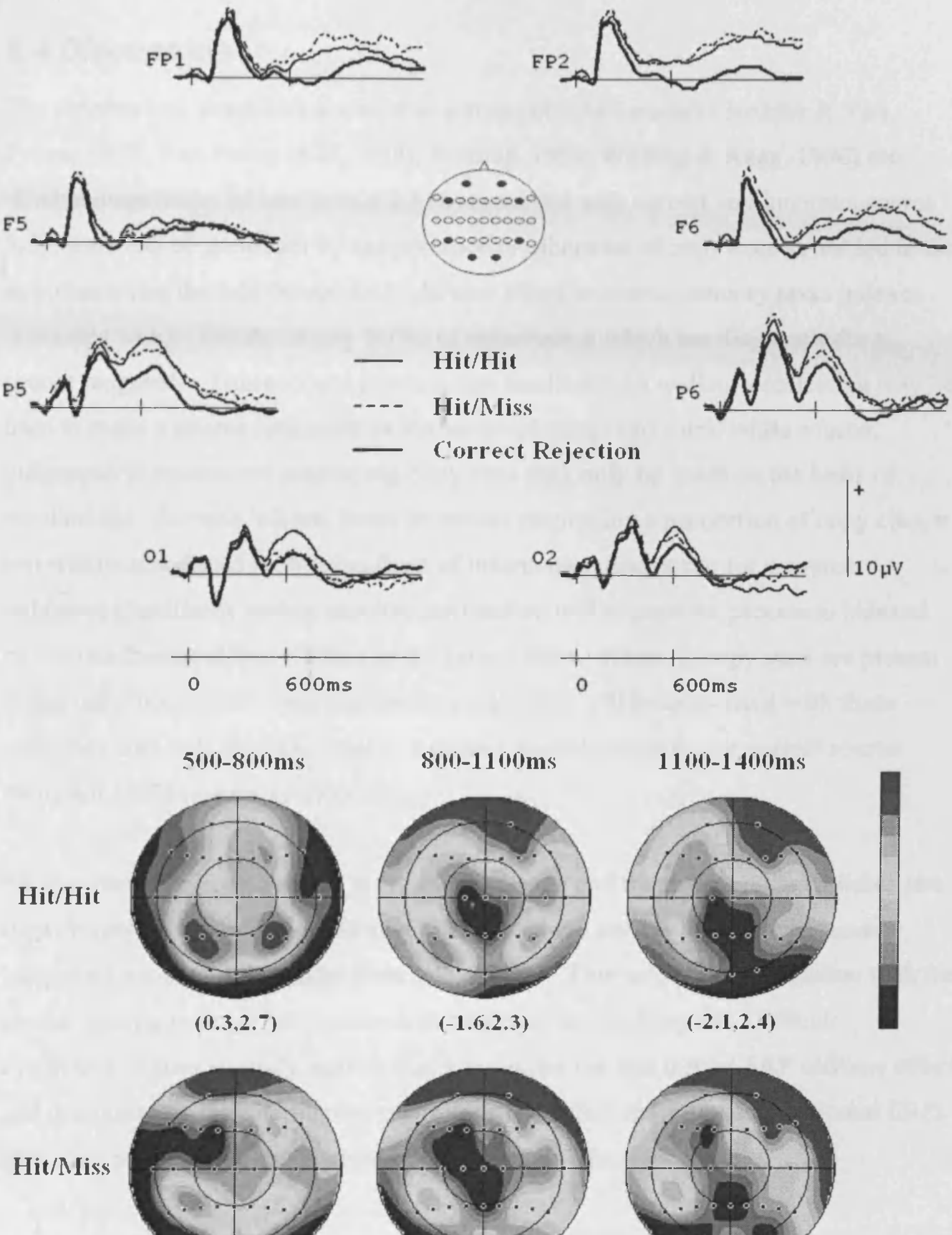


Figure 5.1: *Upper Panel*: Grand average ERPs associated with the hit/hit, hit/miss and correct rejection response categories. *Lower Panel*: Topographic maps showing the scalp distributions of the hit/hit and hit/miss old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows.

5.4 Discussion

The observation, described above, that across published studies (Senkfor & Van Petten, 1998; Van Petten et al., 2000; Wilding, 1999; Wilding & Rugg, 1996) the relative magnitudes of late frontal ERPs associated with correct and incorrect source judgments can be predicted by the presence or otherwise of copy cues at test led to the hypothesis that the late frontal ERP old/new effect in source memory tasks indexes processes which operate on any forms of information which are diagnostic for a source judgment. This account predicts that familiarity as well as recollection may be used to make a source judgment in studies employing copy cues, while source judgments in studies not employing copy cues may only be made on the basis of recollection. As such, all test items in studies employing a proportion of copy cues at test will be associated with some form of information diagnostic for a source judgment (familiarity and/or recollection) and so will engage the processes indexed by the late frontal old/new effect to the same extent. When no copy cues are present at test only those items associated with recollection will be associated with these processes, and will therefore lead to a greater frontal positivity for correct source judgment ERPs relative to incorrect.

No copy cues were used at test in the current study and the data revealed reliable late right-frontal (1100-1400ms) old/new effects for both correct and incorrect source judgments which did not differ from one another. This result, in combination with the similar finding in experiment one when collapsed across Easy and Difficult conditions, argues strongly against this account for the late frontal ERP old/new effect and demonstrates that the relative magnitudes of hit/hit and hit/miss late frontal ERPs cannot be predicted by the presence or absence of copy cues alone.

As observed in experiment one, earlier frontal ERPs differentiated items associated with hit/hit and hit/miss responses such that the hit/miss old/new effect was maximal at fronto-polar sites while the hit/hit effect was maximal at lateral electrode sites from 500-1100ms (see Figure 5.1, page 85). Unlike the results of experiment one, however, these differences did not remain reliable after rescaling. This result argues against the differential prefrontal processing of items attracting correct and incorrect source judgments as suggested by the results of experiment one. It was argued in the

Discussion section of experiment one that the earlier frontal differences in scalp distribution may come about as a result of the extent to which the left-parietal old/new effect projects to anterior electrodes. As in experiment one, while not reliably left-lateralised, both hit/hit and hit/miss response categories are associated with posterior mid-lateral old/new effects in the 500-800ms time-window. These parietal old/new effects are widely held to index recollection (Smith, 1993; Wilding et al., 1995; Wilding, 2000). While only tending towards significance (main effect of category at posterior sites from 500-800ms, $F(1,15) = 3.67$, $p=.08$), Figure 5.1 (page 85) shows that the ERPs associated with hit/hits are more positive at posterior sites from 500-800ms relative to those associated with hit/misses, as expected by a recollection account (Vilberg et al., 2006; Wilding, 2000; Wilding & Rugg, 1996). This relatively more positive hit/hit activity at posterior sites may have been recorded at some frontal electrode sites to a greater degree than the lower amplitude hit/miss activity, thereby resulting in the differences at frontal sites.

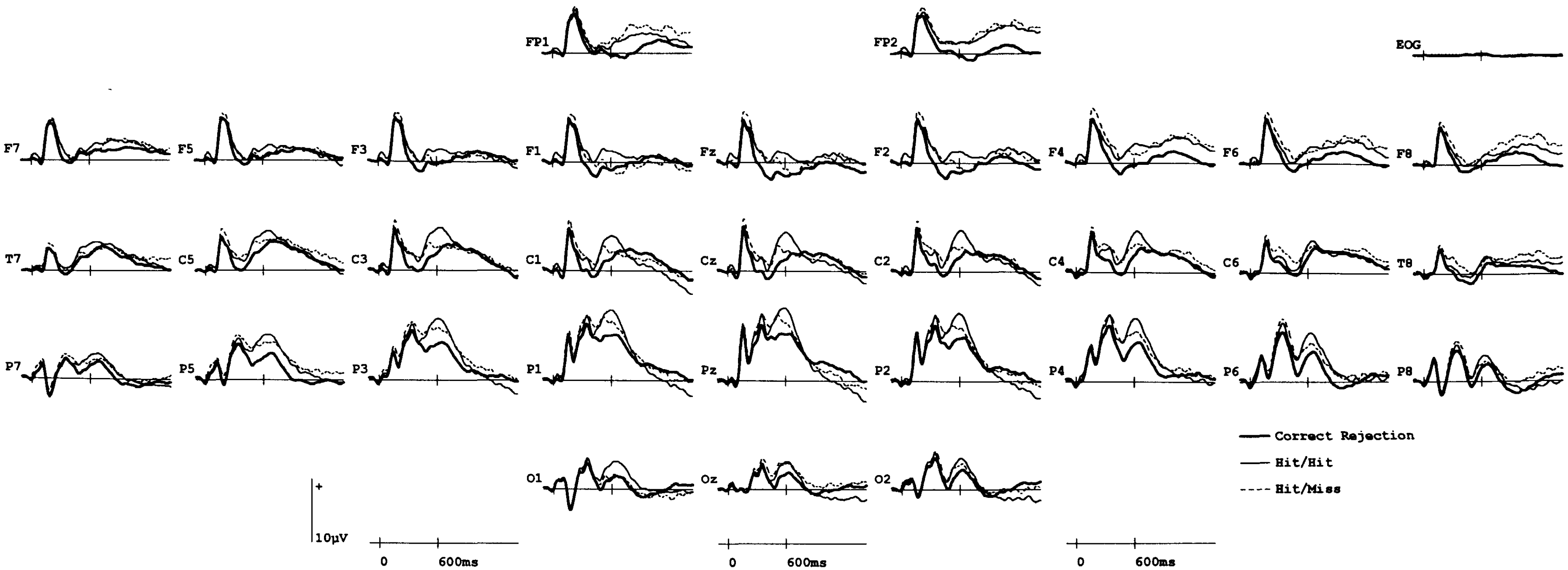
The combined results of Experiment One as well as Experiment Two, therefore, argue against the sole contributions of task difficulty, the format of test stimuli, and test responses on late frontal ERPs. While the equivalent correct/incorrect source late frontal effects from the current experiment and experiment one support a retrieval search account (Senkfor & Van Petten, 1998; Van Petten et al., 2000), the apparent lack of predictability for occasions when this pattern of ERPs will be observed encourages investigation of other factors which have been shown to affect late frontal ERPs in source memory tasks.

In order to begin reconciling the findings for ERPs associated with correct and incorrect source judgments across studies it will be necessary to consider other conditions under which frontal ERPs vary in source retrieval tasks and the ways in which this may contribute to this seemingly disparate pattern. Further investigation of late frontal source memory ERP old/new effects separated according to the confidence with which these judgments are made provides one such starting point. Experiment three was designed to investigate this. Participants were required to make old/new judgments followed by a high/low confidence source judgment. Further detail on the rationale for this approach is provided in the next chapter.

Table 5.3: F-values and significance levels for the paired comparisons between the mean amplitudes associated with the hit/hit, hit/miss and correct rejection (CR) response categories over the 500-800, 800-1100, and 1100-1400ms epochs at anterior and posterior sites separately. Only effects involving response category that were reliable in at least one contrast are shown. RC = response category, HM = hemisphere, ST = site. * = p<.05, ** = p<.01, *** = p<.001, ns. = non-significant (p>.05). Full dfs are shown on the left with epsilon values in brackets alongside each associated F-value.

	500-800ms		**800-1100ms**		**1100-1400ms**	
	Anterior	**Posterior**	**Anterior**	**Posterior**	**Anterior**	**Posterior**
Hit/Hit vs. CR						
RC (1,15)	10.71 **	12.31 **	ns.	ns.	ns.	ns.
RC x HM (1,15)	ns.	ns.	ns.	ns.	6.73 *	ns.
RC x ST (4,60)	4.45 * (0.59)	5.79 ** (0.61)	ns.	4.47 * (0.57)	ns.	3.26 * (0.61)
Hit/Miss vs. CR						
RC (1,15)	ns.	ns.	ns.	ns.	5.34 *	ns.
RC x HM (1,15)	ns.	ns.	4.65 *	ns.	12.59 **	ns.
RC x ST (4,60)	ns.	3.38 * (0.56)	5.41 ** (0.57)	3.75 * (0.56)	ns.	4.16 * (0.53)
RC x HM x ST (4,60)	3.27 * (0.74)	ns.	ns.	ns.	ns.	ns.
Hit/Hit vs. Hit/Miss						
RC x ST (4,60)	6.64 ** (0.67)	ns.	3.29 * (0.71)	ns.	ns.	ns.

Figure 5.2: Grand average ERPs associated with the correct rejection, hit/hit, and hit/miss response categories. Data are shown for all 35 electrodes sites from the recording montage.



Chapter Six : Experiment Three

6.1 Introduction

The combined results of Experiments One and Two provide evidence against the sole contributions of the difficulty of retrieval, the format of test stimuli and the test response requirements as factors which influence the magnitude of late frontal ERP old/new effects. As a result, in order to begin reconciling the ERP findings for correct and incorrect source judgments across studies (compare, for example, Senkfor & Van Petten, 1998; Wilding & Rugg, 1996) consideration of other conditions under which frontal ERPs have been shown to vary in source retrieval tasks is necessary and may speak to the ways in which these conditions may contribute to the seemingly disparate results described previously.

One starting point for this endeavour is the finding that late frontal ERPs varied as a function of the confidence with which source judgments were made (Vallesi and Shallice, 2006). Participants in that study were visually presented with words at test which they had previously studied in a male/female voice, to which they were required to make a high/low confidence judgment alongside a binary source judgment of the voice gender at study. Late frontal ERPs associated with low confidence responses were reliably more positive than those associated with high confidence responses from 1000ms post-stimulus onward. This result was interpreted on the basis of a similar finding in an fMRI recognition memory study by Henson and colleagues (2000). In that study, participants made old/new judgments to previously presented words and indicated their level of confidence (high/low) in this decision. Relative to correct high confidence responses, greater activity in a region of right dorso-lateral prefrontal cortex (DLPFC) was associated with correct low rather than high confidence responses, leading Henson and colleagues (2000) to propose that activity in this region of PFC reflected the engagement of post-retrieval monitoring processes.

This interpretation was made on the basis of a group of memory retrieval processes proposed by Burgess and Shallice (1996; see Chapter One) and considerations derived from signal-detection theory (e.g. Green & Swets, 1966; Murdock, 1965). According to the model of episodic memory retrieval put forward by Burgess and Shallice (1996), *editor processes* monitor the products of retrieval to determine whether the retrieved information is complete or relevant. If these monitoring processes determine that this information is incomplete or irrelevant, further retrieval cues are specified ('descriptor processes') before being subjected to further monitoring. Signal-detection models of memory (e.g. Banks, 1970; M. K. Johnson et al., 1993) propose that decisions are uncertain when an item's memory strength falls near to a response criterion. In these models, old and new items are represented as overlapping distributions of memory strength upon which the individual places a response criterion such that items with stronger memory strength relative to the criterion are judged to be old, and those with weaker memory strength are judged to be new. By these models, items falling nearest to criterion will attract relatively lower confidence responses than those further from criterion, and will be associated with greater post-retrieval monitoring in order to reach the correct memory judgment (Henson et al., 2000).

The right DLPFC has been further implicated in these monitoring processes through fMRI demonstrations of greater activation in tasks requiring the retrieval of contextual information relative to those requiring old/new discrimination (Henson, Shallice et al., 1999; Rugg et al., 2003), as well as greater activation for items attracting K responses in a Remember/Know paradigm (Henson, Rugg et al., 1999). Analogous to these findings, the late-frontal ERP old/new effect has been shown to be larger in tasks requiring the retrieval of contextual information relative to those requiring old/new recognition (Johansson et al., 2002; M. K. Johnson, Kounios et al., 1997; Senkfor & Van Petten, 1998; Van Petten et al., 2000), and on occasions when the quality of retrieved information is low (Rugg et al., 2000; Ullsperger et al., 2000), and has therefore been proposed to reflect the engagement of post-retrieval monitoring processes supported by right DLPFC (Friedman & Johnson, 2000; Rugg et al., 2002; Rugg & Wilding, 2000; Wilding & Rugg, 1996). The findings of Vallesi and Shallice described above (2006) can be considered to be consistent with this interpretation.

By contrast, Hayama, Johnson, & Rugg (2008) have proposed that the right-frontal ERP old/new effect, rather than reflecting the monitoring/evaluation of episodic retrieval, reflects more generic decision processes. In the first of two experiments, participants were cued trial-by-trial at study to make one of two semantic judgments on colour pictures of nameable objects. There were two test tasks. The semantic task required participants to respond on one key to new pictures, and to make a binary semantic judgment to old words (this semantic task was always different to the two performed at study). In the source task, new pictures were again responded to on one key, while a binary judgment of source (the semantic task performed at study) was made for old items. Late right-frontal old/new effects were evident in both tasks, and did not differ between the two. In the second experiment, participants completed the semantic task from the first experiment as well as a similar task which required all old items to be responded to on one key and a binary semantic judgment made for new words instead, thus manipulating the class of items (old/new) for which a second semantic judgment was required. Late right-frontal ERPs in this case were more positive for whichever class of item demanded the semantic judgment.

Hayama and colleagues (2008) considered these findings in the context of two accounts of the right-frontal ERP old/new effect. The first of these was the post-retrieval monitoring account discussed previously. This account can accommodate these results if these processes are also thought to operate on the contents of semantic retrieval. The second account was generated on the basis of a proposal driven by fMRI studies of the functional role of the dorso-lateral prefrontal cortex (DLPFC). Dobbins and Han (2006) presented participants with two words simultaneously at test. In one condition, participants were required to judge whether the old/new status of each of the two items was the same or different. The other condition required a forced-choice 'Which old?' or 'Which new?' judgment. There was greater activity in right DLPFC in the same/different task than in the forced-choice task. Dobbins and Han (2006; Han, Huettel, & Dobbins, 2009) argued that a judgment can only be made in the same/different task when a decision on the old/new status of *both* items has been made, while a judgment in the forced-choice task can be made on the basis of a decision on the old/new status of only one of the items. The authors therefore proposed that activity in the DLPFC is sensitive to the number of internal criterial decisions that need to be made to reach a judgment. The more positive late right-frontal ERPs for whichever class of item required a further semantic decision reported by Hayama and colleagues (2008) certainly fit with this account.

This decision account for the late-frontal ERP old/new effect would seem to be ruled out, however, by the findings reported by Woodruff and colleagues (2006), who acquired ERPs during the test-phase of a modified Remember/Know paradigm. For items not assigned a Remember response, participants rated their confidence (high/low) in the Know response (for a related fMRI study, see Yonelinas et al., 2005). For Know responses, the right-frontal old/new effect was reliably larger for those attracting the higher confidence rating. While this can be interpreted as a challenge to a decision number account of the right-frontal old/new effect, Hayama and colleagues (2008) observed that these data points can be accommodated by such an account if it is assumed that only high confidence Know responses include an additional decision over whether an item might be given a Remember response. The results reported by Vallesi & Shallice (2006), discussed above, also appear to challenge the decision account as frontal ERPs were shown to vary with the confidence with which source judgments are made. However, there were no new items at test in that study (see also Cruse & Wilding, In Press), thereby precluding any analyses of the distributions or magnitudes of old/new effects separated according to confidence.

The current experiment was designed as a test of both the decision and monitoring accounts of late frontal ERP old/new effects. To this end, participants completed a source memory task as in experiment two, with the addition of a high/low confidence judgment alongside the source judgment at test. In so far as the numbers of internal criterial decisions are equated for both levels of confidence, differences in right-frontal ERP old/new effects separated according to confidence will provide evidence against a decision account for this effect. A monitoring account however, in the form of Henson and colleagues (2000), would predict more positive late frontal ERPs associated with low confidence responses relative to high confidence responses.

6.2 Methods

6.2.1 Participants

Thirty-one right-handed native English speakers participated (for exclusion criteria see General Methods, Section 3.2). Data from 3 participants were discarded because they did not contribute at least 16 artefact-free trials to response categories of interest (see below) due to excessive EOG artefact. Data from a further 7 participants were discarded because they were unable to make above chance judgments about study colour (p>.55). Of the remaining 21 participants (mean age 21 years, range 18-27), 17 were female.

6.2.2 Materials

These were 360 low frequency words (MRC psycholinguistic database: frequency 1-9/million, Coltheart, 1981) presented on a black background. All were open-class and ranged between four and nine letters in length.

6.2.3 Design and Procedure

Study and test lists were formed in the same manner as in Experiment two, resulting in six study-test blocks (30 words at study; 30 old + 30 new words at test). Four complete task lists were created by rotating the study/test status and colour of words at study. Unlike Experiment two, half the words at study were presented in pink and the other half in yellow. Source accuracy in Experiment two was significantly higher for words previously presented in red relative to those previously presented in green. Pink and yellow were chosen for this study as other work conducted within the EEG research group in the School of Psychology, Cardiff University, indicated no memory advantage for either of these colours.

All procedures were as Experiment Two with the exception that, following the initial old/new judgment at test, participants were asked to make a second response on one of four keys: *Confident-Pink, Think-Pink, Think-Yellow,* *Confident-Yellow*. Confident responses were always made with middle fingers, and Think responses with index fingers. Pink/Yellow colour responses were always made with the same hand at study and at test. Participants were instructed to respond *Confident* if they were confident that they could remember the colour of the word at study, whilst they were to respond *Think* when they were less confident and only had 'a feeling' for the colour the word was presented in at study. The timings of and intervals between all stimuli are as Experiment Two.

6.2.4 Electrophysiological recording procedure

As Experiments One and Two.

6.3 Results

6.3.1 Behaviour

There were no differences at the group level in response accuracies for words presented in either pink or yellow at study, in keeping with previous findings in similar studies where colour manipulations have been employed (Cycowicz et al., 2001; Wilding et al., 2005). In light of this, the initial behavioural analyses and all ERP data reported are collapsed across study colour. Table 6.1 (below) shows the probabilities of correct/incorrect judgments to old words, as well as the conditional probabilities of correct/incorrect colour judgments separated according to confidence for all 21 participants as well as for the subset of 16 participants contributing to the confidence analyses (described below). The following behavioural analyses are reported for all 21 participants only. However, as can be seen from Table 6.1, behavioural performance for the subset (n=16) was highly similar to that of the 21 participants.

	All participants (n=21)	**Confidence subset (n=16)**
p(Hit)	0.79 (0.09)	0.80 (0.08)
p(FA)	0.17 (0.15)	0.20 (0.17)
p(Hit/hit: high)	0.40 (0.16)	0.39 (0.11)
p(Hit/hit: low)	0.29 (0.07)	0.30 (0.04)
p(Hit/miss: high)	0.09 (0.06)	0.09 (0.06)
p(Hit/miss: low)	0.22 (0.07)	0.22 (0.06)

Table 6.1: Mean probabilities of identifying old words correctly (Hit) and incorrectly identifying new words (FA) for all 21 participants as well as for the subset of 16 participants included in the comparisons of high and low confidence correct source judgments. Also shown are the conditional probabilities of correct (hit/hit) and incorrect (hit/miss) source judgments, split according to the confidence judgments (high/low) that they attracted. Standard deviations are in brackets.

	All participants (n=21)	Confidence subset (n=16)
Hit	1155 (354)	1105 (297)
CR	995 (162)	983 (135)
Hit/hit: high	1059 (222)	1031 (201)
Hit/hit: low	1190 (426)	1135 (370)
Hit/miss: high	1126 (372)	1050 (250)
Hit/miss: low	1245 (493)	1202 (474)

Table 6.2: Mean reaction times for all 21 participants as well as for the subset of 16 participants included in the comparisons of high and low confidence correct source judgments, for correctly (Hit) and incorrectly identifying old words (FA) and for correct (hit/hit) and incorrect (hit/miss) source judgments, split according to the confidence judgments (high/low) that they attracted). Standard deviations are in brackets.

Old/new discrimination was reliably above chance ($t(20) = 16.42$, $p<.001$), as was the conditional probability of a correct source judgment collapsed across response confidence (hereafter hit/hit responses: $t(20) = 7.57$, $p<.001$). A two-way ANOVA conducted on the probability of a hit response separated according to subsequent source accuracy and confidence with factors of accuracy (hit/hit, hit/miss) and confidence (high/low) revealed a reliable interaction between the two ($F(1,20) = 31.64$, $p<.001$). Follow-up t-tests revealed that this interaction reflects the greater probability of a high confidence response for hit/hits than a low confidence response ($t(20) = 2.40$, $p<.05$), whereas for incorrect source judgments (hit/miss responses) the reverse is true ($t(20) = -8.77$, $p<.001$).

Mean reaction times for the initial old/new judgments and for correct initial judgments separated according to source accuracy and response confidence are shown in Table 6.2 (above). Correct rejections were made more quickly than correct responses to old words (collapsed across source accuracy: $t(20) = 2.71$,

$p<.05$). A two-way ANOVA on the RTs for words judged correctly to be old with factors of source accuracy and confidence revealed main effects only: hit/hit responses were faster than hit/miss responses ($F(1,20) = 5.52$, $p<.05$), and high confidence responses were faster than low confidence responses ($F(1,20) = 4.43$, $p<.05$).

6.3.2 ERP Analyses

Two sets of ERP analyses were conducted. The first (n=21) was between the ERPs associated with correct rejections and the hit/hit as well as the hit/miss response categories, in keeping with the analysis strategies in previous source memory studies and experiments one and two in this thesis. The mean numbers of epochs per participant per response category were: correct rejections: 76 (range 44-123), hit/hit: 54 (34-86), hit/miss: 24 (16-46). A second set of ERP analyses was conducted on data from the 16 participants who contributed sufficient trials to the correct rejection response category, as well as to the hit/hit response category split according to whether they were associated with high or low confidence judgments. The mean numbers of epochs per participant per response category were: correct rejections: 65 (44-123), hit/hit (high confidence): 30 (18-51), hit/hit (low confidence): 20 (16-41). As described above, the pattern of behavioural data for this sub-group mirrors closely that shown for all 21 participants (see Tables 6.1 and 6.2, pages 97 & 98).

As in the previous two experiments, the ERPs were analysed for 3 post-stimulus time windows: 500-800, 800-1100 and 1100-1400ms. For each epoch, the data from twenty electrode locations were grouped to form four clusters at anterior-right (FP2, F8, F6, F4, F2), anterior-left (FP1, F7, F5, F3, F1), posterior-right (O2, T6, P6, P4, P2), and posterior-left (O1, T5, P5, P3, P1) locations. For each time window, initial global ANOVAs were conducted including the factors of response category, the anterior/posterior dimension (2 levels), hemisphere (2 levels), and electrode site (5 levels).

Where these ANOVAs revealed reliable effects involving response category, they were followed up by all possible paired comparisons, which were conducted separately at anterior and posterior sites when the initial analyses revealed interactions including response category and the anterior/posterior dimension. Uncorrected degrees of freedom and F-values are shown in the text and results tables, accompanied by their respective epsilon values when appropriate.

6.3.2.1 Accuracy of colour judgments

Figure 6.1 (overleaf) shows that the ERPs associated with the hit/hit and hit/miss response categories begin diverging from those associated with correct rejections after 400ms. These positive-going old/new effects are larger for the hit/hit than the hit/miss category at left-parietal locations from 500-1100ms. Positive-going frontal ERP old/new effects are broadly comparable for the two classes of hits throughout the recording epoch.

In the three initial global analyses, mean amplitude measures for ERPs associated with correct rejections and the hit/hit as well as the hit/miss response categories were contrasted. These revealed reliable interactions between response category, the anterior/posterior dimension, and hemisphere in all epochs (500-800ms: $F(2,40) = 3.96$, $p<.05$, $e = 0.87$; 800-1100ms: $F(2,40) = 9.72$, $p<.001$, $e = 0.97$; 1100-1400ms: $F(2,40) = 12.17$, $p<.001$, $e = 0.80$). Also common to each epoch were response category by anterior/posterior dimension by site interactions (500-800ms: $F(8,160) = 4.82$, $p<.001$, $e = 0.54$; 800-1100ms: $F(8,160) = 5.98$, $p<.001$, $e = 0.52$; 1100-1400ms: $F(8,160) = 4.86$, $p<.01$, $e = 0.46$). The outcomes of the subsequent separate paired contrasts at anterior and posterior sites can be seen in Table 6.3 (page 116), which shows that there are reliable old/new effects for the hit/hit and hit/miss response categories in all time windows.

The results at anterior locations are described first. For the hit/hit old/new effects, the category by hemisphere by site interactions covering the 500-1100ms period, and the category by hemisphere interaction in the 1100-1400ms epoch, reflect the transition over time of positive-going old/new effects with a left fronto-polar maximum to those with a broadly distributed right-lateralised

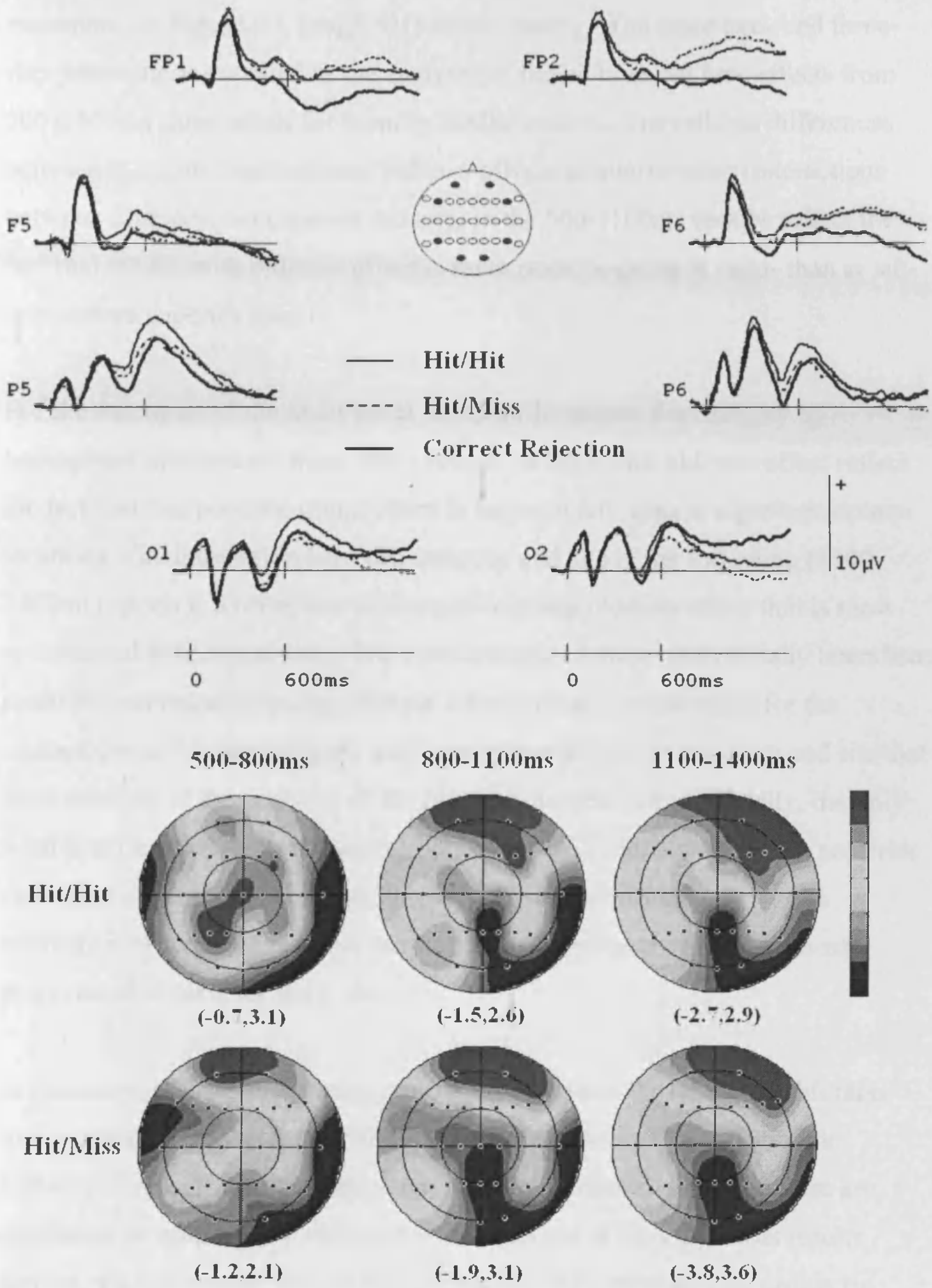


Figure 6.1: *Upper Panel*: Grand average ERPs associated with the hit/hit, hit/miss and correct rejection response categories. *Lower Panel*: Topographic maps showing the scalp distributions of the hit/hit and hit/miss old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows.

maximum, as Figure 6.1 (page 101) shows clearly. The same two- and three-way interactions revealed in the analyses of the hit/miss old/new effects from 500-1400ms came about for broadly similar reasons. The reliable differences between the hit/hit and hit/miss old/new effects at anterior sites (interactions between category, hemisphere and site) in the 500-1100ms epochs reflect the fact that the hit/miss old/new effect is more positive-going at right- than at left-hemisphere superior sites.

For the outcomes of the analyses at posterior locations, the category by hemisphere interactions from 500-1100ms for the hit/hit old/new effect reflect the fact that this positive-going effect is larger at left- than at right-hemisphere locations. The interaction between category and site in the following (1100-1400ms) epoch is a reflection of a negative-going old/new effect that is most pronounced at occipital sites. The contributions of these differentially lateralised positive- and negative-going old/new effects are also responsible for the interactions involving category and hemisphere as well as category and site that were revealed in the analyses of the hit/miss old/new effects. Finally, the only reliable differences between the hit/hit and hit/miss old/new effects at posterior sites were obtained in the 500-800ms epoch, where the category by site interaction reflects the fact that the larger hit/hit old/new effects are most pronounced at superior scalp sites.

In summary, reliable differences were found between the hit/hit and hit/miss frontal old/new effects from 500-1100ms. The outcomes of topographic analyses of rescaled data conducted in order to determine whether these are qualitative or quantitative differences are reported at the end of this results section. First however, the analyses of hit/hit ERPs separated according to confidence (high/low) are reported.

6.3.2.2 High and Low Confidence Hit/Hit Old/New effects

Figure 6.2 (page 104) shows that the ERPs associated with the high confidence hit/hit response category begin diverging from those associated with correct rejections across the majority of scalp locations after around 400ms. The positive-going old/new effects move from a left-posterior to a right-frontal maximum over the course of the recording epoch. There is also a negative-going posteriorly distributed old/new effect that onsets around 800ms post-stimulus. For the low confidence hit/hit category, a greater relative late posterior negativity in comparison to correct rejections is also evident, as is a right-lateralised frontal positivity. This frontal effect is smaller than that which is associated with the high confidence response category.

The analysis strategy for these ERPs was the same as for the analysis of the hit/hit and the hit/miss ERP old/new effects. The three initial global analyses on mean amplitude measures for ERPs associated with correct rejections as well as the high and low confidence hit/hit response categories revealed reliable interactions between category, the anterior/posterior dimension and hemisphere in all epochs (500-800ms: $F(2,30) = 6.03$, $p<.05$, $e = 0.71$; 800-1100ms: $F(2,30) = 12.41$, $p<.01$, $e = 0.74$; 1100-1400ms: $F(2,30) = 12.47$, $p<.01$, $e = 0.77$). Also common were interactions between category, the anterior/posterior dimension, and site (500-800ms: $F(8,120) = 2.62$, $p<.05$, $e = 0.53$; 800-1100ms: $F(8,120) = 3.21$, $p<.05$, $e = 0.47$; 1100-1400ms: $F(8,120) = 2.93$, $p<.05$, $e = 0.57$). These outcomes were followed up within each epoch by all possible paired contrasts at anterior and posterior sites separately, the results of which can be seen in Table 6.4 (page 117).

At anterior locations, there were reliable positive-going high confidence hit/hit old/new effects in each epoch. The main effects were moderated by an interaction with site in the 500-800ms epoch only, reflecting the superior maximum of these frontal effects. Reliable old/new effects for the low confidence hit/hit category were evident from 800-1400ms, with the category by hemisphere interactions reflecting the right-lateralisation of the old/new effects that can be seen in Figure 6.2 (overleaf). The high confidence hit/hit old/new effects were reliably more positive-going than the low confidence effects in each epoch, with the category by site interaction from 500-800ms reflecting the superior maximum of this effect. The category by hemisphere interaction in the 800-1100ms epoch reflects the fact that the greater relative positivity for the high confidence hit/hit ERPs is most pronounced at left frontal sites (see Figure 6.2, overleaf).

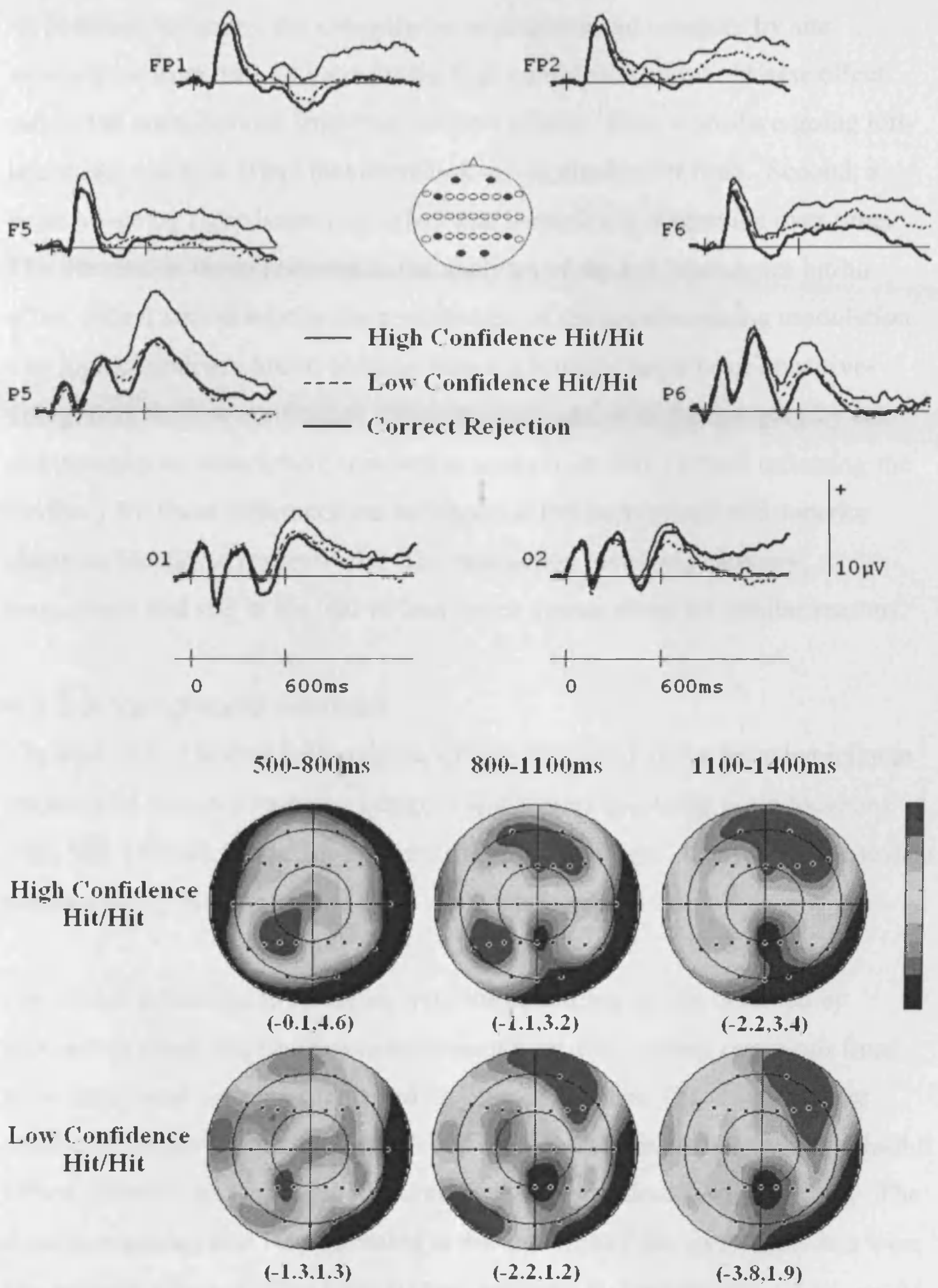


Figure 6.2: *Upper Panel*: Grand average ERPs associated with the high confidence hit/hit, low confidence hit/hit, and correct rejection response categories. *Lower Panel*: Topographic maps showing the scalp distributions of the high confidence hit/hit and low confidence hit/hit old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows.

At posterior locations, the category by hemisphere and category by site interactions from 500-1400ms for the high confidence hit/hit old/new effect reflect the contributions from two old/new effects. First, a positive-going left-lateralised old/new effect that decreases in magnitude over time. Second, a negative-going right-lateralised effect that increases in magnitude over time. The interaction terms revealed in the analyses of the low confidence hit/hit effect reflect almost wholly the contribution of the negative-going modulation. The high confidence hit/hit old/new effect is reliably larger (more positive-going) than the low confidence effect in all epochs, with the category by site and category by hemisphere interaction terms from 500-1100ms reflecting the tendency for these differences to be largest at left-hemisphere and superior electrode locations, respectively. The interaction involving category, hemisphere and site in the 500-800ms epoch comes about for similar reasons.

6.3.2.3 Topographic Analyses

The analyses of frontal ERP old/new effects described above revealed reliable interactions between response category and factors involving scalp locations from 500-1100ms for the hit/hit versus hit/miss contrast. Analyses of these data rescaled using the max-min method were conducted.

The values submitted to rescaling were the difference scores obtained by subtracting mean amplitude measures associated with correct rejections from those associated with the hit/hit and hit/miss categories. The analyses were conducted separately for each epoch and included the factors of category (hit/hit versus hit/miss) and the scalp location dimensions as described previously. The three interactions that were revealed in the analyses of the unrescaled data were also reliable after rescaling (500-800ms: category by site: $F(4,80) = 4.91$, $p<.01$, $e = 0.60$; category by hemisphere by site: $F(4,80) = 2.70$, $p<.05$, $e = 0.83$; 800-1100ms: category by hemisphere by site: $F(4,80) = 3.46$, $p<.05$, $e = 0.86$). These interactions reflect the somewhat more focal left-frontal distribution of the hit/hit than the hit/miss old/new effect.

For the rescaled analyses of data separated according to confidence, points from the 800-1100ms epoch alone were submitted to analysis, because only in this epoch were there reliable old/new effects for both the high and low confidence hit/hit response categories. The reliable interaction between category and hemisphere survived rescaling ($F(1,15) = 10.87$, $p<.01$), reflecting the fact that the low confidence hit/hit frontal old/new effect is right-lateralised to a greater degree than is the high confidence effect.

In summary, from 1100-1400ms the magnitude of the late right-frontal old/new effect is reliably larger for high confidence than for low confidence responses. The scalp distributions of the hit/hit and hit/miss frontal old/new effects differ from 500-1100ms, as do the hit/hit effects separated according to high/low confidence from 800-1100ms. These results are discussed in detail in the following sections.

6.4 Discussion

The current experiment was designed to test two functional accounts which have been proposed for the right-frontal ERP old/new effect – the decision account (Hayama et al., 2008; Hayama & Rugg, 2009), and the post-retrieval monitoring account (Friedman & Johnson, 2000; Rugg & Wilding, 2000; Rugg et al., 2002; Wilding & Rugg, 1996). Data relevant to each account will be discussed separately, beginning with the decision account.

6.4.1 A Decision Account

This account proposes that the right-frontal ERP old/new effect is sensitive to the number of internal criterial decisions required to make a judgment (Hayama et al., 2008). In the current experiment, participants made an old/new judgment to visually presented words followed by a four-way judgment of the colour of the word at study, accompanied by an indication of their confidence (high/low) in this decision. ERPs were analysed for correct and incorrect source judgments collapsed across confidence, as well as for correct source judgments separated according to confidence. Late frontal ERPs associated with hit/hits and hit/misses did not differ reliably, as in experiments one and two, which does not itself challenge a decision interpretation. However, late frontal ERPs associated with high confidence hit/hits were reliably more positive than those associated with low confidence hit/hits. Since the number of internal criterial decisions required to make a judgment are equated for each of these response categories, this result argues strongly against a solely decision-based account for this effect.

6.4.2 A Post-Retrieval Monitoring Account

Common to several accounts of episodic memory retrieval is the view that post-retrieval processes can be engaged in order to monitor and evaluate the contents of retrieval in service of specific retrieval goals (Burgess & Shallice, 1996; M. K. Johnson, 1992; Mecklinger, 2000; Norman & Bobrow, 1979). These processes have been considered in attempts to define the functional significance of the right-frontal ERP old/new effect (Friedman & Johnson, 2000; Rugg et al., 2002; Rugg & Wilding, 2000; Wilding & Rugg, 1996).

Henson and colleagues (2000) argued that items attracting low confidence responses will be those for which memory strength is nearest to criterion, and will therefore be associated with greater monitoring. If a monitoring account for the right-frontal effect is correct, however, the current finding of a reliably larger old/new effect for high confidence hit/hits relative to low confidence hit/hits indicates that items attracting high confidence responses were subjected, on average, to greater levels of monitoring. This finding replicates a result reported by Woodruff and colleagues (2006) who also acknowledged that reconciling this finding with a monitoring account is challenging. One possible way of addressing this is to consider the placement of the criterion and the shape of the underlying distribution. If monitoring requirements increase as distance from a task-relevant decision criterion decreases, then in averaged ERPs the effects will be larger for conditions in which the average distance from criterion across the items contributing to the average is smaller. For example, for a roughly Gaussian distribution, placement of a criterion to the far right will ensure that the average distance to criterion for items falling to the right of criterion will be smaller than that for items falling to the left (see Figure 6.3, overleaf). The shape of the distribution will also be important, and the form that this takes for recollection remains unclear (for relevant perspectives, see Rotello et al., 2006; Yonelinas, 2002). The principle, however, is that, across samples of items that fall either side of a criterion, monitoring processes may on the average be engaged to greater or lesser degrees, or indeed to the same degree, for items attracting high or low confidence judgments.

Evidently, this account predicts all possible outcomes of the relative magnitudes of right-frontal old/new effects in the current data and is therefore untestable with the current design. However the account is testable in other circumstances, for example, when encoding conditions are kept constant and the placement of criterion at test is manipulated via test instructions. In so far as the shape of an underlying distribution will be constant in this design, changes in the magnitude of the right-frontal old/new effect for high and for low confidence responses with changes in criterion placement would be interpretable in terms of the account given above. To date, published ERP studies in which changes in criterion placement have been encouraged by manipulating test instructions have employed old/new recognition memory judgments only, and included no focused analyses of right-frontal old/new effects (Azimian-Faridani & Wilding, 2006; Curran, DeBuse, & Leynes, 2007).

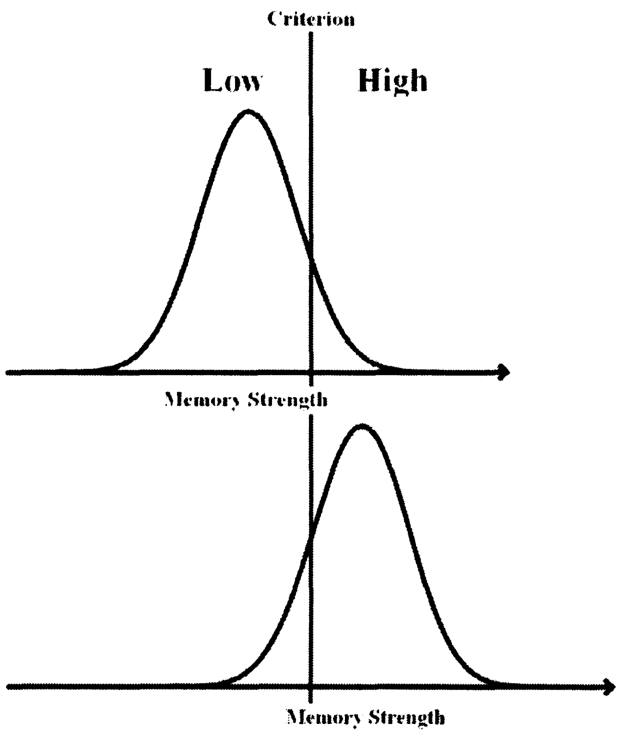


Figure 6.3: Gaussian distributions of memory strength associated with old items. The placement of the high/low confidence response criterion in the *upper panel* results in the average distance to criterion for low confidence responses (left of criterion) being greater than that for high confidence responses (right of criterion). The placement of the criterion further to the left for the distribution in the *lower panel* results in a greater average distance to criterion for high confidence responses. If the amount of monitoring engaged decreases with increasing distance from a task-relevant response criterion, across averaged ERP categories the above distributions illustrate circumstances where *on average* either high or low confidence judgments may be associated with greater levels of monitoring.

In summary then, at first glance the current finding for a reliably larger right-frontal old/new effect for high confidence correct source judgments relative to low confidence is not consistent with a distance-to-criterion post-retrieval monitoring account as envisioned by Henson and colleagues (2000). However, the argument here is that across averaged ERP measures the average distance to criterion may be greater for either classes of response since the location of the criterion and shape of the underlying distribution are not known and may therefore result in a greater average distance from criterion for either high or low confidence correct source judgments.

6.4.3 Dissociable Late Frontal ERP Old/New Effects

Evidence for qualitatively distinct frontal old/new effects was found in the current experiment from 800-1100ms post-stimulus. The scalp maps in Figures 6.1 and 6.2 (pages 101 & 104) show that frontal old/new effects generally become progressively more right-lateralised over time, but the degree to which they do so is greater for the hit/miss than the hit/hit category, and greater for the low confidence than for the high confidence hit/hit category.

One possibility is that these differences are simply a result of the propagation over anterior scalp of the left-parietal old/new effect, which is larger for hit/hit than for hit/miss responses, and markedly larger for high than for low confidence hit/hit responses. The lesser degrees of right-lateralisation for the hit/hit and high confidence hit/hit response categories might therefore reflect the greater extent to which activity associated with the parietal ERP old/new effect projects to left-frontal sites for those categories. The pattern of mean amplitude measures plotted in Figure 6.4 (overleaf) argues against this account, however. The figure shows changes over time in the mean amplitudes of the high confidence hit/hit old/new effects at left- and right-frontal sites, as well as at left-parietal sites. As the figure shows, the magnitudes of the old/new effects at left- and right-frontal sites remains constant across time-periods, while the magnitude of the left-parietal effect reduces. This pattern of activity argues strongly that two electrophysiologically dissociable old/new effects were observed in this study: low confidence correct source judgments elicited a right-frontal old/new effect only, whilst high confidence correct source judgments also elicited a left-lateralised effect with an earlier onset. It seems reasonable to assume that this distinction also explains the evidence for qualitative differences between the hit/hit and hit/miss response categories that was revealed in the analyses of scalp distributions.

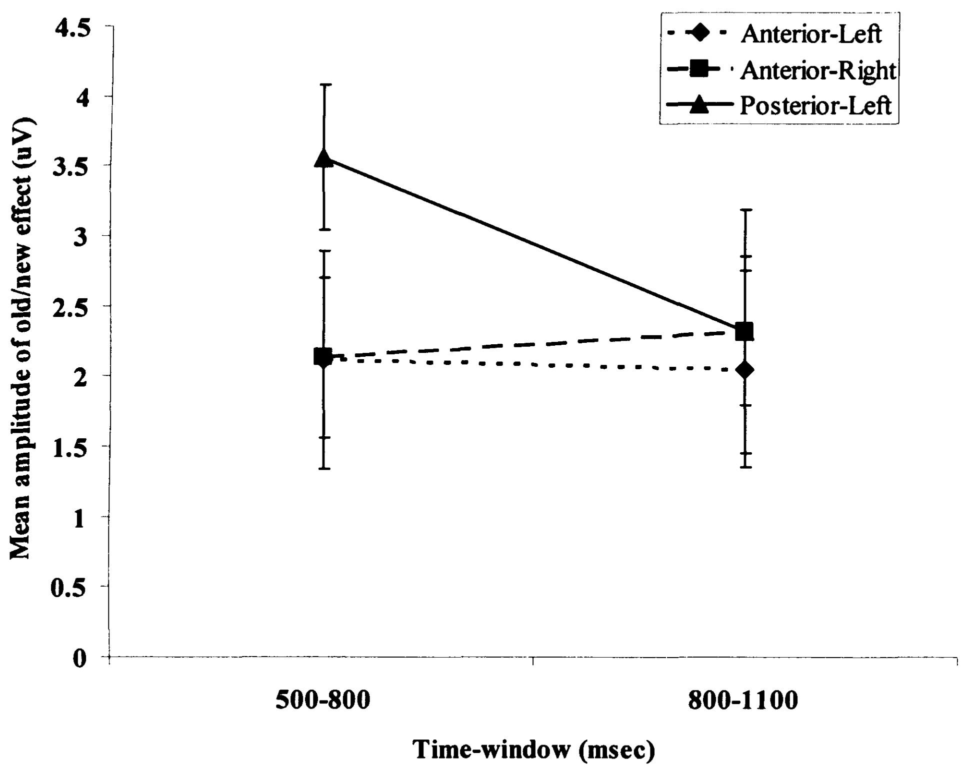


Figure 6.4: Mean amplitudes of the high confidence hit/hit old/new effect averaged across anterior-left (FP1, F7, F5, F3, F1), anterior-right (FP2, F8, F6, F4, F2), and posterior-left (O1, P7, P5, P3, P1) electrode clusters in the 500-800ms and 800-1100ms time-windows. Error bars show ±1 standard error.

Given that the left-frontal old/new effect was extracted via a contrast between correct source judgments separated according to confidence, one possibility is that the effect reflects processes related to recollection of task-relevant content. It is reasonable to assume that averaged ERPs for items attracting high confidence correct source judgments will be associated with recollection to a greater degree than will items attracting low confidence judgments. The same argument can also be applied to the hit/hit versus hit/miss comparison.

In Experiment One, the difficulty of retrieval was manipulated within-participants. Visual inspection of the scalp maps in Figures 4.1 and 4.2 (pages 65 & 66) highlights the somewhat less right-lateralised late frontal hit/hit old/new effect in the easier condition relative to that in the more difficult condition, although this difference was not reliable. On the basis of the distributional differences obtained in the current experiment, exploratory analyses were conducted on data from the Easy and Difficult conditions in Experiment One separately, the outcomes of which are reported in Appendix A (these contrasts were not performed in the initial analyses reported in Chapter Four due to the lack of reliable interaction terms involving the factor of difficulty, and are therefore exploratory only). As these contrasts reveal, bilaterally distributed frontal effects were evident for correct source judgments in the easier condition, while in the more difficult condition correct source judgments were associated with a reliably right-lateralised frontal old/new effect. While the differences between these distributions were not reliable in that experiment, the current evidence for a left-frontal effect associated with high confidence correct source judgments can be considered to be consistent with the bilateral distribution in Experiment One as source judgments are likely to have been made with higher confidence in the Easy condition relative to those made in the Difficult condition.

As discussed earlier, bilateral late frontal old/new effects for correct source judgments have been reported in tasks in which old/new response accuracy is almost at ceiling (hit-rates ~95%; Kuo & Van Petten, 2006; Senkfor & Van Petten, 1998; Van Petten et al., 2000), while those studies for which late-frontal effects are right-lateralised employed tasks eliciting lower levels of accuracy (hit-rates ~65%; Experiment Two; Wilding, 1999; Wilding & Rugg, 1996). It is reasonable to assume that conditions under which 'old' decisions are made with very high levels of accuracy are more likely to be associated with high confidence retrieval of contextual information than those for which 'old' items are recognized with less accuracy. Hence, differences in response accuracy may well be linked to the circumstances under which variations in the degree of lateralisation of frontal ERP old/new effects are obtained. A functionally similar effect was described by Woodruff and colleagues (2006), discussed above. In their experiment, items assigned a Remember response diverged from those assigned high confidence Know responses at frontal and fronto-polar scalp sites in the same time period as the left-lateralised effect described here (in particular, see Figure 9, p 132 of Woodruff et al., 2006).

The current results therefore provide evidence that at least two neurally and functionally dissociable late frontal old/new effects can be observed in ERP studies of episodic memory. This finding may also go some way toward explaining the disparities across published studies of the behaviour of frontal effects, in that not entirely the same frontal effects may have been elicited in each case. Informal inspection of variations in the locations of the scalp maxima and degrees of laterality of late frontal old/new effects across studies provide general support for this view (compare, for example, Johansson & Mecklinger, 2003; Senkfor & Van Petten, 1998; Tendolkar & Rugg, 1998; Trott et al., 1997; Trott et al., 1999).

The left-lateralisation of one frontal effect in the current study implicates regions of the left PFC as generators of this activity. Studies employing fMRI have tied activity in left PFC to processes involved in recollecting specific attributes of an item (Dobbins et al., 2004; Ranganath, 2004). For example, left ventro-medial PFC has been associated with the selection of task-relevant information from many competing and irrelevant pieces of information (Buckner, 2003; Gold & Buckner, 2002; Lundstrom, Ingvar, & Petersson, 2005; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). Items with high memory strength, like those attracting high confidence correct source responses in the current study, are likely to be associated with multiple pieces of contextual detail of the event from which the relevant detail, in this case word colour, would need to be selected. These selection processes would therefore be engaged to a greater extent for items subsequently attracting a high confidence rather than a low confidence response, as these items are less likely to be associated with such rich contextual details. While this interpretation fits with the current data, there are however other models of the roles of left PFC in retrieval which do not fit with a left PFC generator of this old/new effect (e.g. Cabeza, Locantore, & Anderson, 2003; Nolde, Johnson, & Raye, 1998), nor is the laterality of a frontal ERP effect necessarily reflective of the hemisphere in which it was generated (see Barrett, Blumhardt, Halliday, Halliday, & Kriss, 1976; Brunia & Vingerhoets, 1981; Woodruff et al., 2006). Further investigation into the circumstances eliciting the left-frontal old/new effect is therefore necessary to inform an understanding of the processes which it indexes along with an understanding of the roles of the PFC in episodic memory retrieval.

The right-frontal ERP old/new effect in the current study was of equivalent magnitude for correct and incorrect source judgments, as was also the case in the similar paradigms in experiments one and two. The right-frontal effect was also larger for high confidence correct source judgments relative to low confidence correct source judgments. The variation of the right-frontal effect in this way may go some way toward explaining the disparate findings for the relative magnitudes of hit/hit and hit/miss ERPs across published studies (e.g. Senkfor & Van Petten, 1998; Wilding & Rugg, 1996). Variations in the proportions of source judgments made with high/low confidence contributing to the correct/incorrect source ERP categories across studies may contribute to the apparent disparities and subsequent difficulty in forming a consensual account encompassing all published data points. The observation of two distinct late frontal effects in the current study also raises the possibility that not entirely the same effects have been observed across the published ERP source memory studies.

In summary, the current experiment has provided strong evidence which argues against a decision account for the right-frontal old/new effect. While the reliably larger high confidence hit/hit right-frontal effect relative to low confidence hit/hits does not initially appear to fit in with a distance-to-criterion post-retrieval monitoring account (Henson et al., 2000) for this effect, arguments have been provided for the possible ways in which this account can explain this pattern across averaged ERP measures. Frontal ERPs also, for the first time in a forced-choice source memory task, provided evidence of two functionally and neurally dissociable late occurring effects.

Experiment Four was designed to further probe the functional significance of this left-frontal old/new effect by investigating its material-specificity. If the left-frontal old/new effect indexes processes associated with the retrieval of contextual information then the same pattern of frontal effects observed here would be expected in an experiment for which auditory rather than visual contextual information of the study event is to be retrieved.

Table 6.3: Outcomes of the paired comparisons between the mean amplitudes associated with hit/hits, hit/misses, and correct rejections (CR) over the 500-800, 800-1100, and 1100-1400ms epochs at anterior and posterior sites separately. Only effects involving response category that were reliable in at least one contrast are shown. RC = response category, HM = hemisphere, ST = site. * = p<.05, ** = p<.01, *** = p<.001, ns. = non-significant (p>.05). Full dfs are shown with epsilon values in brackets alongside each associated F-value.

	500-800ms		**800-1100ms**		**1100-1400ms**	
	Anterior	**Posterior**	**Anterior**	**Posterior**	**Anterior**	**Posterior**
Hit/hit vs. CR						
RC (1,20)	11.84 **	23.40 ***	15.77 **	ns.	20.30 ***	ns.
RC x ST (4,80)	6.00 ** (0.65)	7.72 ***	ns.	ns.	ns.	3.93 * (0.62)
RC x HM (1,20)	ns.	7.65 *	ns.	11.84 **	11.83 **	ns.
RC x HM x ST (4,80)	4.03 * (0.75)	ns.	3.69 * (0.74)	ns.	ns.	ns.
Hit/miss vs. CR						
RC (1,20)	ns.	ns.	4.95 *	ns.	10.48 **	6.32 *
RC x ST (4,80)	4.80 * (0.55)	2.83 * (0.72)	5.72 ** (0.45)	6.22 ** (0.62)	4.56 ** (0.50)	9.25 *** (0.52)
RC x HM (1,20)	ns.	ns.	5.99 *	4.66 *	8.96 **	5.52 *
RC x HM x ST (4,80)	3.37 * (0.69)	ns.	ns.	ns.	ns.	ns.
Hit/hit vs. hit/miss						
RC (1,20)	ns.	14.79 **	ns.	ns.	ns.	ns.
RC x ST (4,80)	4.98 ** (0.59)	3.85 * (0.62)	ns.	ns.	ns.	ns.
RC x HM x ST (4,80)	2.69 * (0.85)	ns.	3.01 * (0.84)	ns.	ns.	ns.

Table 6.4: Outcomes of the paired comparisons between the mean amplitudes associated with the high confidence hit/hit, low confidence hit/hit, and correct rejection (CR) response categories for the 500-800, 800-1100, and 1100-1400ms epochs at anterior and posterior sites separately. Reporting criteria and nomenclature are as for Table 6.3.

	500-800ms		**800-1100ms**		**1100-1400ms**	
	Anterior	**Posterior**	**Anterior**	**Posterior**	**Anterior**	**Posterior**
High Confidence Hit/hit vs. CR						
RC (1,15)	11.61 **	31.03 ***	16.84 **	ns.	20.33 ***	ns.
RC x ST (4,60)	7.88 *** (0.71)	10.24 *** (0.49)	ns.	ns.	ns.	3.79 * (0.42)
RC x HM (1,15)	ns.	13.98 **	ns.	14.03 **	ns.	6.23 *
Low Confidence Hit/hit vs. CR						
RC (1,15)	ns.	ns.	ns.	ns.	ns.	6.16 *
RC x HM (1,15)	ns.	ns.	9.49 **	6.54 *	15.33 ***	ns.
RC x HM x ST (4,60)	ns.	ns.	ns.	3.33 * (0.66)	ns.	ns.
High Confidence Hit/hit vs. Low Confidence Hit/hit						
RC (1,15)	11.85 **	10.24 **	10.51 **	8.13 *	9.08 **	6.81 *
RC x ST (4,60)	5.41 * (0.44)	8.46 *** (0.65)	ns.	6.02 ** (0.77)	ns.	ns.
RC x HM (1,15)	ns.	7.84 *	6.57 *	5.48 *	ns.	ns.
RC x HM x ST (4,60)	ns.	4.23 * (0.59)	ns.	ns.	ns.	ns.

Figure 6.5: Grand average ERPs associated with the correct rejection, hit/hit, and hit/miss response categories. Data are shown for all 35 electrode sites.

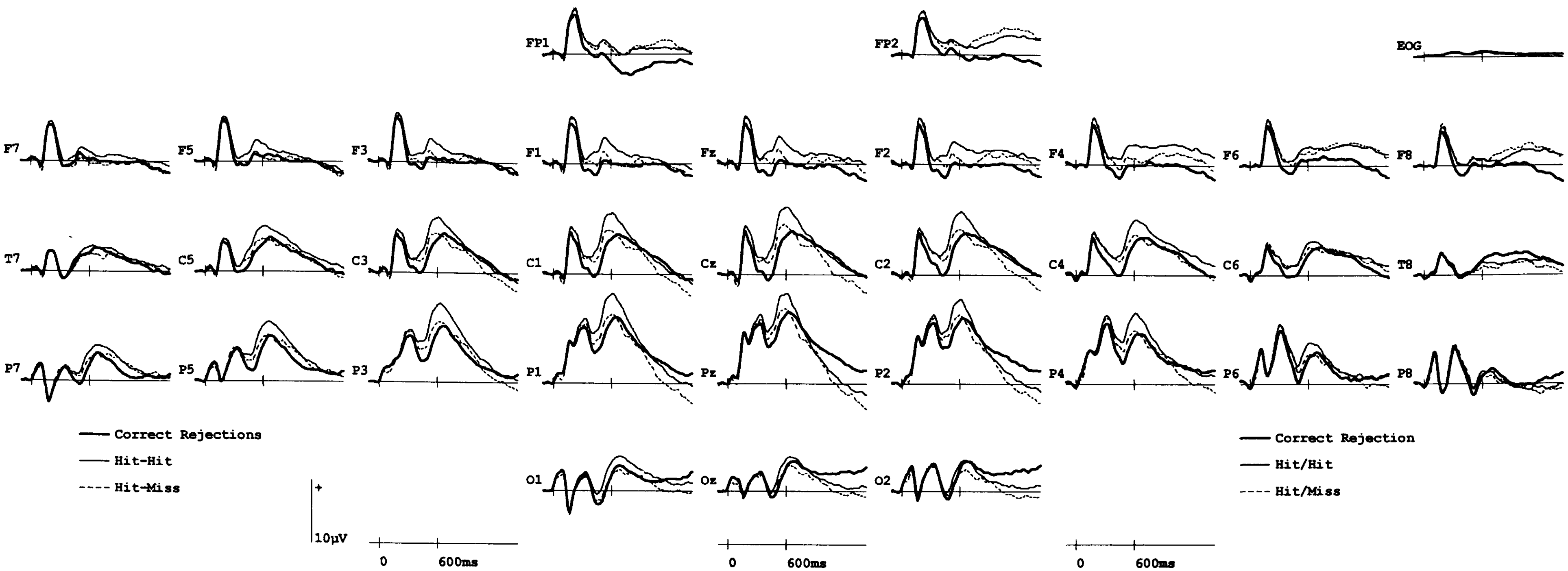
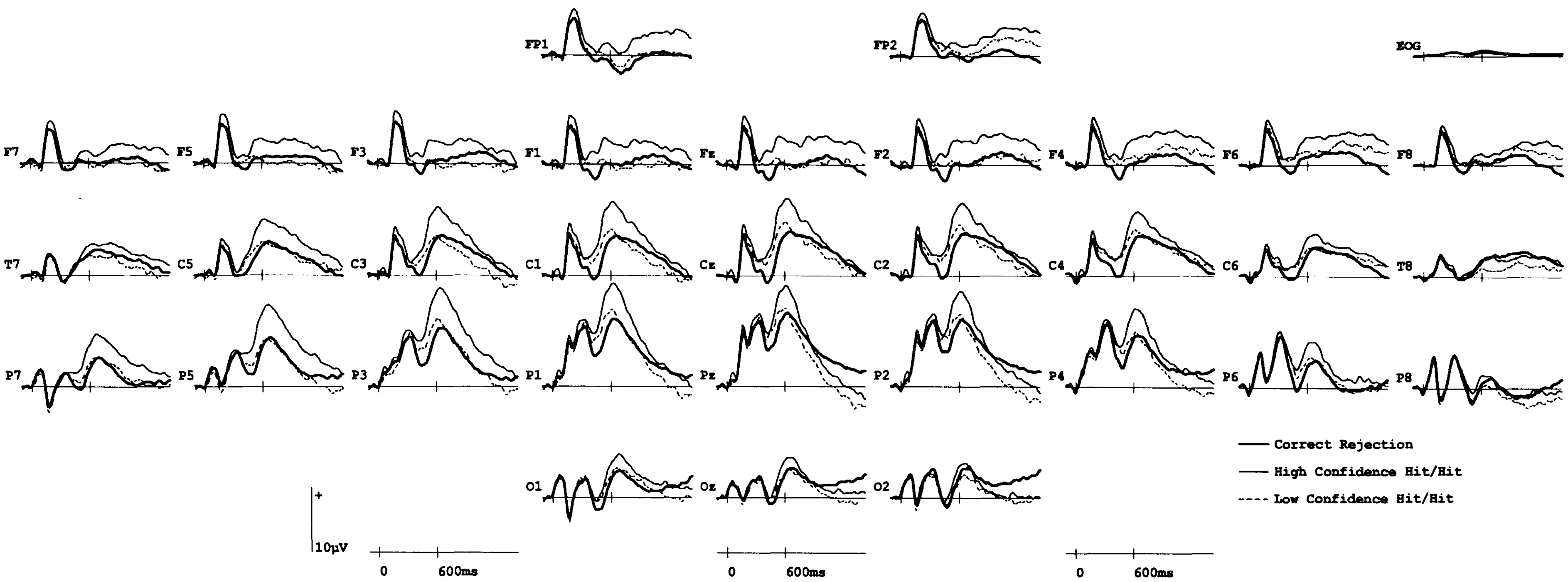


Figure 6.6: Grand average ERPs associated with correct rejections and hit/hit responses separated according to confidence judgment (high/low). Data are shown for all 35 electrode sites.



Chapter Seven : Experiment Four

7.1 Introduction

The results of Experiment Three provided evidence for two neurally dissociable late frontal ERP old/new effects for the first time in a source memory paradigm (for what may be a comparable dissociation in a modified recognition memory task, see comments regarding Woodruff et al. 2006 in Section 1.3.3.3). In Experiment Three, participants studied words presented in one of two colours (pink and yellow). At test, old words were presented intermixed with an equal number of new words to which an old/new response was required. For words judged to be old, a second four-way judgment was required for the colour in which the word had been presented (pink/yellow) at study, and the confidence with which that response was made (high/low). The scalp distributions of the ERP old/new effects associated with high confidence correct source judgments differed qualitatively from those associated with low confidence correct source judgments from 800-1100ms post-stimulus. In this time-period, the high confidence hit/hit old/new effect was distributed bilaterally across anterior scalp sites, while the low confidence hit/hit effect was right-lateralised. This result was interpreted as reflecting the contributions of a late right-frontal old/new effect (e.g. Experiments One and Two; Johansson et al., 2002; Wilding & Rugg, 1996) to both high and low confidence hit/hit response categories, and a second *left-frontal old/new effect* associated with high confidence hit/hits only to a greater degree.

The observation of this qualitative difference for items attracting high confidence correct source judgments led to the proposal that the left-frontal old/new effect reflects processes associated with the recollection of task-relevant content. Alternatively, since the task required the retrieval of colour information from the study event, the effect may be associated with processes more specific to the recollection of colour or visual source information. To distinguish between these competing interpretations and investigate the conditions under which neurally dissociable late frontal effects may be elicited, in the current experiment the source paradigm with confidence judgments used in Experiment Three was again employed, but participants retrieved auditory information from study events rather than visual information. Half the study words were spoken in a male voice, and the other half in a female voice. As in Experiment Three, all test items were presented visually and required participants to make an old/new decision followed by a four-way *confident-male, think-male, think-female, confident-female* decision for words judged to be old. If the proposed left-frontal old/new effect reflects processes associated with the retrieval of task-relevant content regardless of the form this content takes, dissociable late frontal effects would be expected between the ERPs associated with high and low confidence correct source judgments as observed in Experiment Three. If, however, the processes indexed by the left-frontal effect are specific to the task in Experiment Three, perhaps tied to the recollection or subsequent processing of visual or colour source information, then the dissociable late frontal old/new effects obtained in Experiment Three will not be observed in Experiment Four.

In summary, the current experiment employed the design used in Experiment Three, with the exception that auditory source information, the voice in which the study word was spoken, was to be retrieved at test. A lack of reliable qualitative differences in the scalp distributions of the high and low confidence hit/hit late frontal ERP old/new effects would suggest that the left-frontal old/new effect, observed in Experiment Three, reflects processes which are specific to the recovery of visual or colour information. If, however, the left-frontal effect reflects processes more generally associated with the recovery of task-relevant content, qualitatively different distributions for high and low confidence hit/hit late frontal old/new effects will be observed.

7.2 Methods

7.2.1 Participants

Twenty-four right-handed native English speakers participated. All had normal or corrected to normal vision and hearing, no diagnosis of dyslexia, and gave informed consent prior to the start of the experiment. Data from 8 participants were discarded for not contributing at least 16 artefact-free trials to the response categories of interest due to poor performance (5 participants) and excessive EOG artefact (3 participants). Of the remaining 16 participants (mean age 21 years, range 19-26 years), 11 were female.

7.2.2 Materials

These were 360 low frequency words (MRC psycholinguistic database: frequency 1-9/million, Coltheart, 1981). All were open-class and ranged between four and nine letters in length.

7.2.3 Design and Procedure

Study and test lists were formed in the same manner as in Experiment Three, resulting in six study-test blocks (30 words at study; 30 old + 30 new at test). All stimulus timings and procedures were as Experiment Three, with the exception that study words were presented auditorily via headphones. Half of the words in each study list were spoken in a male voice and half were spoken in a female voice. All auditory stimuli were digitised at 16 KHz and had a mean length of 770 ms, which did not differ between voice genders. As with Experiments One to Three, all test words were presented visually in white letters. Four complete task lists were created by rotating the study/test status and gender of voice at study.

7.2.4 Electrophysiological recording procedure

As Experiments One to Three.

7.3 Results

7.3.1 Behaviour

Table 7.1 (below) shows the overall probabilities of correct and incorrect judgments to old words, as well as the conditional probabilities of correct and incorrect source judgments, split according to the confidence judgments that they attracted. These data are also shown separated according to the gender of the voice in which the word was studied. A three-way ANOVA conducted on the conditional probabilities of correct and incorrect source judgments separated according to high/low accuracy with the factors of study voice (2 levels: male, female), source accuracy (2 levels: hit/hit, hit/miss), and confidence (2 levels: high/low) revealed a reliable interaction between study voice and source accuracy ($F(1,15) = 13.24$, $p<.01$) reflecting the greater probability of a correct source judgment to an old item spoken in the male voice.

	Male	Female	Overall
p(Hit)	0.76 (0.10)	0.75 (0.10)	*0.75 (0.09)*
p(FA)	-	-	*0.22 (0.13)*
p(Hit/hit: high)	0.44 (0.14)	0.39 (0.14)	*0.42 (0.13)*
p(Hit/hit: low)	0.30 (0.12)	0.25 (0.09)	*0.28 (0.09)*
p(Hit/miss: high)	0.06 (0.04)	0.11 (0.08)	*0.08 (0.05)*
p(Hit/miss: low)	0.20 (0.07)	0.25 (0.08)	*0.23 (0.06)*

Table 7.1: Mean probabilities of identifying old words correctly (Hit) and incorrectly identifying new words (FA). Also shown are the conditional probabilities of correct (hit/hit) and incorrect (hit/miss) source judgments, split according to the confidence judgments (high/low) that they attracted. Data for old words are shown separated according to the voice gender in which they were studied, as well as collapsed across this factor. Standard deviations are in brackets.

As with Experiment Two, in order to determine whether this behavioural effect of study voice is reflected in the electrophysiological data, the ERPs associated with correct source judgments (hit/hits) were separated according to the voice in which they were studied. The average numbers of trials per participant contributing to each of these hit/hit response categories were: male: 53 (range 24-78), female: 52 (26-72). These ERPs were contrasted across the 500-800, 800-1100, and 1100-1400ms time-windows using data from the same electrode locations as used throughout this thesis (see ERP analyses below) and with factors of response category (2 levels: male hit/hit, female hit/hit), the anterior/posterior dimension (2 levels), hemisphere (2 levels), and electrode site (5 levels). There were no reliable effects or interactions with response category in any time-window. As in Experiment two, this result is taken as justification for all subsequent behavioural and ERP analyses to be conducted on data collapsed across the factor of study voice.

As shown in Table 7.1, overall old/new discrimination was significantly above chance ($t(15) = 19.27$, $p<.001$) as was the conditional probability of a correct voice judgment ($t(15) = 12.37$, $p<.001$). A two-way ANOVA conducted on the probabilities of hit responses separated according to source accuracy and confidence with factors of accuracy (hit/hit, hit/miss) and confidence (high/low) revealed a reliable interaction between the two ($F(1,15) = 44.19$, $p<.001$). Follow-up t-tests revealed that this interaction reflects the greater probability of a high confidence response than a low confidence response for hit/hit responses ($t(15) = 2.69$, $p<.05$) and the reverse pattern for hit/miss responses ($t(15) = -6.03$, $p<.001$). A three-way mixed models ANOVA conducted on the probabilities of high/low confidence judgments to hit/hit and hit/miss responses in the current experiment (n=16) and those in Experiment 3 (n=21), with a between-subjects factor of source content (2 levels: colour, voice) and within-subjects factors of confidence and source accuracy, revealed no main effect or interactions with source content, indicating equivalent proportions of responses for each category in the current experiment and in Experiment 3 (compare Table 6.1 with 7.1, pages 97 & 123).

Table 7.2 (overleaf) shows the mean reaction times (RTs) for the initial old/new judgments in the current experiment. Correct responses to new words tended to be made faster than those to old words (collapsed across source accuracy), although this difference was not reliable. As with the analyses on accuracy data reported above, RTs were contrasted across the current experiment and Experiment 3. A two-way mixed-models ANOVA conducted on the mean RTs for correct responses to old and new items in the current experiment (n=16) and those in Experiment 3 (n=16) with a within-subjects factor of old/new status and between-subjects factor of source content (2 levels: colour, voice) revealed no main effects or interactions. A further three-way mixed-models ANOVA on the mean RTs for words correctly judged to be old with within-subjects factors of confidence and source-accuracy and the same between-subjects factor also revealed no reliable effects or interactions with content. Together these results indicate equivalent response times across experiment three and the current experiment. A follow-up two-way ANOVA on the RTs from the current experiment only for words judged correctly to be old with factors of source accuracy and confidence revealed a reliable main effect of confidence only ($F(1,15) = 9.54$, $p < .01$) reflecting the faster RTs for high confidence responses in this experiment.

	Male	**Female**	**Overall**
Hit	1053 (200)	1085 (217)	1077 (204)
CR	-	-	1040 (257)
Hit/hit: high	1022 (195)	1022 (234)	1015 (195)
Hit/hit: low	1093 (249)	1167 (269)	1134 (250)
Hit/miss: high	1011 (220)	1004 (269)	1035 (211)
Hit/miss: low	1089 (251)	1136 (239)	1116 (273)

Table 7.2: Mean reaction times with standard deviations in brackets for correctly identifying old words (Hit), correctly identifying new words (CR), and for correct (hit/hit) and incorrect (hit/miss) source judgments, split according to the confidence judgments (high/low) that they attracted.

7.3.2 ERP Analyses

Two sets of ERP analyses were conducted. The first was between the ERPs associated with correct rejections and the hit/hit as well as the hit/miss response categories (collapsed across response confidence), in keeping with the analysis strategies in Experiments One to Three. The mean numbers of epochs per participant per response category were: correct rejections: 101 (range 38-142), hit/hit: 74 (37-97), hit/miss:31 (20-54). A second set of ERP analyses was conducted on ERPs associated with the correct rejection response category, as well as the hit/hit response category split according to whether they were associated with high or low confidence judgments. The mean numbers of epochs per participant per hit/hit response category were: hit/hit (high confidence): 45 (18-81), hit/hit (low confidence): 29 (16-56). All participants with sufficient artefact-free trials in each category (N= 16) were included in both of these sets of analyses. The ERPs were analysed with the same strategy as employed throughout this thesis (see Section 3.6) for the same 3 post-stimulus time windows: 500-800, 800-1100 and 1100-1400ms.

7.3.2.1 Hit/Hit and Hit/Miss ERP Old/New Effects

The ERPs associated with the hit/hit and hit/miss response categories, as shown in Figure 7.1 (overleaf), begin diverging from those associated with correct rejections at around 300ms post-stimulus. These positive-going old/new effects are largest at parietal sites from 500-800ms, before switching to a later right-frontal maximum from 800ms onward. The ERPs associated with hit/hits are more positive-going than those associated with hit/misses from around 400ms. These differences continue until the end of the recording epoch.

In the three initial global analyses, mean amplitude measures for ERPs associated with correct rejections and the hit/hit as well as the hit/miss response categories were contrasted. These revealed reliable interactions between category and the anterior/posterior dimension from 500-800ms ($F(2,30) = 7.32$, $p<.01$, $e = 0.94$), category by anterior/posterior dimension by site interactions from 800-1400ms (800-1100ms: $F(8,120) = 3.58$, $p<.05$, $e = 0.43$; 1100-1400ms: $F(8,120) = 5.32$, $p<.01$, $e = 0.47$), and a category by anterior/posterior dimension by hemisphere interaction from

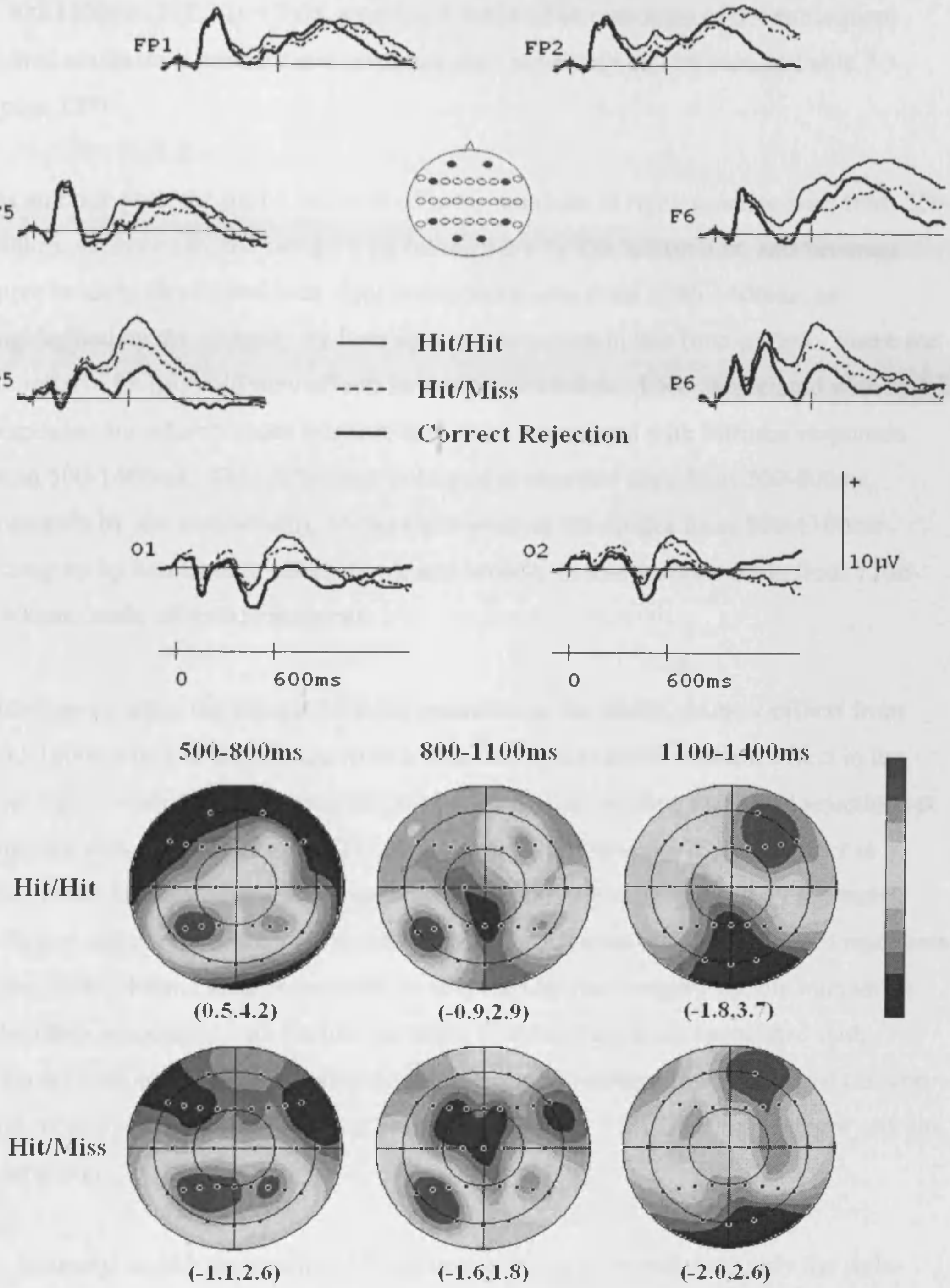


Figure 7.1: *Upper Panel*: Grand average ERPs associated with the hit/hit, hit/miss and correct rejection response categories. *Lower Panel*: Topographic maps showing the scalp distributions of the hit/hit and hit/miss old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows.

1100-1400ms ($F(2,30) = 7.65$, $p<.01$, $e = 0.88$). The outcomes of the subsequent paired contrasts at anterior and posterior sites separately can be seen in Table 7.3 (page 135).

At anterior sites, the hit/hit old/new effect is maximal at right-superior sites from 500-800ms, as shown by the category by hemisphere by site interaction, and becomes more broadly distributed over right hemisphere sites from 1100-1400ms, as highlighted by the category by hemisphere interaction in this time-period. There are no reliable hit/miss old/new effects in any time-window. ERPs associated with hit/hit responses are reliably more positive than those associated with hit/miss responses from 500-1400ms. This difference is largest at superior sites from 500-800ms, (category by site interaction), across right-anterior electrodes from 800-1100ms (category by hemisphere interaction), and broadly across anterior scalp from 1100-1400ms (main effect of category).

At posterior sites, the category by site interactions for hit/hit old/new effects from 500-1400ms reflect the change from a mid-lateral maximum old/new effect in the early time-windows to a greater negativity for hit/hits relative to correct rejections at superior sites in the final epoch (1100-1400ms). The hit/miss old/new effect is distributed broadly across posterior sites from 500-800ms, as shown by the main effect of category, before a greater negativity for hit/miss relative to correct rejections from 1100-1400ms at superior sites, as reflected by the category by site interaction. The ERPs associated with hit/hits are more positive than those associated with hit/miss responses across all posterior sites from 500-800ms (main effect of category) and subsequently more negative at superior sites from 1100-1400ms (category by site interaction).

In summary, unlike the results of Experiment Three, at frontal sites only the right-lateralised hit/hit old/new effect was reliable in any of the time-windows and was of greater magnitude than the hit/miss old/new effect throughout (500-1400ms). The analyses of hit/hit old/new effects separated according to confidence are reported next.

7.3.2.2 High and Low Confidence Hit/Hit Old/New Effects

As shown in Figure 7.2 (page 131), both the high and low confidence hit/hit ERPs begin diverging from correct rejections at around 300ms post-stimulus. The positive-going old/new effects associated with each of the classes of hit/hit response are maximal at parietal electrode sites from around 500-800ms, and subsequently maximal at right-frontal sites from 800ms onward. ERPs associated with high confidence hit/hits are more positive than those associated with low confidence hit/hits from around 400ms post-stimulus. Towards the end of the recording epoch (~1100ms onward) the differences in amplitude between these ERP categories becomes less pronounced at right-frontal sites.

The three initial global analyses conducted on mean amplitude measures associated with correct rejections and high and low confidence hit/hit responses revealed reliable interactions between category, the anterior/posterior dimension, and hemisphere from 500-800ms ($F(2,30) = 3.41$, $p<.05$, $e = 0.96$) and 1100-1400ms ($F(2,30) = 8.26$, $p<.01$, $e = 0.93$), as well as category by anterior/posterior dimension by site interactions from 800-1100ms ($F(8,120) = 4.29$, $p<.01$, $e = 0.55$) and 1100-1400ms ($F(8,120) = 4.49$, $p<.01$, $e = 0.59$). The outcomes of the subsequent paired contrasts at anterior and posterior sites separately can be seen in Table 7.4 (page 136).

At anterior sites, the high confidence hit/hit old/new effect is maximal at right mid-lateral sites from 500-1100ms, as highlighted by the reliable category by hemisphere by site interactions in this time-period. The effect becomes broadly right-lateralised from 1100-1400ms, as reflected by the category by hemisphere interaction. A right-lateralised low confidence old/new effect is only reliable from 1100-1400ms, as reflected by the category by hemisphere interaction in this epoch. The ERPs associated with high confidence hit/hit responses are reliably more positive than those associated with low confidence hit/hits at superior sites from 500-800ms, as reflected by the category by site interaction, and more broadly across anterior sites from 800-1100ms as shown by the main effect of category in this time-window. There are no reliable differences between these categories of ERPs from 1100-1400ms.

At posterior sites, reliable category by site interactions from 500-1400ms reflect the mid-lateral maximum of the high confidence hit/hit old/new effect in the earliest time-window, which changes to a greater negativity for high confidence hit/hits relative to correct rejections at superior sites in the later epochs. The category by site interactions from 800-1400ms for the low confidence hit/hit old/new effect also reflect this greater negativity at superior sites. High confidence hit/hit ERPs are reliably more positive than low confidence hit/hits at mid-lateral sites from 500-1100ms, as reflected by the category by site interactions in these time-periods.

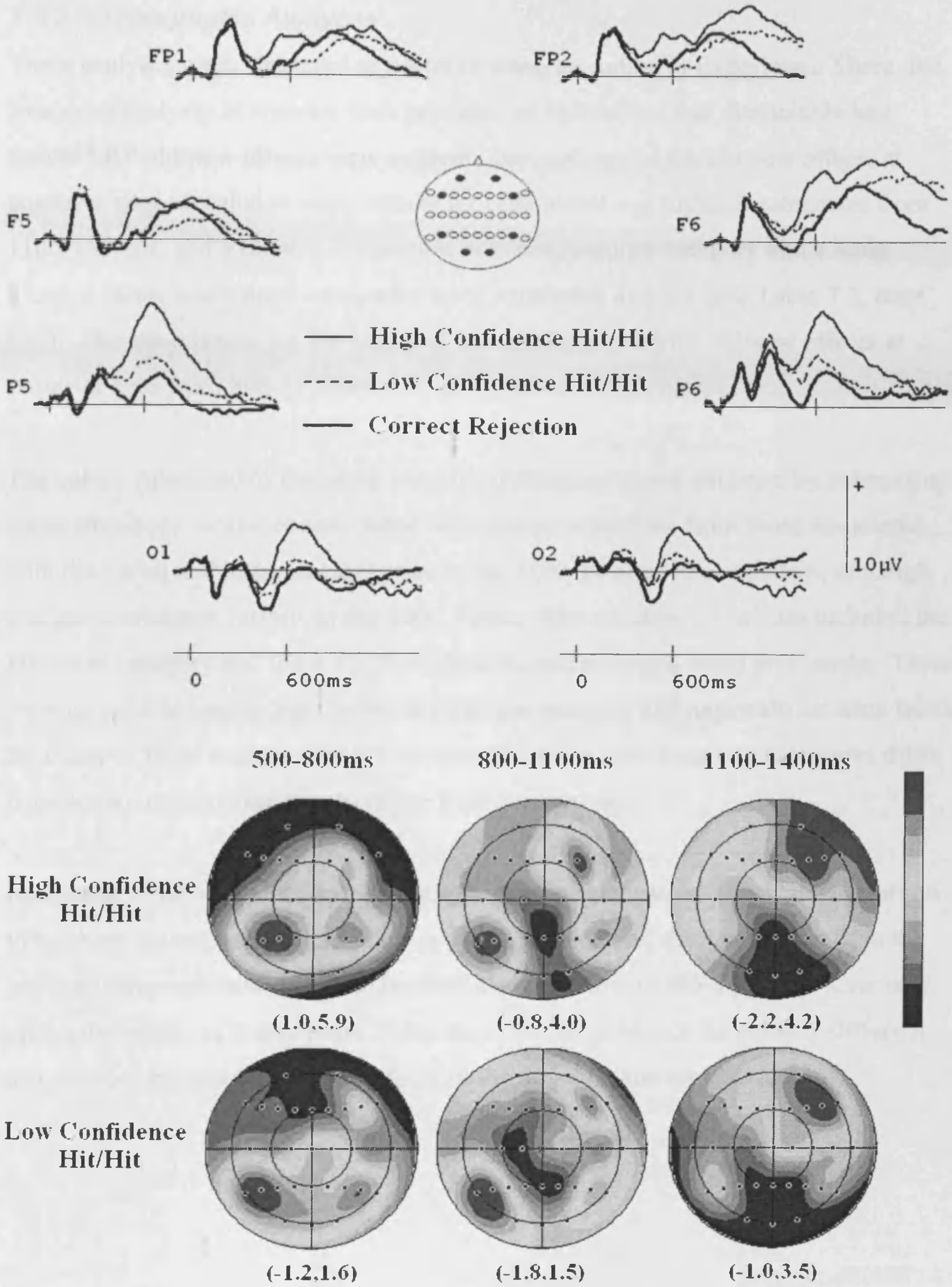


Figure 7.2: *Upper Panel*: Grand average ERPs associated with the high confidence hit/hit, low confidence hit/hit, and correct rejection response categories. *Lower Panel*: Topographic maps showing the scalp distributions of the high confidence hit/hit and low confidence hit/hit old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows.

7.3.2.3 Topographic Analyses

These analyses were restricted to posterior sites, as, unlike in Experiment Three, the foregoing analyses at anterior sites provided no indications that dissociable late frontal ERP old/new effects were evident. The analyses of the old/new effects at posterior sites revealed reliable effects for both hit/hit and hit/miss categories from 1100-1400ms, and a reliable interaction between response category and a scalp location factor when these categories were contrasted directly (see Table 7.3, page 135). The same is true for the high and low confidence hit/hit old/new effects at posterior sites from 800-1100ms.

The values submitted to rescaling were the difference scores obtained by subtracting mean amplitude measures associated with correct rejections from those associated with the hit/hit and hit/miss categories in the 1100-1400ms time-window, and high and low confidence hit/hits in the 800-1100ms time-window. Analyses included the factors of category and the scalp location dimensions as described previously. There were no reliable interactions between response category and any scalp location factor for either of these analyses, demonstrating that these ERP response categories differ from one another quantitatively rather than qualitatively.

In summary, the high confidence hit/hit old/new effect was reliably right-lateralised throughout the analysed time-windows (500-1400ms) and does not differ from the low confidence old/new effect in the final time-window (1100-1400ms). Crucially, unlike the results of Experiment Three there was no evidence for reliably different distributions between these two effects in the 800-1100ms time period.

7.4 Discussion

The current experiment was designed to probe the conditions eliciting the left-frontal ERP old/new effect observed in a comparison of high and low confidence correct source judgments in Experiment Three. In order to determine whether the processes indexed by the left-frontal old/new effect are specific to the retrieval of colour or visual information, as required by the task in Experiment Three, or are more generally related to the retrieval of task-relevant content, the design of the current experiment was the same as Experiment Three with the exception that participants were required to retrieve auditory information (male/female voice) from the study episode, rather than visual information. In contrast to Experiment Three, there were no qualitative differences between the frontal ERP old/new effects associated with high and low confidence correct source judgments. This lack of evidence for a left-frontal old/new effect in the current design supports the proposal that this effect, observed in an experimental design which differed only in terms of the modality of the source information to be retrieved (Experiment Three), reflects processes that are not engaged for all kinds of information that support source judgments.

The evidence from Experiment Three for at least two separable late-frontal old/new effects, along with the absence of the proposed left-frontal ERP old/new effect in the current study, provides some evidence that multiple PFC-supported processes may be detectable with ERPs, and that these may be sensitive to the forms of content which are to be retrieved. This interpretation may also account for the inconsistencies in the relative magnitudes of late frontal ERPs associated with correct and incorrect source judgments across published studies. Unlike the results of Experiments One to Three, late frontal hit/hit ERPs were more positive-going than hit/miss ERPs in the current study, replicating the findings of some (Wilding, 1999; Wilding & Rugg, 1996), but not all (Vallesi & Shallice, 2006) previous studies in which words spoken in male and female voices were used at study. The apparent content-specificity of late frontal ERPs seen when comparing data from Experiments Three and Four, suggests that these inconsistencies across the literature may come about as the result of the contributions of multiple late frontal old/new effects which are engaged to differing degrees across task designs.

The conclusion that the distributions of late frontal ERP old/new effects in source studies are content-specific, however, is based solely on a null effect in the current study and the visual inspection of late frontal distributions across studies (compare Figure 6.2 with 7.2, pages 104 & 131). A comparison of the retrieval of auditory and visual contextual information within-subjects – i.e. Experiments Three and Four combined into a single within-subjects design – would provide a more robust means of testing this proposal. Experiment Five was designed to accomplish this. It is hypothesised that late frontal ERP old/new effects associated with high confidence correct source judgments will differ qualitatively between a task requiring the retrieval of visual (colour) information and one which requires the retrieval of auditory (voice) information. Such an observation would provide further evidence for multiple dissociable late frontal ERP old/new effects (see Experiment Three), and would inform our understanding of the apparently disparate late frontal old/new effects reported in source memory studies employing different forms of content at study.

Table 7.3: F-values and significance levels for the paired comparisons between the mean amplitudes associated with the hit/hit, hit/miss, and correct rejection (CR) response categories over the 500-800, 800-1100, and 1100-1400ms epochs at anterior and posterior sites separately. Only effects involving response category that were reliable in at least one contrast are shown. RC = response category, HM = hemisphere, ST = site. * = p<.05, ** = p<.01, *** = p<.001, ns. = non-significant (p>.05). Full dfs are shown on the left with epsilon values in brackets alongside each associated F-value.

	500-800ms		**800-1100ms**		**1100-1400ms**	
	Anterior	**Posterior**	**Anterior**	**Posterior**	**Anterior**	**Posterior**
Hit/hit vs. CR						
RC (1,15)	ns.	26.86 ***	ns.	ns.	8.21 *	ns.
RC x HM (1,15)	ns.	ns.	ns.	ns.	16.12 **	ns.
RC x ST (4,60)	6.86 ** (0.44)	6.03 ** (0.48)	ns.	8.74 ** (0.55)	ns.	14.87 *** (0.51)
RC x HM x ST (4,60)	2.85 * (0.73)	ns.	ns.	ns.	ns.	ns.
Hit/miss vs. CR						
RC (1,15)	ns.	9.16 **	ns.	ns.	ns.	ns.
RC x ST (4,60)	ns.	ns.	ns.	ns.	ns.	6.09 ** (0.62)
Hit/hit vs. hit/miss						
RC (1,15)	17.45 **	5.60 *	9.12 **	ns.	5.72 *	ns.
RC x HM (1,15)	ns.	ns.	5.06 *	ns.	ns.	ns.
RC x ST (4,60)	6.63 ** (0.43)	ns.	ns.	ns.	ns.	3.81 * (0.45)

Table 7.4: Outcomes of the paired comparisons between the mean amplitudes associated with the high confidence hit/hit, low confidence hit/hit, and correct rejection (CR) response categories for the 500-800, 800-1100, and 1100-1400ms epochs at anterior and posterior sites separately. Reporting criteria and nomenclature are as for Table 7.3.

	500-800ms		800-1100ms		1100-1400ms	
	Anterior	**Posterior**	**Anterior**	**Posterior**	**Anterior**	**Posterior**
High Confidence Hit/hit vs. CR						
RC (1,15)	6.69 *	53.31 ***	ns.	ns.	9.65 **	ns.
RC x HM (1,15)	ns.	ns.	ns.	ns.	12.53 **	ns.
RC x ST (4,60)	13.51 ***	9.00 ** (0.46)	ns.	10.35 *** (0.53)	ns.	16.25 *** (0.49)
RC x HM x ST (4,60)	3.09 * (0.71)	ns.	2.88 * (0.78)	ns.	ns.	ns.
Low Confidence Hit/hit vs. CR						
RC x HM (1,15)	ns.	ns.	ns.	ns.	8.89 **	ns.
RC x ST (4,60)	ns.	ns.	ns.	5.76 ** (0.64)	ns.	4.89 ** (0.71)
High Confidence Hit/hit vs. Low Confidence Hit/hit						
RC (1,15)	11.87 **	64.48 ***	5.88 *	15.98 **	ns.	ns.
RC x ST (4,60)	16.06 *** (0.55)	6.66 ** (0.48)	ns.	4.76 ** (0.63)	ns.	ns.

Figure 7.3: Grand average ERPs associated with the correct rejection, hit/hit, and hit/miss response categories. Data are shown for all 35 electrode sites.

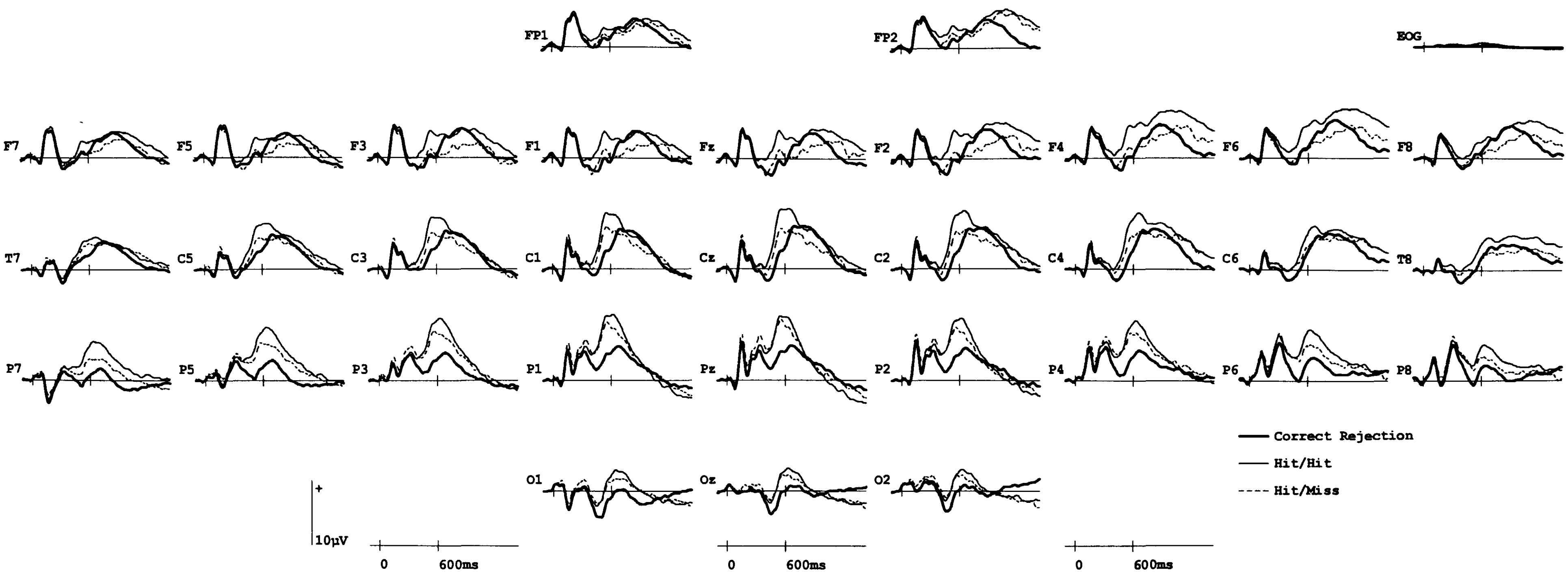
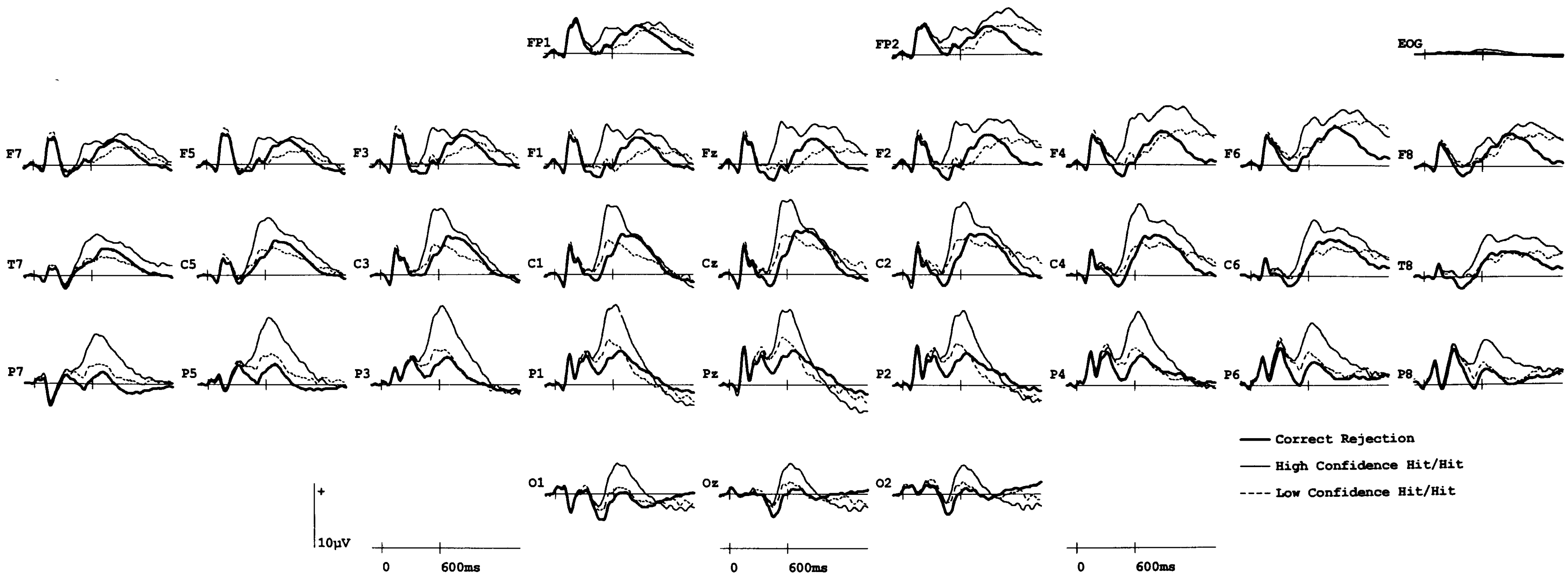


Figure 7.4: Grand average ERPs associated with correct rejections and hit/hit responses separated according to confidence judgment (high/low). Data are shown for all 35 electrode sites.



Chapter Eight : Experiment Five

8.1 Introduction

Experiments Three and Four employed a source memory confidence paradigm in which participants made old/new judgments to visually presented words, followed by a combined judgment of source and confidence (high/low) in the source judgment for items identified as 'old'. The source information to be retrieved in Experiment Three was the colour (pink/yellow) of visually presented words at study. In Experiment Four, the source information to be retrieved was the voice in which a word was spoken at study (male/female). Frontal old/new effects from 800-1100ms for items attracting high confidence correct source judgments were bilaterally distributed when visual information (word colour) was the source information to be retrieved in Experiment Three, and were right-lateralised when auditory information (voice gender) was to be retrieved in Experiment Four (compare Figures 6.2 and 7.2, pages 104 and 131). In combination these data suggest that not entirely the same late frontal ERP old/new effects are associated with the retrieval of different forms of episodic content.

As noted in previous chapters, late frontal ERP old/new effects which have been reported in source memory tasks have not behaved in a consistent and predictable manner across published studies (compare, for example, Senkfor & Van Petten, 1998; Wilding & Rugg, 1996). The apparent content-specificity of late frontal ERP old/new effects seen in a comparison of data from Experiments Three and Four suggests that, across published studies employing different forms of study content, not entirely the same brain regions have been engaged. This is also likely to be partially responsible for the difficulty in providing one functional account for all late frontal published data points, since not entirely the same processes will have been engaged in each case.

The proposal that late frontal ERP old/new effects in source memory studies are sensitive to the contents of retrieval, however, comes only from the visual inspection of topographic differences across Experiments Three and Four. The current experiment was designed to investigate this proposed content-specificity in a within-subjects design. In effect, participants completed versions of both Experiments Three and Four in the same session. The condition in the current experiment analogous to the design of Experiment Three was the Visual condition, and that condition analogous to Experiment Four, the Auditory condition. Participants completed the entirety of one condition before completing the other, the order of which was counterbalanced across participants. Since the critical difference observed across the data from Experiments Three and Four was in the ERPs associated with high confidence correct source judgments, study lists in the current experiment were shortened relative to those used in Experiments Three and Four in order to increase the likelihood of this type of judgment and subsequently increase signal:noise for this response category. If the left-lateralised frontal old/new effect in Experiment Three reflects a content-sensitive process, then the distributions of the high confidence correct source old/new effects in the 800-1100ms time-window will differ qualitatively at frontal electrodes between the Visual and Auditory conditions, with a right-lateralised Auditory old/new effect and a relatively more bilaterally distributed Visual old/new effect.

8.2 Method

8.2.1 Participants

Forty-nine participants took part (exclusion criteria as Experiment Four, see General Methods, Section 3.2). Data from 17 participants were discarded for not contributing at least 16 artefact-free trials to the response categories of interest due to poor performance (9 participants), excessive EOG artefact (7 participants), and experimenter error (1 participant). Of the remaining 32 participants (mean age 21 years, range 18-29 years), 26 were female.

8.2.2 Materials

These were 320 low frequency words (MRC psycholinguistic database: frequency 1-9/million, Coltheart, 1981). All were open-class and ranged between four and nine letters in length.

8.2.3 Design and Procedures

The 320 words were randomly divided into 16 lists of 20 words which were paired at random to form 8 list pairs. One of the word lists in each pair was assigned to be the study list. All 20 words from the study list were presented again at test along with all words from the unstudied list to form one study-test block. A complete task list comprised 8 study-test blocks. Half of the blocks were randomly assigned to appear in the Visual condition, and half to the Auditory condition.

In the Visual condition, an equal number of study words were presented in pink/yellow. Study words in the Auditory condition were presented auditorily, via headphones, an equal number in a male/female voice. All test words in both the Visual and Auditory conditions were presented visually in white letters. Eight complete task lists were created by rotating the study/test status and context at study of all words across both Visual and Auditory conditions.

Participants were fitted with an electrode cap prior to the experiment and were seated in a sound attenuated room 1.2m away from a computer monitor with their fingers on response keys. A short practice session preceded the first condition. The order in which conditions were completed was counterbalanced, and each participant completed all study-test blocks from the first condition before receiving instructions regarding the second condition, for which there was also a short practice session. Participants were instructed that, in each study phase, they would be presented with words in two contexts (pink/yellow for Visual condition, male/female for Auditory condition), and that their memories for the words and their contexts would be assessed afterwards. For each study word, participants were instructed to press key pads using their index fingers to indicate the context in which the word was presented (pink/yellow or male/female).

Each test phase began shortly after each study phase. Participants were informed that they would see words shown one at a time in white which were either from the immediately preceding study phase or were new to the experiment. Participants were asked to make an initial old/new judgment with their index fingers. For words judged old, participants were also asked to make a second response on one of four keys: *Confident-Pink, Think-Pink, Think-Yellow, Confident-Yellow* in the Visual condition, and *Confident-Male, Think-Male, Think-Female, Think-Male* in the Auditory condition. Confident responses were always made with middle fingers, and Think responses with index fingers. Pink/yellow and male/female responses were always made with the same hand at study and at test. Participants were instructed to respond *Confident* if they were confident that they could remember the colour of the word at study, whilst they were to respond *Think* when they were less confident and only had 'a feeling' for the colour the word was presented in at study. For words judged to be new, participants were instructed to press any key after the initial old/new judgment to proceed to the next trial. The hands used to make old/new judgments at test and context judgments at study were counterbalanced across participants. For each participant, the hands used to make old/new judgments remained the same across both conditions. The hands used to make pink/yellow and male/female responses were counterbalanced orthogonally across participants.

Each study trial began with an asterisk that was displayed on screen for 500ms, followed by a blank screen for 200ms, after which the word was presented either auditorily via headphones or visually for 300ms. The next trial began 1000ms after a response was made. Test trials began with an asterisk that was visible for 500ms, following which a blank screen was presented for 200ms before presentation of the word for 300ms. The screen remained blank for 1000ms after the initial old/new response before a question mark signalling that a context judgment was required was shown for 300ms. The screen then remained blank until 1000ms after the participant responded, at which point the next trial started.

8.2.4 Electrophysiological recording procedure

As Experiments One to Four.

8.3 Results

8.3.1 Behaviour

Table 8.1 (below) shows the probabilities of correct/incorrect judgments to old words, as well as the conditional probabilities of correct source judgments separated according to the Visual and Auditory conditions for all 32 participants. Four initial paired-samples t-tests were conducted on the probabilities of a correct old judgment (hits) and the conditional probabilities of a correct source judgment (hit/hits) for items studied in each context (male/female and pink/yellow) revealing no reliable differences. This licensed subsequent analyses to be conducted on data collapsed across study context in keeping with similar studies (Experiment One; Experiment Three; Cycowicz et al., 2001; Wilding et al., 2005; Wilding & Rugg, 1996).

	Auditory	**Visual**
p(Hit)	0.80 (0.08)	0.85 (0.10)
p(FA)	0.11 (0.12)	0.08 (0.08)
p(Hit/hit : high)	0.61 (0.17)	0.58 (0.20)
p(Hit/hit : low)	0.22 (0.12)	0.21 (0.13)
p(Hit/miss : high)	0.05 (0.06)	0.08 (0.07)
p(Hit/miss : low)	0.12 (0.08)	0.12 (0.09)

Table 8.1: Mean probabilities of identifying old words correctly (Hit) and incorrectly identifying new words (FA) in the Auditory and Visual conditions for all participants (n=32). Also shown are the conditional probabilities of correct (hit/hit) and incorrect (hit/miss) source judgments, split according to the confidence judgments (high/low) that they attracted. Standard deviations are in brackets.

As shown in Table 8.1, old/new discrimination was reliably above chance for both the Auditory ($t(31) = 35.32$, $p<.001$) and Visual ($t(31) = 37.63$, $p<.001$) conditions, and was greater for items in the Visual condition ($t(31) = 4.69$, $p<.001$). The conditional probability of a correct source judgment was also reliably above chance in each condition (Auditory: $t(31) = 17.95$, $p<.001$; Visual: $t(31) = 13.23$, $p<.001$). A three-way ANOVA conducted on the conditional probabilities of correct/incorrect source judgments made with high/low confidence with factors of condition (2 levels: Auditory, Visual), source accuracy, and confidence revealed a reliable interaction between confidence and source accuracy ($F(1,31) = 128.08$, $p<.001$) highlighting the fact that a correct source judgment was more likely to be made with high confidence and an incorrect source judgment made with low confidence. There were no reliable effects or interactions involving condition.

Mean RTs for the initial old/new judgments are shown in Table 8.2 (overleaf). A three-way ANOVA conducted on the RTs for words judged correctly to be old with factors of source accuracy, confidence, and condition (2 levels: Auditory, Visual) revealed a main effect of confidence only ($F(1,18) = 20.18$, $p<.001$) reflecting the faster RTs for high confidence judgments (N.B. 13 participants made either no high confidence hit/miss or low confidence hit/miss responses in at least one of the conditions and have therefore been removed from this particular analysis). A second two-way ANOVA conducted on the RTs for correct test judgments (collapsed across source accuracy and confidence) with factors of old/new status and condition revealed a main effect of old/new status ($F(1,31) = 33.85$, $p<.001$) reflecting faster RTs for correct rejections, and a main effect of condition ($F(1,31) = 7.72$, $p<.01$) reflecting faster overall RTs in the Visual condition.

8.3.2 ERP Analyses

The ERPs associated with correct rejections and the high confidence hit/hit response categories in both the Auditory and Visual conditions were submitted to these analyses. The mean numbers of epochs per participant per response category for the initial analyses were: auditory correct rejections: 56 (range 26-71), auditory high confidence hit/hit: 31 (16-57), visual correct rejections: 57 (27-77), visual high confidence hit/hit: 32 (18-70). The ERPs were analysed in the same 3 post-stimulus time windows as employed throughout this thesis: 500-800, 800-1100 and 1100-1400ms. As in Experiments One to Four, the initial analyses included the data from twenty electrode locations grouped to form four clusters at anterior-right (FP2, F8, F6, F4, F2), anterior-left (FP1, F7, F5, F3, F1), posterior-right (O2, T6, P6, P4, P2), and posterior-left (O1, T5, P5, P3, P1) locations. For these time windows, initial global ANOVAs were conducted including the factors of response category (4 levels: visual correct rejections, visual high confidence hit/hits, auditory correct rejections, auditory high confidence hit/hits), the anterior/posterior dimension, hemisphere, and electrode site.

Where initial global ANOVAs revealed reliable effects involving response category, they were followed up by paired comparisons, which were conducted separately at anterior and posterior sites when the initial analyses revealed interactions including response category and the anterior/posterior dimension. Where necessary, analyses included the Greenhouse-Geisser correction for non-sphericity (Greenhouse & Geisser, 1959). Uncorrected degrees of freedom and F-values are shown in the text and results tables, accompanied by their respective epsilon values when appropriate.

	Auditory	**Visual**
Hit	1279 (380)	1159 (386)
CR	1027 (263)	879 (143)
Hit/hit: high	1090 (274)	990 (209)
Hit/hit: low	1313 (408)	1276 (569)
Hit/miss: high	1205 (451)	1135 (455)
Hit/miss: low	1392 (608)	1271 (572)

Table 8.2: Mean reaction times (standard deviations in brackets) for correctly identifying old words (Hit), correctly identifying new words (CR), and for correct (hit/hit) and incorrect (hit/miss) source judgments, split according to the confidence judgments (high/low) that they attracted. Data from all 32 participants are shown for the Auditory and Visual condition separately.

8.3.2.1 High confidence hit/hit old/new effects – Visual versus Auditory

As shown in Figures 8.1 and 8.2 (pages 148 & 149), the ERPs associated with high confidence hit/hits in both the Visual and Auditory conditions begin diverging from their respective correct rejection ERPs from around 400ms. The magnitudes of these positive-going old/new effects are equivalent across posterior sites throughout the recording epoch. At anterior sites, the ERPs associated with Auditory high confidence hit/hits become more positive-going than those associated with the same responses in the Visual condition from around 800ms post-stimulus.

The three initial global analyses revealed reliable category by anterior/posterior dimension by hemisphere interactions in all time-windows (500-800: $F(3,93) = 3.40$, $p<.05$, $e = 0.76$; 800-1100: $F(3,93) = 9.75$, $p<.001$, $e = 0.81$; 1100-1400: $F(3,93) = 24.84$, $p<.001$, $e = 0.86$) as well as category by anterior/posterior dimension by site interactions in the same windows (500-800: $F(12,372) = 2.31$, $p<.05$, $e = 0.53$; 800-1100: $F(12,372) = 5.98$, $p<.001$, $e = 0.56$; 1100-1400: $F(12,372) = 4.48$, $p<.001$, $e = 0.61$). The outcomes of the follow-up analyses conducted on data from anterior and posterior sites separately are shown in Table 8.3 (page 174) and are described below.

At anterior sites, the positive-going Visual old/new effect is maximal at right-superior sites from 500-800ms, as reflected by the category by hemisphere by site interaction in this time-window, before becoming maximal at right mid-lateral electrode site F6 from 800-1400ms, as reflected by the category by hemisphere by site interactions in this time-period. The Auditory old/new effect is maximal at superior sites from 500-1100ms, as highlighted by the category by site interactions in these time-windows, before becoming broadly distributed across right-anterior sites from 1100-1400ms (category by hemisphere interaction). Contrasting the magnitudes of these old/new effects (calculated by subtracting the mean amplitudes associated with correct rejections from those associated with high confidence hit/hits for each condition in turn) revealed reliable category by hemisphere by site interactions from 500-1400ms. These interactions reflect the greater extension into left-superior electrode sites of the Auditory old/new effect relative to the focal right-lateralised distribution of the Visual old/new effect in each time-window.

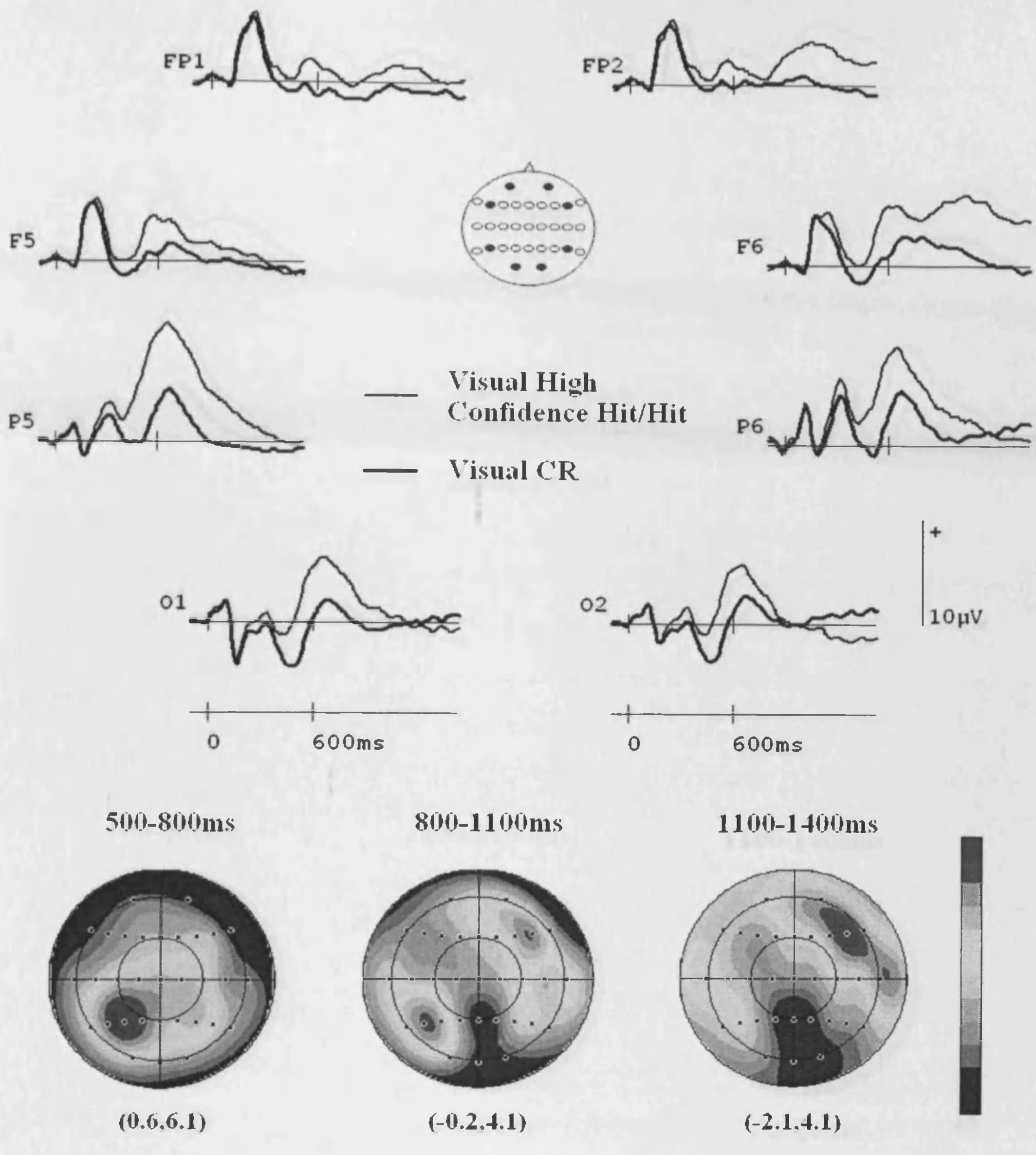


Figure 8.1: *Upper Panel*: Grand average ERPs associated with the high confidence hit/hit and correct rejection response categories in the Visual condition. *Lower Panel*: Topographic maps showing the scalp distributions of the high confidence hit/hit old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows.

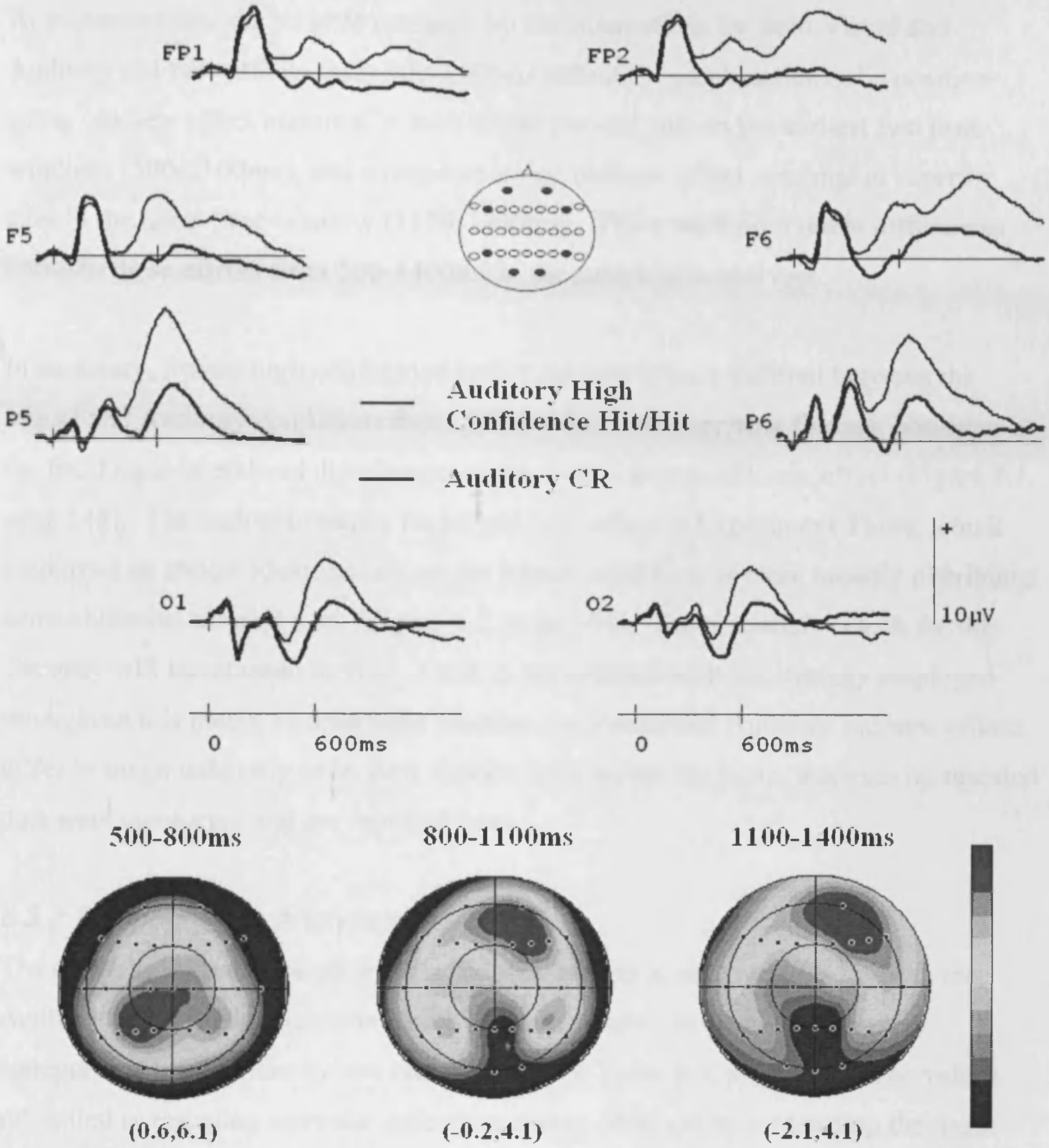


Figure 8.2: *Upper Panel*: Grand average ERPs associated with the high confidence hit/hit and correct rejection response categories in the Auditory condition. *Lower Panel*: Topographic maps showing the scalp distributions of the high confidence hit/hit old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows.

At posterior sites, the reliable category by site interactions for both Visual and Auditory old/new effects from 500-1400ms reflect the combinations of a positive-going old/new effect maximal at mid-lateral parietal sites in the earliest two time-windows (500-1100ms), and a negative-going old/new effect maximal at superior sites in the latest time-window (1100-1400ms). There were no reliable differences between these effects from 500-1400ms in the subtraction analyses.

In summary, frontal high confidence hit/hit old/new effects differed between the Visual and Auditory conditions from 500-1400ms. A surprising finding, however, is the focal right-lateralised distribution of the Visual frontal old/new effect (Figure 8.1, page 148). The high confidence hit/hit old/new effect in Experiment Three, which employed an almost identical task to the Visual condition, is more broadly distributed across bilateral anterior sites (Figure 6.2, page 104). The potential reasons for this disparity will be returned to later. First, in accordance with the strategy employed throughout this thesis, to determine whether the Visual and Auditory old/new effects differ in magnitude only or in their distributions across the scalp, analyses on rescaled data were conducted and are reported next.

8.3.2.2 Topographic Analyses

The above analyses revealed reliable old/new effects at anterior sites for both the Auditory and Visual conditions which differed reliably in each time-window (category by hemisphere by site interactions; see Table 8.3, page 174). The values submitted to rescaling were the difference scores obtained by subtracting the mean amplitudes associated with correct rejections from those associated with high confidence hit/hits for the Auditory and Visual condition separately. These rescaled old/new effects were subsequently contrasted in each of the three time-windows (500-800, 800-1100, 1100-1400ms). The category by hemisphere by site interactions remained reliable in each time-window (500-800ms: $F(4,124) = 2.70$, $p<.05$, $e = 0.90$; 800-1100ms: $F(4,124) = 2.85$, $p<.05$, $e = 0.87$; 1100-1440ms: $F(4,124) = 2.69$, $p<.05$, $e = 0.88$) reflecting the qualitatively different high confidence hit/hit frontal old/new effects associated with the Auditory and Visual conditions in each period.

8.4 Order Effects

While the above results indicate qualitative differences between the Visual and Auditory old/new effects in the 800-1100ms time-window, the focal right-lateralised distribution of the frontal old/new effect in this time-window in the Visual condition is markedly different from the bilaterally distributed effect observed in Experiment Three in the same time-window (compare Figures 6.2 with 8.1, pages 104 & 148). It is somewhat surprising that two experimental conditions with almost identical designs would be associated with such different patterns of neural activity. One possible explanation for these differences is that the averaged pattern of activity in Figure 8.1 (page 148) from all 32 participants is affected by the order in which the two conditions were completed. Interference effects from the previously completed condition may have resulted in different retrieval processing during completion of the second condition (for comments on interference in memory retrieval, see Anderson, 2003).

To investigate order effects further, the 32 participants contributing to the above analyses were subsequently divided into two equal groups according to the order in which they completed the conditions (Visual-Auditory or Auditory-Visual) to allow comparisons of the Visual and Auditory old/new effects both across and within these groups to investigate the possible contribution of task order to the grand average ERPs for all 32 participants. Comparisons of the behavioural data across groups are reported first, followed by the outcomes of the ERP analyses. A "Bonferroni-like" corrected significance level of 0.025 is used in the following analyses due to the unplanned nature of these comparisons.

8.4.1 Behaviour

Table 8.4 (overleaf) shows the proportions of correct and incorrect old judgments along with the proportions of correct and incorrect source judgments separated according to whether these were made with high or low confidence. The data are separated by condition (Visual, Auditory) as well as the position in which the condition was completed (First, Second). A mixed models two-way ANOVA conducted on old/new discrimination accuracies with a within-subjects factor of

Content (Visual, Auditory) and a between-subjects factor of the Order in which conditions were completed (Visual-Auditory, Auditory-Visual) revealed a main effect of content only (F(1,30) = 22.35, p<.001), reflecting superior old/new discrimination in the Visual condition.

	Visual First	**Visual Second**	**Auditory First**	**Auditory Second**
p(Hit)	0.85 (0.09)	0.85 (0.11)	0.81 (0.08)	0.78 (0.07)
p(FA)	0.08 (0.09)	0.08 (0.07)	0.15 (0.14)	0.07 (0.09)
p(Hit/hit : high)	0.54 (0.20)	0.63 (0.20)	0.58 (0.18)	0.64 (0.16)
p(Hit/hit : low)	0.25 (0.12)	0.18 (0.13)	0.20 (0.12)	0.23 (0.12)
p(Hit/miss : high)	0.07 (0.06)	0.09 (0.08)	0.07 (0.07)	0.03 (0.04)
p(Hit/miss : low)	0.14 (0.10)	0.11 (0.08)	0.15 (0.09)	0.10 (0.07)

Table 8.4: Mean probabilities of identifying old words correctly (Hit) and identifying new words incorrectly (FA), separated according to the order in which each of the Visual and Auditory conditions were completed. Also shown are the conditional probabilities of correct (hit/hit) and incorrect (hit/miss) source judgments, split according to the confidence judgments (high/low) that they attracted. Standard deviations are in brackets.

A further mixed-models four-way ANOVA was conducted on the proportions of correct and incorrect source judgments separated according to high and low confidence with within-subjects factors of Content (Visual, Auditory), Confidence (High/Low) and Source Accuracy (Hit/hit, Hit/miss), as well as a between-subjects factor of Order (Visual-Auditory, Auditory-Visual). This analysis revealed interactions between Order, Content, and Confidence (F(1,30) = 6.24, p<.025) and between Order, Content, and Source Accuracy (F(1,30) = 9.33, p<.01). Subsidiary ANOVAs conducted on data from the Visual and Auditory content conditions separately with the same within- and between-subjects factors revealed a reliable interaction between Order and Source Accuracy in the analyses of data from the Auditory condition only (F(1,30) = 7.34, p<.025), reflecting the greater probability of a correct source judgment in this condition when it was completed second. There were no reliable interactions between Order and Confidence in the analyses of data from either the Visual or Auditory condition, although the Order by Content by Confidence interaction in the global ANOVA reflects a higher proportion of high confidence responses in the Visual condition when this was completed second.

Mean RTs for each of these categories are shown in Table 8.5 (overleaf). A mixed models three-way ANOVA conducted on the mean RTs for correct judgments to new and old (collapsed across source accuracy and confidence) items with within-subjects factors of Content (Visual, Auditory) and Item Status (Old, New) and a between-subjects factor of Order (Visual-Auditory, Auditory-Visual) revealed a main effect of old/new status ($F(1,30) = 32.85$, $p<.001$) reflecting the faster RTs for correct rejections. There was also an interaction between content and order ($F(1,30) = 18.80$, $p<.001$) reflecting the disproportionately greater RT benefit to the Auditory condition of being completed second. A further mixed models four-way ANOVA conducted on RTs for words judged correctly to be old with a between-subjects factor of order and within-subjects factors of content, source accuracy, and confidence revealed a reliable interaction between all four of these factors ($F(1,30) = 6.85$, $p<.025$). Subsidiary ANOVAs conducted on data from each level of the content factor with the between-subjects factor of order and within-subjects factors of confidence and accuracy revealed main effects of confidence in each case (Visual: $F(1,30) = 12.19$, $p<.01$; Auditory: $F(1,30) = 11.24$, $p<.01$) reflecting the faster RTs for high confidence responses.

8.4.2 ERP Analyses

The ERPs associated with correct rejections and high confidence hit/hits in the Visual and Auditory conditions were separated according to those participants who completed the conditions in the Visual-Auditory order (n=16), and those who completed the conditions in the reverse order (Auditory-Visual; n=16), resulting in eight ERP response categories overall. The mean numbers of epochs per participant in the Visual-Auditory group were: visual-first correct rejections: 57 (range 39-73), visual-first high confidence hit/hit: 29 (18-65), auditory-second correct rejections: 57 (37-70), auditory-second high confidence hit/hits: 32 (16-57). The mean numbers of epochs per participant in the Auditory-Visual group were: auditory-first correct rejections: 54 (26-76), auditory-first high confidence hit/hit: 30 (16-44), visual-second correct rejections: 58 (27-77), visual-second high confidence hit/hit: 35 (20-70).

	Visual First	**Visual Second**	**Auditory First**	**Auditory Second**
Hit	1213 (466)	1105 (290)	1390 (388)	1168 (346)
CR	921 (122)	837 (153)	1153 (290)	901 (156)
Hit/hit: high	1029 (199)	952 (216)	1220 (305)	960 (159)
Hit/hit: low	1390 (697)	1154 (363)	1411 (362)	1221 (428)
Hit/miss: high	1221 (523)	1042 (312)	1390 (456)	1004 (180)
Hit/miss: low	1218 (597)	1331 (518)	1443 (493)	1340 (682)

Table 8.5: Mean reaction times (standard deviations in brackets) for correctly identifying old words (Hit), correctly identifying new words (CR) and for correct (hit/hit) and incorrect (hit/miss) source judgments, split according to the confidence judgments (high/low) that they attracted, shown separated according to the order in which the Visual and Auditory conditions were completed.

The ERPs were analysed in the same 3 post-stimulus time windows (500-800, 800-1100, 1100-1400ms) using data from the same electrode locations as used in the main ERP analyses above. Initial global ANOVAs included the between-subjects factor of group (Visual-Auditory, Auditory-Visual) and within-subjects factors of content (Visual, Auditory), category (correct rejections, high confidence hit/hits), the anterior/posterior dimension, hemisphere, and electrode site. Where initial global ANOVAs revealed reliable interactions between group, content, and category they were followed up by comparisons within each level of the group factor. Analyses included the Greenhouse-Geisser correction for non-sphericity where necessary (Greenhouse & Geisser, 1959) with uncorrected degrees of freedom and F-values shown in the text accompanied by their respective epsilon values when appropriate.

These analyses revealed reliable group by content by category by hemisphere by site interactions from 500-1100ms (500-800ms: $F(4,120) = 4.01$, $p<.01$, $e = 0.82$; 800-1100ms: $F(4,120) = 4.22$, $p<.01$, $e = 0.79$). The interaction terms involving group, content, and category in these time-windows license the subsequent analyses of old/new effects in each of the groups separately. These analyses followed the same strategy as employed in the analyses of data from all 32 participants above. The outcomes of the analyses of data from the 16 participants in the Visual-Auditory group are reported first, followed by the analyses of data from the 16 participants in the Auditory-Visual group. Finally, the Visual and Auditory old/new effects are contrasted separately between those participants for whom each condition was completed first and second.

8.4.2.1 Visual-Auditory Order

Figures 8.3 and 8.4 (pages 156 & 157) show the ERP waveforms and scalp distributions of the Visual and Auditory old/new effects in each time-window for these participants. As can be seen, the pattern of activity broadly mimics the pattern seen in data from all 32 participants (see Figures 8.1 and 8.2, pages 148 & 149). Global ANOVAs with within-subjects factors of content (Visual, Auditory), category (correct rejections, high confidence hit/hits), the anterior/posterior dimension, hemisphere, and electrode site revealed no reliable interactions involving content and category in either time-window.

8.4.2.2 Auditory-Visual Order

The scalp distributions and ERP waveforms for the Visual and Auditory old/new effects in each time-window are shown in Figures 8.5 and 8.6 (pages 158 & 159) for these participants. The Auditory old/new effect appears to be more right-lateralised at frontal sites from 800ms for these participants than those in the Visual-Auditory group, and the Visual old/new effect smaller and more diffuse across right-frontal electrodes in the same time-period. As in the analyses of data from the Visual-Auditory group, the global ANOVAs revealed no reliable interactions in either time-window involving the factors of content and category.

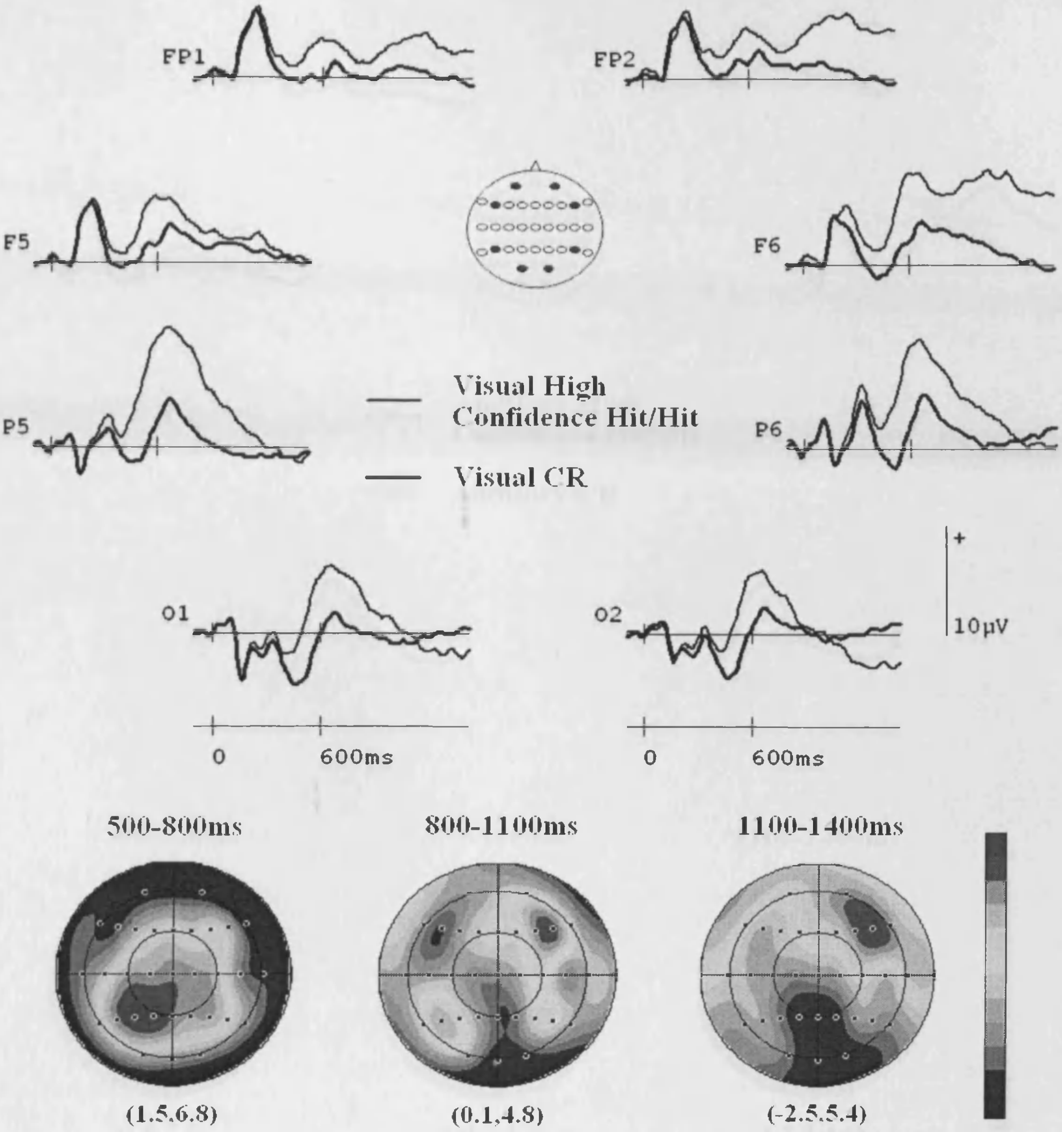


Figure 8.3: *Upper Panel*: Grand average ERPs associated with the high confidence hit/hit and correct rejection response categories in the Visual condition for those participants in the **Visual-Auditory group only**. *Lower Panel*: Topographic maps showing the scalp distributions of the high confidence hit/hit old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows.

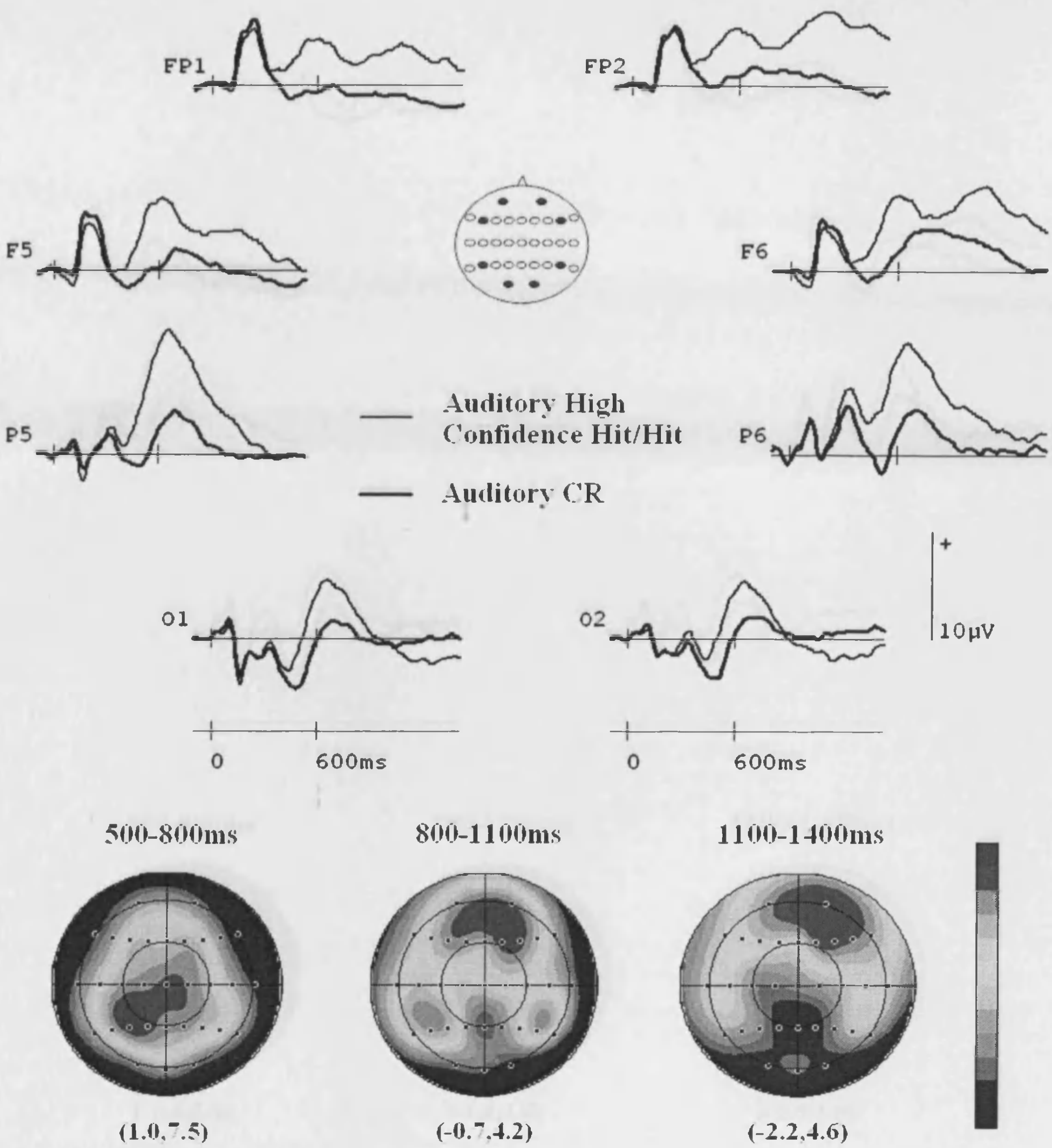


Figure 8.4: *Upper Panel*: Grand average ERPs associated with the high confidence hit/hit and correct rejection response categories in the Auditory condition for those participants in the **Visual-Auditory group only**. *Lower Panel*: Topographic maps showing the scalp distributions of the high confidence hit/hit old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows.

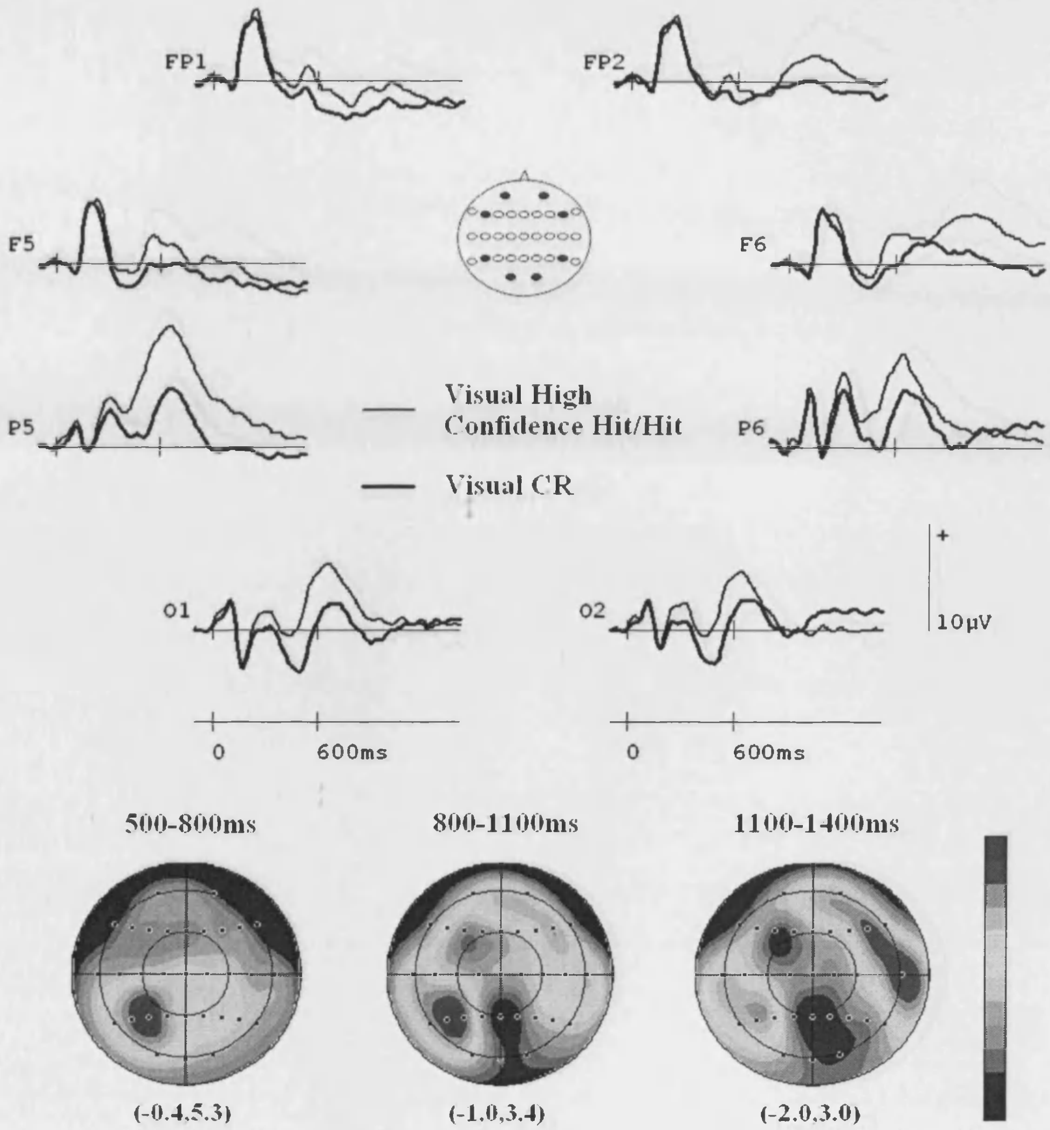


Figure 8.5: *Upper Panel*: Grand average ERPs associated with the high confidence hit/hit and correct rejection response categories in the Visual condition for those participants in the **Auditory-Visual group only**. *Lower Panel*: Topographic maps showing the scalp distributions of the high confidence hit/hit old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows.

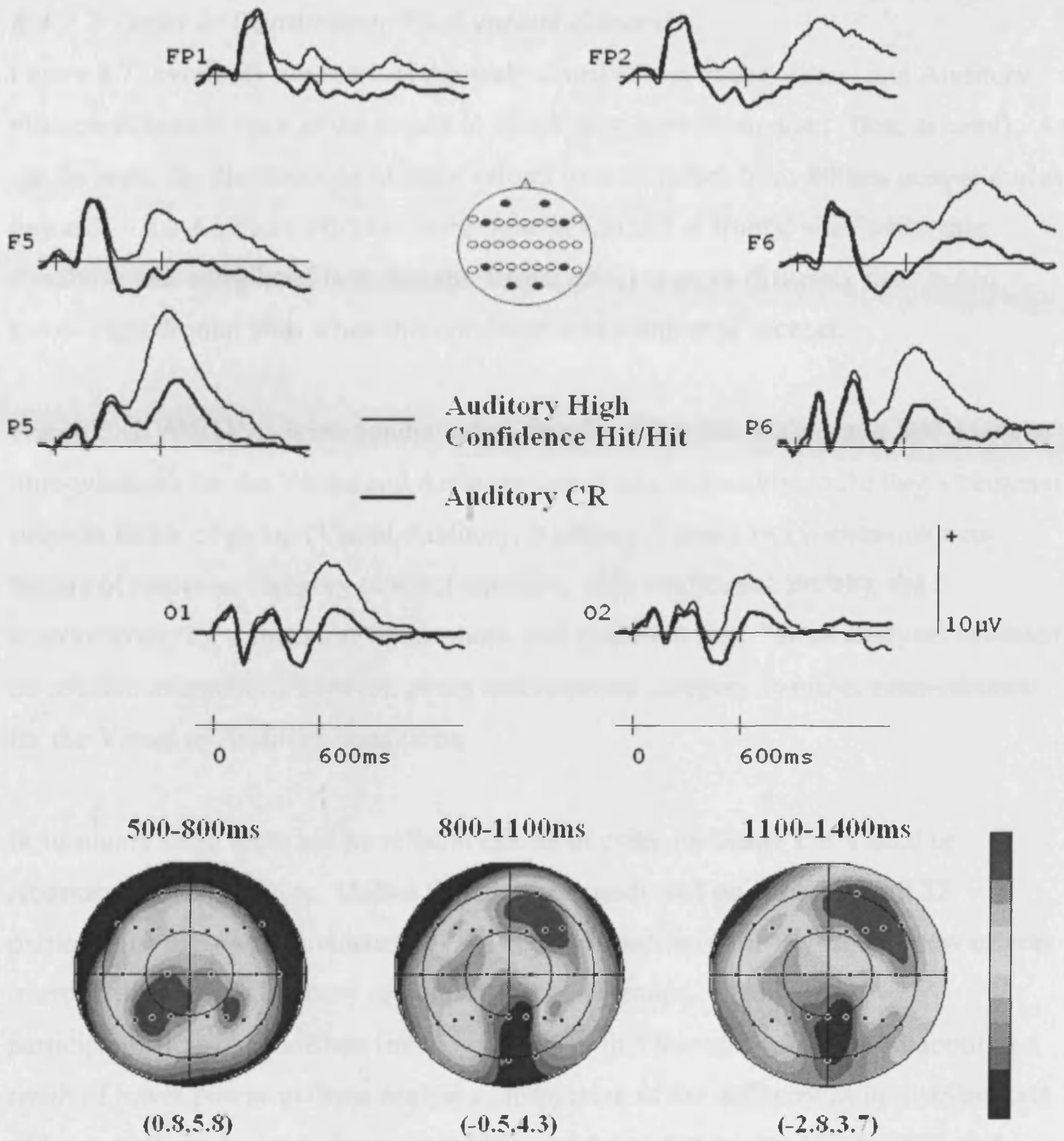


Figure 8.6: *Upper Panel*: Grand average ERPs associated with the high confidence hit/hit and correct rejection response categories in the Auditory condition for those participants in the **Auditory-Visual group only**. *Lower Panel*: Topographic maps showing the scalp distributions of the high confidence hit/hit old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows.

8.4.2.3 Order of Completion: First versus Second

Figure 8.7 (overleaf) summarises the scalp distributions of the Visual and Auditory old/new effects in each of the orders in which they were completed (first, second). As can be seen, the distributions of these effects look different from 800ms post-stimulus onwards – the Auditory effect is more right-lateralised at frontal sites when this condition was completed first, and the Visual effect is more diffusely distributed across right-frontal sites when this condition was completed second.

Four global ANOVAs were conducted on data from the 500-800ms and 800-1100ms time-windows for the Visual and Auditory conditions separately, including a between subjects factor of group (Visual-Auditory, Auditory-Visual) and within-subjects factors of response category (correct rejection, high confidence hit/hit), the anterior/posterior dimension, hemisphere, and electrode site. These analyses revealed no reliable interactions between group and response category in either time-window for the Visual or Auditory conditions.

In summary then, there are no reliable effects of order for either the Visual or Auditory old/new effects. Unlike the analyses conducted on data from all 32 participants, there is no evidence for the content-specificity of frontal old/new effects in either the Visual-Auditory or Auditory-Visual groups. Due to the fewer participants in these contrasts (n=16), it is likely that this null effect came about as a result of lower power in these analyses. Inspection of the differences in distributions of frontal effects in the scalp maps in Figures 8.3 and 8.4 (pages 156 & 157), and those in Figures 8.5 and 8.6 (pages 158 & 159), provide general support for this.

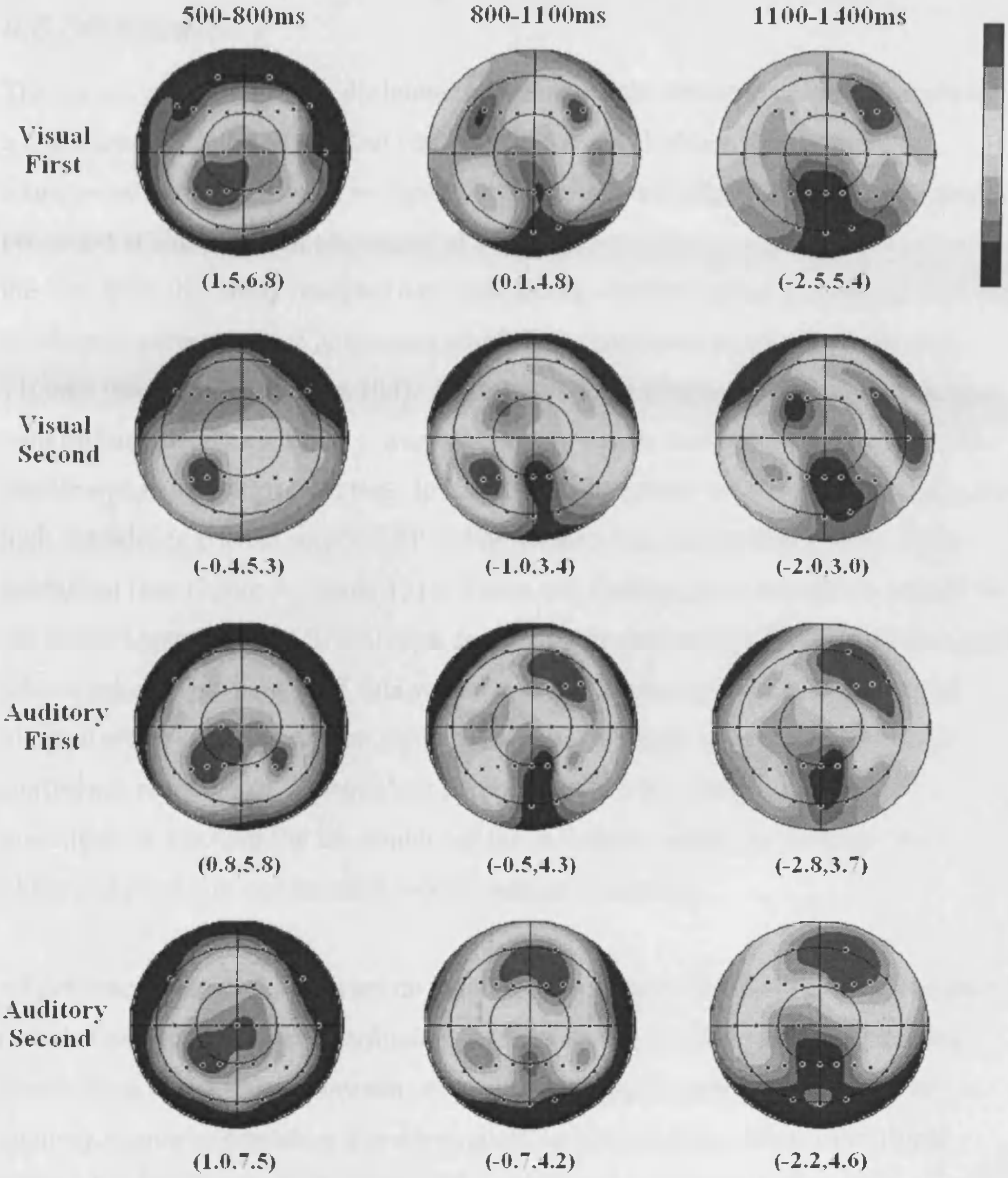


Figure 8.7: Topographic maps showing the scalp distributions of the high confidence hit/hit old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows in the Visual and Auditory conditions, separated according to whether each of these were completed first or second in the task order.

8.5 Discussion I

The current experiment was designed to investigate the possible content-specificity of a left-frontal ERP old/new effect observed in the 800-1100ms time-window. Experiment Three employed a visual source memory paradigm (the colour of words presented at study) which also required high/low confidence judgments. Analyses of the data from that study revealed a reliable frontal old/new effect associated with high confidence correct source judgments which was distributed bilaterally from 800-1100ms (see Figure 6.2, page 104). Experiment Four employed the same paradigm with different study materials – words spoken in a male and female voice – speaker gender was to be retrieved at test. In the 800-1100ms time-window in that study, the high confidence correct source ERP old/new effect was considerably more right-lateralised (see Figure 7.2, page 131). These two findings in combination argued for the content-specificity of frontal high confidence correct source old/new effects in this time-window. This pattern of data was interpreted as consisting of a right-frontal old/new effect common to both, and a left-frontal old/new effect specific to high confidence recovery of visual/colour source. The current study was designed to investigate this possibility by combining the paradigms employed in Experiments Three and Four into one blocked, within-subjects paradigm.

As predicted, the above analyses on data from all 32 participants in the current study revealed reliably different distributions of frontal high confidence hit/hit old/new effects from 800-1100ms between two tasks requiring the retrieval of visual or auditory source information, thereby supporting the previous claims of multiple dissociable late frontal ERP old/new effects in source memory studies (Experiment Three). The current results, however, are not entirely consistent with the data from Experiments Three and Four in the 800-1100ms time-window. A comparison of the scalp maps in Figures 6.2 and 8.1 (pages 104 & 148) highlights the markedly different distributions of frontal high confidence hit/hit old/new effects between Experiment Three and its analogous condition in the current experiment, the Visual condition. The effect in Experiment Three was distributed bilaterally while the Visual effect in the current study has a very focal right mid-lateral maximum. In fact, the Auditory effect in the current study has a more broad distribution into left-superior sites relative to the Visual effect – the opposite pattern to that seen when comparing the high confidence hit/hit effects found in Experiments Three and Four (see Figures 7.2 and 8.2, pages 131 & 149).

Unique to the task demands of the Visual condition in the current experiment relative to those in Experiment Three is the addition of a second source memory task, the Auditory condition, which, for half of the participants, will have been completed before the Visual condition. One possible explanation for the inconsistent scalp distributions from 800-1100ms across Experiment Three and the Visual condition of the current experiment is that the processing associated with high confidence correct source judgments in this condition is not consistent across those participants for whom this condition was completed first or second. It is possible that the memory traces of items seen in the previously completed Auditory condition will have interfered with those of items from the subsequent Visual condition and led to the requirement to engage in some form of interference resolution processes to a greater extent when this condition was completed second. As a result of this, when averaged across the order of task completion, the ERP old/new effect associated with high confidence hit/hits may not have resembled that seen in Experiment Three.

However, comparisons of each of the high confidence hit/hit old/new effects in the Auditory and Visual conditions between when these were completed first and second revealed no reliable differences. Figure 8.3 (page 156) shows the scalp distribution of the Visual old/new effect in the group of participants (n=16) who completed the Visual condition first. The condition completed by this group of participants most resembled the conditions experienced by participants in Experiment Three since they had only been informed of, and given instructions for, the Visual condition. As can be seen in Figure 8.3 (page 156), the focal right-lateral distribution of the Visual old/new effect in this group of participants resembles that seen in the data from all 32 participants, and is also markedly different to the bilateral distribution seen in Experiment Three (see Figure 6.2, page 104). This result argues strongly against a content-specific interpretation for the left-frontal old/new effect observed from 800-1100ms in Experiment Three.

The Visual condition of the current experiment consisted of four study-test blocks (20 words at study, 40 at test) whereas the task in Experiment Three consisted of six longer study-test blocks (30 words at study, 60 at test). A possibility is that the left-frontal effect found in the grand average in Experiment Three reflects processes engaged only, or to a greater extent, in the later test phases and which may not have been associated with these judgments in the relatively shorter Visual condition. Test items in these later test phases are likely to have suffered from interference from previously seen items to a greater extent than those in the earlier test phases, and may therefore have been associated with different processing. In order to investigate the possible impact of the amount of time spent performing a memory task on the distribution of frontal ERPs from 800-1100ms, the high confidence hit/hit old/new effects from the first three test phases of Experiment Three were contrasted with those from the final three test phases of that experiment, the outcomes of which are described below.

8.6 Re-analysis of Experiment Three – Effects of Time on Task

The behavioural and ERP data across all 6 test phases from each of the 16 participants in Experiment Three contributing to the analyses of high confidence hit/hit old/new effects were divided equally into two – data from test phases 1-3, and data from test phases 4-6. The analyses of the behavioural data across the factor of block (2 levels: phases 1-3, phases 4-6) are reported first. The significance level for all analyses is corrected to 0.025 according to a "Bonferroni-like" correction, for the same reasons given earlier in this chapter.

8.6.1 Behaviour

Table 8.6 (overleaf) shows the proportions of correct and incorrect old judgments alongside the proportions of correct and incorrect source judgments separated according to the confidence (high/low) assigned to these responses, for phases 1-3 and 4-6 separately. A paired t-test conducted on the old/new discrimination data revealed no reliable difference between phases 1-3 and 4-6. A three-way within-subjects ANOVA conducted on the conditional probabilities of correct and incorrect source judgments separated according to the high/low confidence judgment with which they were associated, with factors of block (phases 1-3, phases 4-6), confidence, and accuracy, revealed no main effects or interactions involving block.

Table 8.7 (overleaf) shows the RTs to hits, correct rejections (CR), and correct and incorrect source judgments split according to confidence (high/low) separately for phases 1-3 and 4-6. A two-way ANOVA conducted on the probabilities of correct judgments to old (collapsed across source accuracy and confidence) and new words with factors of block (phases 1-3, phases 4-6) and old/new status revealed a main effect of block only ($F(1,15) = 13.23$, $p<.01$) reflecting the generally faster RTs in phases 4-6. A three-way ANOVA conducted on the RTs associated with correct and incorrect source judgments separated according to high/low confidence with factors of block, confidence, and source accuracy also revealed a main effect of block only ($F(1,15) = 6.36$, $p<.025$) reflecting the same facilitation of RTs in the later test phases.

In summary, there were no differences in performance accuracy between the first and last three phases of the task in Experiment Three. Mean RTs, however, were reliably quicker for all responses in the later phases.

	Test Phase	
	1-3	**4-6**
p(Hit)	0.79 (0.10)	0.80 (0.10)
p(FA)	0.20 (0.14)	0.20 (0.21)
p(Hit/hit : high)	0.37 (0.11)	0.40 (0.14)
p(Hit/hit : low)	0.29 (0.06)	0.30 (0.07)
p(Hit/miss : high)	0.10 (0.07)	0.08 (0.07)
p(Hit/miss : low)	0.24 (0.07)	0.21 (0.08)

Table 8.6: Mean probabilities of identifying old words correctly (Hit) and identifying new words incorrectly (FA) in Experiment Three, separated according to test phases 1-3 and 4-6. Also shown are the conditional probabilities of correct (hit/hit) and incorrect (hit/miss) source judgments, split according to the confidence judgments (high/low) that they attracted. Standard deviations are in brackets.

	Test Phase	
	1-3	**4-6**
Hit	1154 (310)	1037 (305)
CR	1048 (142)	919 (145)
Hit/hit: high	1093 (252)	979 (218)
Hit/hit: low	1214 (430)	1045 (342)
Hit/miss: high	1093 (292)	908 (139)
Hit/miss: low	1215 (417)	1216 (674)

Table 8.7: Mean reaction times (standard deviations in brackets) for correctly identifying old words (Hit), correctly identifying new words (CR) and for correct (hit/hit) and incorrect (hit/miss) source judgments, split according to the confidence judgments (high/low) that they attracted, shown separately for test phases 1-3 and 4-6.

8.6.2 ERP Analyses

Figure 8.8 (overleaf) shows the scalp distributions of the high confidence hit/hit old/new effects from test phases 1-3 and 4-6 separately (for the ERP waveforms from which these scalp maps are generated, see Figures 8.12 and 8.13, pages 178 & 179). As these figures show, the distributions of frontal effects are considerably more left-lateralised from 800-1400ms in the later test phases (4-6). It is easy to see how the grand average across all 6 blocks from Experiment Three showed a bilaterally distributed frontal high confidence hit/hit effect in the 800-1100ms time-window as a result of the combination of these two frontal effects with different left-right lateralisation (Figure 6.2, page 104).

The mean (range) numbers of epochs per category per participant contributing to the analyses were: correct rejections phases 1-3: 40 (25-61), high confidence hit/hit phases 1-3: 17 (6-28), correct rejections phases 4-6: 38 (13-66), high confidence hit/hit phases 4-6: 17 (7-30). Due to the exploratory nature of these analyses, and unlike all other analyses in this thesis, data from all participants were included regardless of whether or not they contributed 16 or more trials to the categories of interest. Any conclusions made on the basis of the outcomes of these analyses are therefore necessarily made with caution.

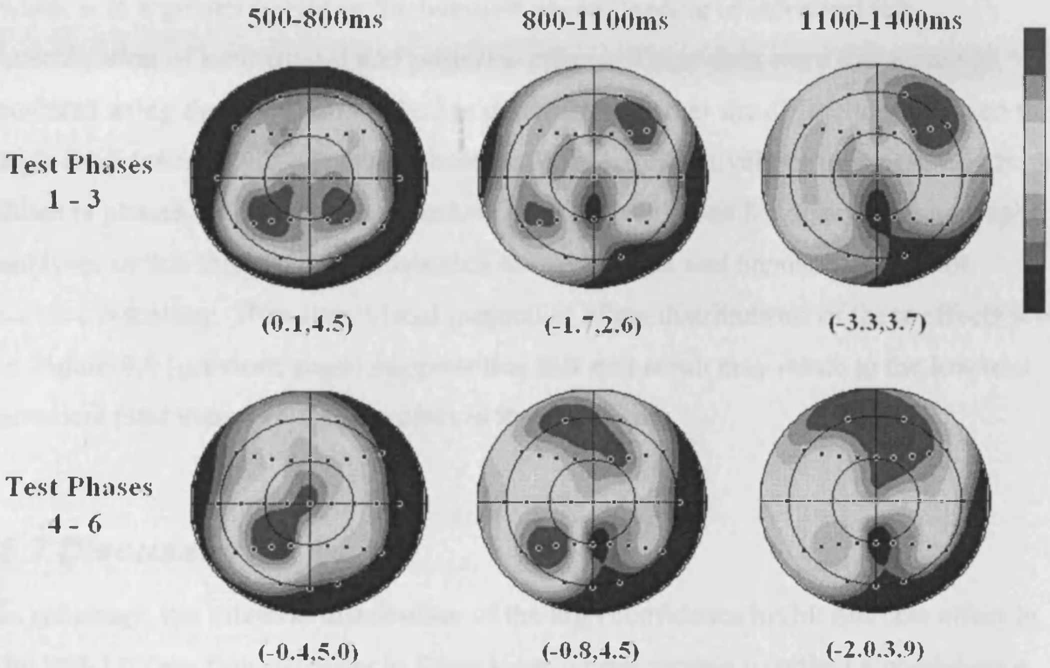


Figure 8.8: Topographic maps showing the scalp distributions of the high confidence hit/hit old/new effects over the 500–800, 800–1100, and 1100–1400ms time windows Experiment Three, separated between the first three and last three test phases.

The mean amplitudes submitted to the analyses were the difference amplitudes calculated by subtracting the mean amplitudes associated with correct rejections from those associated with high confidence hit/hits in phases 1-3 and 4-6 separately. These ERP old/new effects were analysed across the same 3 post-stimulus time windows (500-800, 800-1100, 1100-1400ms) using data from the same electrode locations as throughout this thesis. In each of the 3 time-windows, ANOVAs included factors of block (phases 1-3, phases 4-6), the anterior/posterior dimension, hemisphere, and electrode site. These analyses revealed reliable effects or interactions involving the factor of block in the 800-1100ms time-window only. This block by hemisphere interaction ($F(1,15) = 9.87$, $p<.01$) reflects the greater left-lateralisation of the markedly larger high confidence hit/hit old/new effect in the later phases (4-6). This did not interact with the anterior/posterior dimension, however. This is likely to have come about as a result of the concurrent differences in the magnitudes of the posteriorly-distributed left-parietal old/new effect which extends into this time-window to a greater extent in the later test phases leading to increased left-lateralisation of both frontal and posterior effects. These data were subsequently rescaled using the max-min method to determine whether the differences between the high confidence hit/hit effects in phases 1-3 differ qualitatively or quantitatively from those in phases 4-6 in this time-window (see Chapter Three for details of topographic analyses in this thesis). The interaction between block and hemisphere did not survive rescaling. However, visual inspection of the distributions of these effects seen in Figure 8.8 (previous page) suggests that this null result may relate to the low trial numbers (and therefore signal:noise) in these analyses.

8.7 Discussion II

In summary, the bilateral distribution of the high confidence hit/hit old/new effect in the 800-1100ms time-window in Experiment Three appears to reflect a combination of two frontal effects in this time-period – a right-lateralised effect associated with these judgments in the early phases of the experiment, and a relatively more left-lateralised effect associated with the same judgments in the later test phases. The presence of this left-frontal effect only in the later test phases of Experiment Three explains its initially surprising absence from the Visual condition grand average in the current experiment. What are the possible functional interpretations for the processes indexed by this left-frontal effect?

Kuo and Van Petten (2008) reported a functionally similar bilateral fronto-polar old/new effect from 800-1200ms in a source recognition task which was reliably larger in whichever of two perceptual source tasks were completed second. The authors interpreted this difference as reflecting a change in retrieval strategy in the second session in order to reduce the interference from previously associated attributes. A number of regions of PFC have been attributed a role in the resolution of interference in haemodynamic studies of memory retrieval. For example, Henson, Shallice, Josephs, and Dolan (2002) reported greater fMRI activity in left inferior frontal cortex and bilateral fronto-polar cortex during cued recall of words associated with high interference relative to low. Interference was operationalised by increasing or decreasing the number of items with which the cue had been previously associated. In another fMRI study, Sohn, Goode, Stenger, Carter, and Anderson (2003) reported activity in regions of bilateral DLPFC and VLPFC which increased with the number of competing items with which a test probe had been previously associated. Dobbins and Wagner (2005) interpreted activity in a region of left mid-VLPFC during correct source recollection which was insensitive to the domain of the target details (conceptual or perceptual) as reflecting the operations of a mechanism which selects the task-relevant target from competing, irrelevant details (see also Badre & Wagner, 2007; Buckner, 2003; Gold & Buckner, 2002; Lundstrom et al., 2005; Thompson-Schill et al., 1997).

As the number of preceding items increases, as in the later phases of Experiment Three, greater interference from these previously seen study events is likely to influence task judgments for both new and old items, perhaps requiring the engagement of such a mechanism in order to resolve this interference and select the task-relevant mnemonic detail. If the left-frontal old/new effect reflects the engagement of such a mechanism, however, it would not be expected to increase in magnitude over time since judgments to both new and old items would be equally affected by the increased interference. On average, however, the correct rejection of new items occurs early in the time-course of the 800-1100ms left-frontal old/new effect (919ms in phases 4-6 of Experiment Three), after which the requirement to resolve interference for these items is removed. This is not the case for items assigned to the correct source with high confidence, for which a correct old judgment is made after 979ms on average before an enforced pause of 1000ms precedes the source/confidence judgment. If, as has been proposed (Senkfor & Van Petten, 1998), source retrieval attempts are delayed until after an 'old' decision has been made, resolution and selection processes will continue to be required for the period of time following the 'old' decision in order to select the task-relevant contextual detail, and will therefore lead to the engagement of these processes to a greater extent for high confidence correct source judgments in the later test phases.

Study items in Experiment Four and the Auditory condition of the current study were presented auditorily and subsequent test items presented visually. It is possible that the amount of interference associated with test items in these cases will have been lower since fewer of the preceding items will have been presented in the same domain. Such an account may explain the absence of a left-frontal old/new effect in Experiment Four – a task of equal length to that in Experiment Three. A source memory experiment which employed auditory stimuli at study (male/female voice) and test was reported by Senkfor and Van Petten (1998) with old items presented in either the same or different voice as at study to which a three-way same/different/new decision was required. The bilateral distribution of the frontal old/new effect from 800-1200ms in this task is consistent with the above interpretation if it is assumed that the presentation of a familiar though incorrect feature, as in the case of 'different' test presentations, results in high levels of interference (Dodson, 2007; Dodson & Shimamura, 2000). Van Petten and colleagues (2000) also employed a same/different/new paradigm at test in a source memory task for which the spatial position of line drawings was to be retrieved at test and reported a bilaterally distributed late frontal old/new effect. In neither of these studies, however, were there reliable differences between the left frontal ERPs associated with items presented in the same or different source as at study, as might be expected if activity at this part of the scalp in this time-period were to reflect processes related to the resolution of interference. Kuo and Van Petten (2006), however, have reported such a result with reliably more positive-going ERPs associated with correct 'different' judgments at left-frontal electrodes from around 800ms onward in one of a pair of source memory tasks for which source accuracy was highest. In so far as test items presented in a familiar but incorrect context are associated with higher levels of interference (Dodson, 2007; Dodson & Shimamura, 2000), this result may also be considered to be consistent with a resolution/selection interpretation for left-frontal ERPs in source memory tasks during this time-period.

This resolution/selection account would seem to predict a left-frontal old/new effect for low confidence correct source judgments as well as high, perhaps even to a greater extent if it were considered that a low confidence response is made due to an inability to confidently select from a large number of competing memory traces. The response options in the combined source/confidence judgment of Experiments Three to Five did not include a 'don't know' option. As a result, a proportion of guessed responses are likely to have contributed to the low confidence correct source judgment category, for which a correct old judgment was made on the basis of familiarity alone. The greater noise in this category from responses not associated with recollected detail may have contributed to the attenuation of left-frontal old/new effects for these experiment conditions. This argument, however, cannot account for the bilaterally distributed frontal old/new effects associated with incorrect source judgments from 800-1200ms in the same/different studies reported by Van Petten and colleagues described above (Senkfor & Van Petten, 1998; Van Petten et al., 2000) since these judgments also would be considered to have been made on the basis of familiarity.

An alternative interpretation is that, during the course of time spent on task, changes occur in the ways in which study items are encoded. In the later study phases participants may have spontaneously adopted a more efficient and elaborative encoding strategy in order to successfully complete the task. Late frontal ERP old/new effects associated with the recollection of events which have been subject to different forms of encoding have been shown to vary in previous studies (for example J. D. Johnson et al., 2008; Rugg et al., 2000). Analyses of the ways in which ERPs acquired during the study phases change across time on task would speak to this possibility, however EEG was not recorded during the study phases of any of the experiments in the current thesis. This avenue may be a fruitful one to explore in future studies in order to elucidate the functional significance of the left-frontal old/new effect.

In summary, the left-frontal old/new effect observed in Experiment Three does not reflect processes engaged throughout the source retrieval task, but rather processes engaged only or to a greater extent in the later test phases – perhaps reflecting a change in encoding or retrieval strategy in order to complete the task successfully. This result has implications for claims made on the basis of averaged measures of neural activity. For the field of ERPs, the current finding suggests that averaged scalp distributions will not be reflective of the neural generators engaged throughout the task. This may have particular implications for studies which have employed lengthy retrieval tasks. More generally, for studies employing haemodynamic methods such as fMRI, this pattern of activity suggests that the brain regions identified as being active during retrieval may only support retrieval processing under some circumstances.

8.7.1 Content-Specificity of Late Frontal ERP Old/New Effects

In the analyses of data from all 32 participants in the current study the scalp topography of frontal high confidence hit/hit old/new effects from 500-1400ms was right-lateralised but differed reliably between the requirements to retrieve Visual or Auditory source information. As there were no reliable order effects, this result provides evidence for the engagement of prefrontally-mediated processes during contextual memory retrieval which are dependent upon the form of content to be retrieved. This neural dissociation also supports the claim from Experiment Three for multiple frontal old/new effects in source memory tasks.

Content-specific activations in PFC have been reported previously. In an fMRI comparison of the retrieval of visually presented abstract words versus monochromatic textured patterns, the former exhibited greater left PFC activation during encoding and retrieval relative to the greater right PFC activation of the latter during encoding and retrieval (Wagner et al., 1998). Greater left-lateralised activation of a region of PFC has also been reported during the retrieval of object names versus more right-lateralised activation during the retrieval of unfamiliar faces (McDermott et al., 1999). It has been observed in fMRI and PET studies that activation in PFC is lateralised according to the nature of the information to be retrieved/encoded, with left-PFC activation associated with the retrieval/encoding of verbal materials, and right-PFC activation associated with the retrieval/encoding of non-verbal, visuo-object materials (Badre & Wagner, 2007; Casasanto, 2003; Lee et al., 2000).

Dobbins and Wagner (2005) extended these findings by contrasting the retrieval of conceptual information – the conceptual encoding task which was performed at study – with the retrieval of perceptual information – the size (small/large) of the study drawing at encoding. The recollection of conceptual source information from the study episode was associated with activation in left anterior VLPFC, while the recollection of perceptual source information was associated with activation in right VLPFC. Interestingly, the levels of activation in these regions were also correlated with activations in more posterior content-specific regions leading the authors (see also, Badre & Wagner, 2007) to postulate that activity in left anterior VLPFC and right VLPFC reflects controlled retrieval processes which bias processing in the goal-relevant domain, by specifying, elaborating, or refining memory cues. One possibility is that the neurally dissociable right-frontal old/new effects in the current study may reflect these domain-specific processes.

The reliable qualitative differences between the distributions of the right-frontal Auditory and Visual old/new effects from 1100-1400ms reflects the fact that not entirely overlapping regions of cortex are involved in the generation of each of these effects (Rugg & Coles, 1995). As discussed previously in this thesis, a consensual account of the processes indexed by the late right-frontal old/new effect has yet to be realised. The current result suggests that this may be due to the variety of forms of source information employed in published ERP source memory studies – e.g. auditory, visual, conceptual – and are therefore not associated with entirely the same right-frontal old/new effects in each case.

8.8 Summary

The data from the current study provides strong evidence for dissociable late frontal ERP old/new effects between the retrieval of two forms of episodic content – visual and auditory. These differences at right-frontal sites from 1100-1400ms highlight the inappropriateness of the term ***the right-frontal ERP old/new effect*** since they provide evidence that multiple right-lateralised frontal old/new effects which are generated by not entirely overlapping regions of cortex are associated with the retrieval of different forms of content. The re-analysis of the data from Experiment Three revealed dissociable frontal old/new effects in the 800-1100ms time-window which are dependent not only upon the confidence with which correct source judgments are made, but also upon the time spent performing the memory task. These results in combination, therefore, provide evidence that ERPs are sensitive to the engagement of multiple PFC-supported processes which operate at different loci during the retrieval of episodic information. The question of the identity of these processes is one that is addressed, amongst other issues, in the General Discussion.

Table 8.3: Outcomes of the paired comparisons between the mean amplitudes associated with the high confidence hit/hit (HCHH), and correct rejection (CR) response categories, as well as for the old/new effects (O/N: calculated by subtracting the mean amplitudes associated with CR from those associated with HCHHs) in the Auditory and Visual conditions over the 500-800, 800-1100, and 1100-1400ms epochs at anterior and posterior sites separately. Reporting nomenclature are as throughout this thesis.

	500-800ms		**800-1100ms**		**1100-1400ms**	
	Anterior	**Posterior**	**Anterior**	**Posterior**	**Anterior**	**Posterior**
Visual HCHH vs. Visual CR						
RC (1,31)	16.15 ***	77.79 ***	8.56 **	9.15 **	4.93 *	ns.
RC x HM (1,31)	ns.	14.88 **	6.95 *	8.51 **	24.08 ***	ns.
RC x ST (4,124)	11.08 *** (0.63)	12.82 *** (0.50)	ns.	8.08 *** (0.61)	ns.	9.64 *** (0.71)
RC x HM x ST (4,124)	3.96 ** (0.87)	ns.	4.63 ** (0.81)	ns.	5.39 ** (0.84)	ns.
Auditory HCHH vs. Auditory CR						
RC (1,31)	42.08 ***	94.76 ***	24.36 ***	7.02 *	17.00 ***	ns.
RC x HM (1,31)	ns.	5.15 *	ns.	ns.	23.14 ***	ns.
RC x ST (4,124)	24.52 *** (0.62)	22.69 *** (0.52)	5.75 ** (0.72)	9.80 *** (0.51)	ns.	11.14 *** (0.78)
Visual O/N vs. Auditory O/N						
RC (1,31)	5.12 *	ns.	ns.	ns.	ns.	ns.
RC x ST (4,124)	3.35 * (0.73)	ns.	ns.	ns.	ns.	ns.
RC x HM x ST (4,124)	2.68 * (0.90)	ns.	2.66 * (0.88)	ns.	2.60 * (0.88)	ns.

Figure 8.9: Grand average ERPs associated with correct rejections and high confidence hit/hit responses for both the Visual and Auditory conditions. Data are shown for all 35 electrode sites.

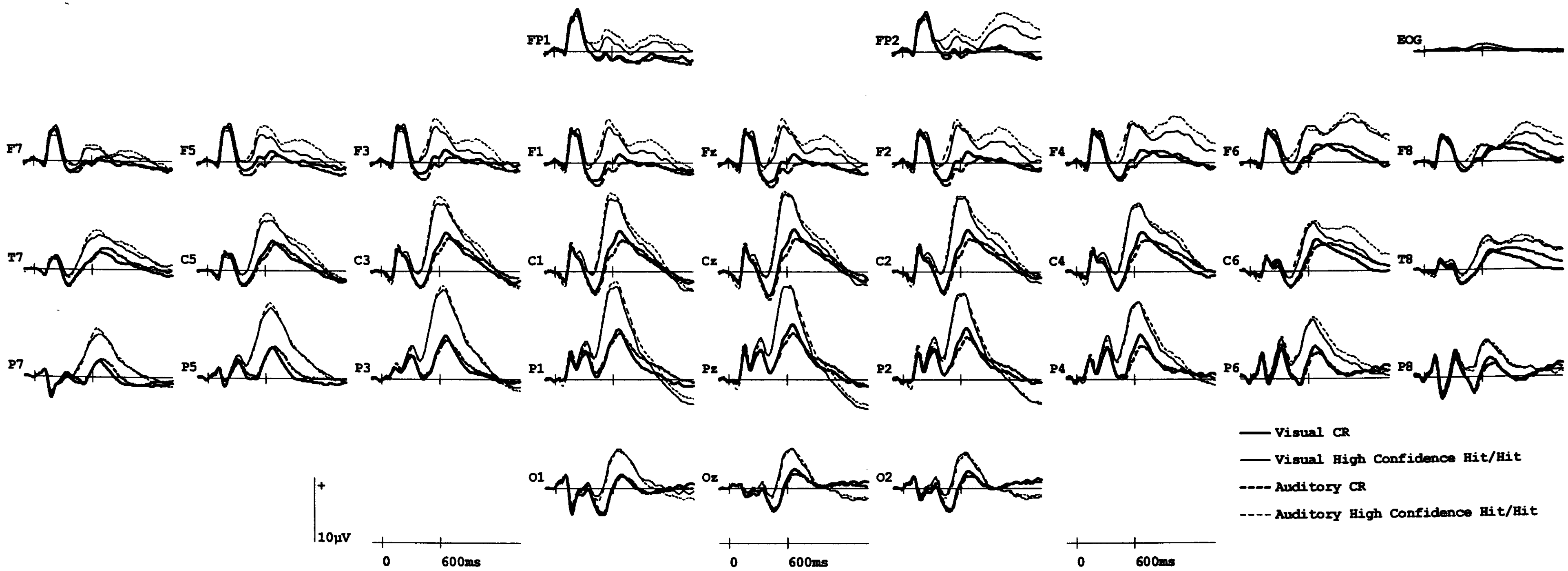


Figure 8.10: Grand average ERPs associated with correct rejections and high confidence hit/hit responses for both the Visual and Auditory conditions for those participants in the Visual-Auditory group only. Data are shown for all 35 electrode sites.

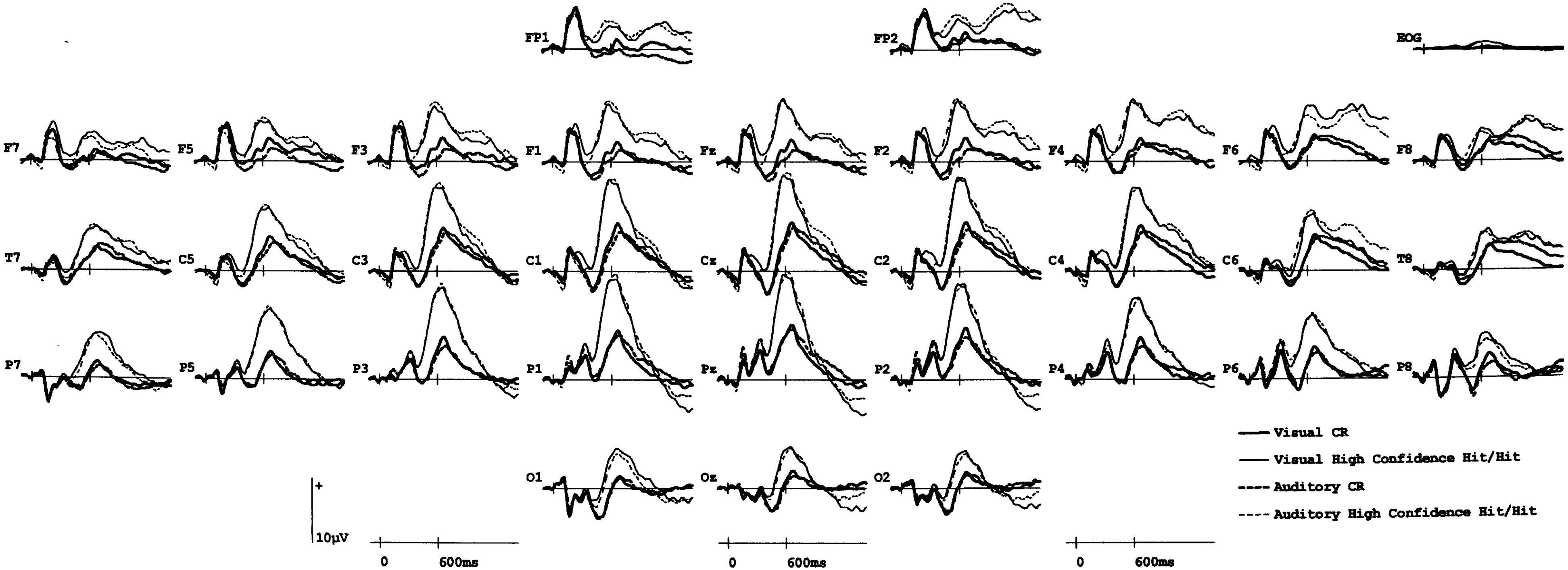


Figure 8.11: Grand average ERPs associated with correct rejections and high confidence hit/hit responses for both the Visual and Auditory conditions for those participants in the Auditory-Visual group only. Data are shown for all 35 electrode sites.

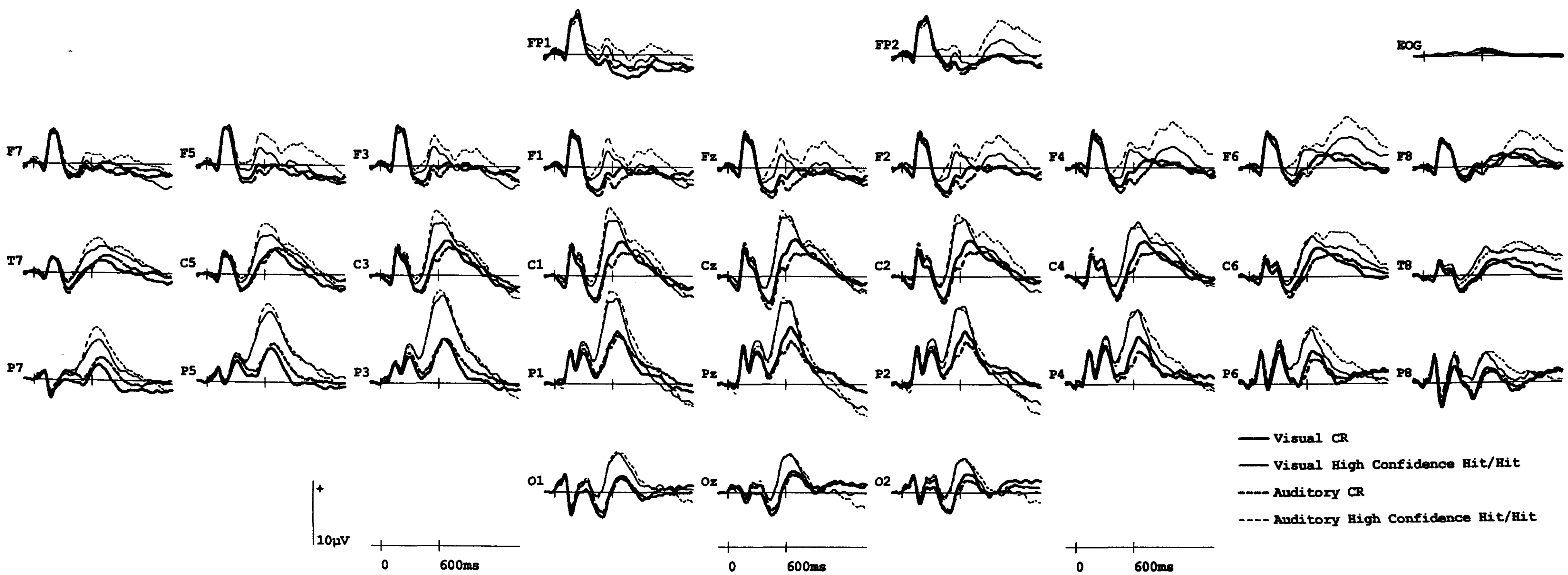


Figure 8.12: Grand average ERPs associated with correct rejections and high confidence hit/hit responses from test phases 1-3 of Experiment Three. Data are shown for all 35 electrode sites.

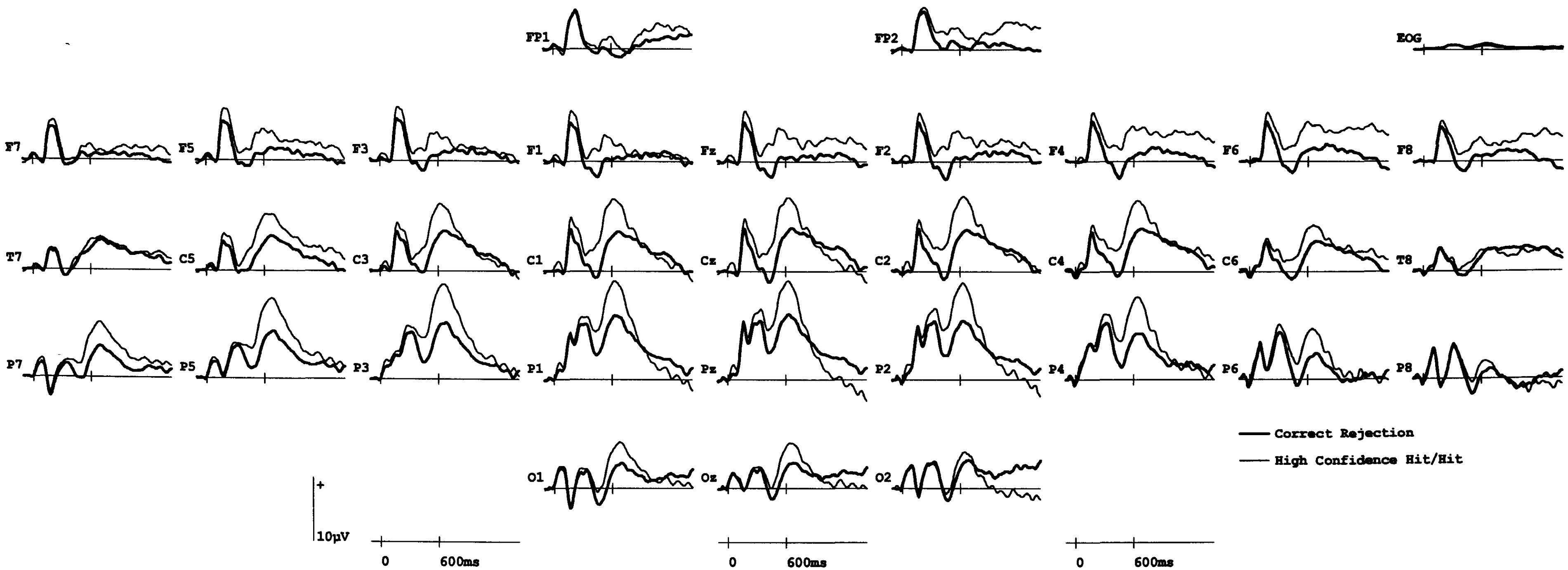
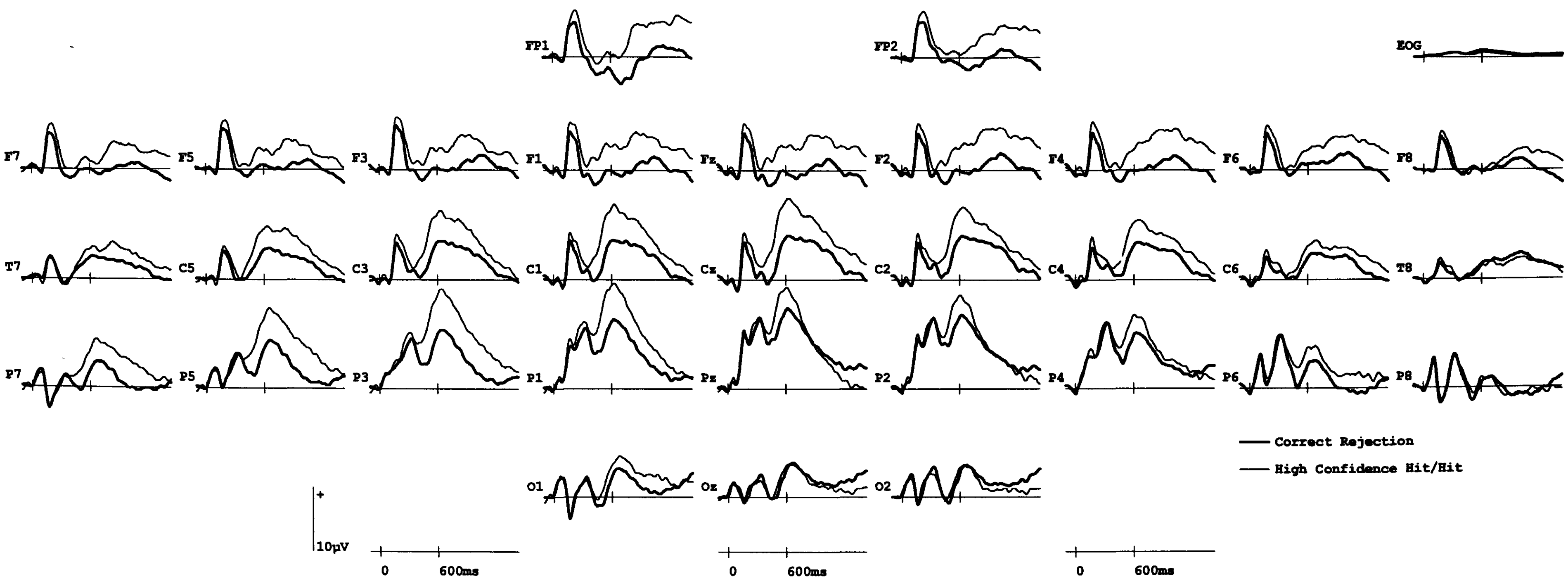


Figure 8.13: Grand average ERPs associated with correct rejections and high confidence hit/hit responses from test phases 4-6 of Experiment Three. Data are shown for all 35 electrode sites.



Chapter Nine : General Discussion

9.1 Introduction

The focus of the work in this thesis has been on contributing to a characterisation of the processes that are supported by the PFC during episodic retrieval. This has been accomplished by assessing the likely functional significance of a known ERP old/new effect, and by extending the work to related questions concerning PFC contributions to episodic retrieval on the basis of experiment outcomes. The key findings are discussed in this chapter, beginning with those aspects that have contributed to our understanding of one well-documented but poorly understood ERP modulation obtained in source memory tasks – the right-frontal ERP old/new effect. The findings in this thesis are relevant to functional accounts of this modulation, as well as considerations about the brain regions that are responsible for the effect.

9.2 Insights into the Functional Significance of the Right-Frontal ERP Old/New Effect

As noted in the introductory chapter of this thesis, disparate findings in the contrasts between ERPs associated with correct and incorrect source judgments across studies have offered a challenge for a unified account of the functional significance of the right-frontal ERP old/new effect. In some experiments the effect is larger for correct than for incorrect source judgments (Wilding, 1999; Wilding & Rugg, 1996), while in others the effect does not predict source accuracy (Senkfor & Van Petten, 1998; Van Petten et al., 2000). The findings from Experiments One to Three take us forward in that they discount two potential contributing factors to these existing disparities.

First, in the published studies in which right-frontal old/new effects have not predicted the accuracy of source judgments, a proportion of test items were copy cues of studied items. For example, in the study reported by Senkfor & Van Petten (1998), words were spoken in a male or female voice at study and an equal number of words were spoken in the same/different voice as at test. By contrast, in the studies where right-frontal old/new effects predicted accurate source judgments, no test items were copy cues. There were no copy cues in Experiment One, in which the source judgment comprised study colour. The key finding was that late right-frontal old/new effects (1100-1400ms) did not predict the accuracy of source judgments. This outcome suggested that the presence or absence of copy cues does not predict when the right-frontal old/new effect will predict the accuracy of source judgments. In order to provide sufficient trials for this contrast, however, it was necessary to collapse across the manipulation of task difficulty. The difficulty manipulation was included to investigate how the right-frontal effect was influenced by this factor. As a result of this, the insensitivity to source accuracy may have come about as a result of differences in the way items were processed between the two difficulty conditions. This consideration motivated the design of Experiment Two which had the same source memory design as Experiment One – i.e. no copy cues at test – but did not include the difficulty manipulation. Consistent with the result from Experiment One, there were no reliable differences between the correct and incorrect source right-frontal old/new effects in Experiment Two. The analyses in Experiment Three also included this contrast and demonstrated the same pattern of equivalent right-frontal effects, although this comparison was made on data collapsed across the confidence with which source judgments were made. This consistency across three experiments provides strong evidence that the correspondence between study items and test cues is not a critical antecedent for the conditions under which the right-frontal effect will predict the accuracy of source judgments.

Second, in the studies where right-frontal old/new effects did not predict source accuracy, the old/new and source judgments were made at the same time. For example, in the Senkfor & Van Petten (1998) study described above, the test judgment was a single three-way *same voice/different voice/new* distinction. In the studies reported by Wilding & colleagues (Wilding, 1999; Wilding & Rugg, 1996), however, an initial old/new judgment was followed by a delayed binary (male/female voice) source judgment. Similarly, in Experiments One to Three, an old/new judgment preceded the source judgments (or source/confidence judgment in Experiment Three). The divergences between the findings for the right-frontal ERP old/new effects in Experiments One to Three and the earlier experiments by Wilding and colleagues, despite the use of two-step test judgments in all cases, argue that the format of test responses does not contribute to the circumstances under which the accuracy of source judgments is predicted by the magnitude of right-frontal old/new effects.

Recently, the seemingly disparate data points across the literature have encouraged a somewhat more generic processing characterisation for the right-frontal old/new effect. An account entertained by Hayama and colleagues (2008), who obtained equivalent right-frontal effects in two tasks requiring either source or semantic retrieval, is that the right-frontal old/new effect is sensitive to the number of internal criterial decisions made in order to reach a task judgment. Experiment Three was designed to test this account directly. In that experiment, participants studied words presented visually in either pink or yellow. At test, an old/new judgment was made to words presented in white and, for words judged to be old, a subsequent judgment of the study source (pink/yellow) alongside the confidence (high/low) with which that judgment was made. It was argued that the number of criterial decisions required to make a correct source judgment was equivalent regardless of the level of confidence with which it was made. The reliable differences between the right-frontal ERP old/new effects associated with high and low confidence correct source judgments in Experiment Three, therefore, provide a strong challenge to this account.

This result also speaks to the issue of the regions of PFC which are involved in generating this right-frontal activity. The decision account was proposed on the basis of fMRI evidence that activity in right dorso-lateral PFC (DLPFC) was sensitive to this variable. Dobbins and Han (2006) contrasted activity in PFC across two memory tasks. In each task, participants were presented with two words simultaneously at test. In the forced-choice condition the participants were required to judge which of the two items was old (or new). In the other condition, the participants were required to judge whether the old/new status of both items was the same or different. Right DLPFC was more active during the same/different task than the forced-choice task. The authors argued that the number of internal criterial decisions required for the judgment was larger in the same/different task – i.e. a decision about the old/new status of *both* items was required rather than the old/new status of only one of the items for the forced-choice task – and that right DLPFC was therefore sensitive to this difference across tasks. In a subsequent study, Han and colleagues (2009) provided further support for this account by demonstrating that activity in lateral PFC is insensitive to the level of item competition (i.e. 2, 3, or 4 simultaneous test cues) or task difficulty, but varies with the number of internal decisions required by the task.

Consequently, if there was strong evidence linking the right-frontal ERP effect with activity in right DLPFC and to no other regions of PFC, the findings in Experiment Three would also present a challenge to the account of DLPFC function offered by Dobbins & Han (2006; Han et al., 2009). The neural generators of the right-frontal old/new effect, however, are not well-established. In light of this, the neuroanatomical conclusion to be drawn for the right-frontal ERP old/new effect is that the generators of the effect are not restricted to the right DLPFC.

This is not to say, however, that right-DLPFC plays no role in the generation of right-frontal old/new effects in source retrieval tasks, since a good case for its involvement can be made. For instance, the right-frontal ERP old/new effect is the difference between the neural activity elicited by correct judgments to old and to new items, and is pronounced when source judgments are required. In tasks where an old/new judgment precedes a source judgment that is made only for items judged to be old, the number of decisions required is greater for old than for new items. If neural activity in right-DLPFC is sensitive to this parameter then it is a candidate as a contributor to the right-frontal ERP old/new effect. Similarly, in tasks where a three-way task judgment is required (old context A/old context B/new), the presence of right-frontal old/new effects is consistent with the view that the effect receives a contribution from right-DLPFC if, as has been claimed, an internal decision that an item is old typically precedes the source judgment despite the presence of a single three-way response requirement (Senkfor & Van Petten, 1998). These arguments link activity within right-DLPFC to the right-frontal ERP old/new effect and predict that there will be circumstances in which the effect will vary according to the number of internal decisions that are made. However, the foregoing arguments regarding the data from Experiment Three also make it clear that the right-frontal old/new effect does not *only* receive contributions from this region of the PFC. These additional generators do not necessarily have to be located in right PFC, as generators located on the medial walls are capable of producing a scalp field with a contralateral maximum (see Barrett et al, 1976; Brunia & Vingerhoets, 1981; Woodruff et al., 2006). Complimenting ERP findings with haemodynamic imaging data, therefore, will be a fruitful approach to identifying potential neural generators of the right-frontal effect in source retrieval, and may contribute to a unified characterisation for the processes with which it is associated (cf. Hayama et al., 2008; Hayama & Rugg, 2009).

Another account which has been considered in attempts to define the functional role of the right-frontal ERP old/new effect proposes that it indexes the engagement of post-retrieval processes to monitor and/or evaluate the products of retrieval (Friedman & Johnson, 2000; Rugg et al., 2002; Rugg & Wilding, 2000; Wilding & Rugg, 1996). As noted in Chapter Six, the reliably larger right-frontal old/new effect associated with high confidence correct source judgments relative to low confidence correct source judgments obtained in Experiment Three is difficult to reconcile with one incarnation of this account (Henson et al., 2000) in which monitoring requirements increase with a decrease in the quality of information recovered, and a decrease in information quality is indicated by low confidence responses.

A similar pattern of activity at right-frontal sites to that in Experiment 3 was observed by Woodruff and colleagues (2006). In that study, participants completed a modified Remember/Know procedure in which, for words not assigned a Remember response, participants rated their confidence (high/low) in the Know and New responses. From 800ms post-stimulus, the ERPs associated with high confidence Know responses at right-frontal sites were more positive than those associated with low confidence Know and high/low confidence New responses. The latter three response categories did not differ reliably from one another. As the authors acknowledged, it is difficult to accommodate this pattern of data with Henson and colleagues' (2000) monitoring account as low confidence responses would be considered to have been associated with monitoring to a greater extent than high confidence. It was argued in Chapter Six, however, that the larger right-frontal effect for high than low confidence judgments can be considered to be consistent with such a monitoring account if it is assumed that in averaged ERPs the right-frontal effects will be larger for conditions in which the *average* distance to criterion across the items contributing to the average is smaller and that this will depend upon both the shape of the underlying distribution and the placement of the response criterion. For example, for the Gaussian distribution shown in Figure 6.3 (page 109), placement of a criterion to the far right will lead to a smaller average distance to criterion for those items falling to its right than for those items falling to its left. One means of testing this proposal will be to hold encoding conditions constant and manipulate the placement of criterion by means of test instructions. Any changes in the magnitudes of right-frontal ERPs alongside the changes in criterion placement could therefore be interpreted in terms of this account, and speak to the ways in which monitoring processes can be considered to be indexed by the right-frontal old/new effect.

9.3 Evidence for Dissociable PFC-Supported Processes Indexed by ERPs

It was noted in Chapter One that, given the evidence from haemodynamic imaging and lesion studies for the neuroanatomical and functional heterogeneity of the PFC across numerous cognitive domains (Fletcher & Henson, 2001; Ranganath, 2004; Ranganath & Knight, 2003; Stuss et al., 1994), it is somewhat surprising that, thus far, ERPs in tasks requiring source retrieval have not been shown to be sensitive to more than one PFC-supported process. The results of Experiments Three to Five, however, provide compelling evidence for the presence of multiple neurally and functionally dissociable PFC-supported processes in the electrical record. The data pertinent to this is discussed next, beginning with the evidence for the content-specificity of late frontal ERP old/new effects.

9.3.1 The Content-Specificity of the Right-Frontal ERP Old/New Effect

The results of Experiment Five provide strong evidence for the content-specificity of late frontal ERPs. In that study, frontal ERP old/new effects associated with high confidence correct source judgments were reliably right-lateralised for both the retrieval of visual and auditory information. However, from 500-1400ms the scalp distributions of these effects differed reliably between the two forms of content, thereby implicating not entirely overlapping regions of PFC in their generation (Rugg & Coles, 1995), consistent with the findings in fMRI studies that have shown activity in PFC to be dependent upon the contents of retrieval (Badre & Wagner, 2007; Casasanto, 2003; Dobbins & Wagner, 2005; Lee et al., 2000; McDermott et al., 1999; Wagner et al., 1998;).

It has been noted (J. D. Johnson et al., 2008; Yick & Wilding, 2008) that, due to the sluggish nature of the haemodynamic response, it is not possible on the basis of fMRI data alone to determine whether content-specific cortical activations (e.g. Wheeler, Petersen, & Buckner, 2000; Woodruff, Johnson, Uncapher, & Rugg, 2005) reflect the retrieval of the episodic content directly, or are a reflection of content-dependent processing which occurs subsequently. Recent studies have employed ERPs in order to investigate these possibilities by using the left-parietal old/new effect, widely held to index recollection (Curran, 2000; Vilberg et al., 2006), as a temporal marker within the time-course of episodic retrieval. Content-dependent activity preceding or within the same time-frame as the left-parietal old/new effect (observed at posterior sites between 500-800ms in this thesis) is considered to support the proposal that the content-dependent neural activity observed in fMRI studies reflects the online recovery of the distinct forms of content. Content-dependent ERP activity found later in the recording epoch would also provide evidence for the content-dependence of subsequent processing.

In one relevant study by Johnson and colleagues (2007), participants studied object names superimposed onto pictures of scenes or presented onto a grey background. For words presented onto images of scenes (Scene condition), the participants were required to imagine the object as part of the scene, whereas for words presented on a grey background (Sentence condition), the encoding task was to generate a meaningful sentence which incorporated the word. At test, participants were presented with previously studied and new words and made a Remember/Know/New judgment. Reliable qualitative differences in the scalp topographies of the old/new effects associated with Remember responses – occasions in which the retrieval of contextual information is thought to have occurred (Tulving, 1985) – in the Scene and Sentence conditions were evident from 500ms post-stimulus. A similar finding was reported by Yick and Wilding (2008) who contrasted the old/new effects associated with correct old judgments to studied faces and words. The scalp distributions of the face and word old/new effects differed reliably from 500ms post-stimulus onwards. The onset time of these content- (Johnson et al., 2007) and material-dependent (Yick & Wilding, 2008) activations (see also MacKenzie & Donaldson, In Press) provides support for the proposal that at least some of the content- and material-dependent neural activity observed in fMRI studies reflects activity associated with the online recovery of different episodic contents.

The task employed in the study by Yick and Wilding (2008), however, only required an old/new recognition judgment at test. The old/new effects in that study are therefore not necessarily representative of processes associated solely with recollection of the study event. Similarly, while the instructions for the task employed by Johnson and colleagues (2007) were to respond Remember only when specific details of the study event could be remembered, there was no requirement to justify these responses. The content-dependent old/new effects evident from 500ms in Experiment Five therefore are consistent with the proposal that at least some content-dependent fMRI activations reflect the online recovery of episodic content since they are associated with high confidence correct judgments of a contextual detail from the study event, which are likely to have been made solely on the basis of recollection[3].

Johnson and colleagues (2007) reported content-dependent activity later in the recording epoch also. There was an anteriorly-distributed old/new effect in the Sentence condition and a posteriorly-distributed effect in the Scene condition. These effects were reliable from 300ms and 500ms respectively, and lasted up to 1400ms post-stimulus. This pattern of activity likely reflects the operation of PFC-supported processes in the former case to a greater degree than in the latter. Conversely, the results of Experiment Five demonstrate reliable frontally-distributed old/new effects associated with *both* the retrieval of visual and auditory content but which do not receive contributions from completely overlapping regions of PFC. This takes the result of Johnson and colleagues (2007) further and demonstrates that the retrieval of two different kinds of episodic content may both be associated with PFC-supported post-retrieval processes in service of the same task goal, but that not entirely the same operations are engaged to equivalent extents in each case.

[3] One caveat here, discussed by Yick and Wilding (2008), is that the content-dependent activity observed in the same time period as the left-parietal old/new effect (500-800ms) may instead reflect the engagement of content-dependent post-retrieval processes, which operate iteratively, and come online as recovered information becomes available. Evidence for content-dependent activity occurring prior to the onset of the left-parietal old/new effect in Experiment Five would allow for stronger claims to be made with regard to activity associated with the online recovery of episodic content. However, analyses in this early time-period are not reported in this thesis.

Studies employing fMRI and PET have shown that activation in PFC is lateralised according to the nature of the retrieved/encoded information, with left-PFC associated with the retrieval/encoding of verbal materials, and right-PFC with non-verbal, visuo-object materials (Badre & Wagner, 2007; Casasanto, 2003; Lee et al., 2000). In an fMRI study, Dobbins and Wagner (2005; see also Badre & Wagner, 2007) contrasted the retrieval of conceptual information from the study episode – the encoding task which was performed – with the retrieval of perceptual information from the study episode – the size (small/large) of the study drawing. Correct judgments for the conceptual source of the study episode were associated with activation in left anterior ventro-lateral PFC (VLPFC), while correct judgments for the perceptual source were associated with activation in right VLPFC. Interestingly, the levels of activation in these regions correlated with activations in more posterior content-specific cortical regions, leading the authors to posit that this content-dependent lateralisation of PFC activity may reflect controlled retrieval processes involved in biasing processing in goal-relevant posterior cortex by specifying, elaborating, or refining memory cues. The content-dependent late frontal ERP old/new effects observed in Experiment Five may be homologous electrophysiological signatures of the content-dependent activity that was observed using fMRI.

This result of Experiment Five also highlights the fact that the term ***the right-frontal old/new effect*** used in reports of source memory tasks is inappropriate, since it provides evidence for at least two old/new effects with spatially distinct maxima in the same time-period. This finding indicates that the effects are either not generated by entirely the same regions of PFC, or that the relative degree of engagement of the same set of generators is not equivalent. Clearly this finding has implications for a unified account of the right-frontal old/new effect since it suggests that the same effect may not have been observed across studies employing different forms of study content or study operations. This is highlighted further by the results of Experiment Four in which study items were words spoken in a male/female voice, and all test items were presented visually. As with the source memory studies by Wilding and colleagues (Wilding, 1999; Wilding & Rugg, 1996), late right-frontal ERPs were reliably more positive for correct relative to incorrect source judgments. This is in contrast to the consistent pattern of equivalent correct and incorrect source right-frontal effects across Experiments One to Three in which study materials were presented visually rather than auditorily. Such a change in the relative magnitudes of these effects across studies employing the same paradigm but with different study materials is consistent with the content-specificity of frontal ERPs observed in Experiment Five and again serves to highlight the likelihood that not entirely the same right-frontal old/new effects have been observed across published studies in which a variety of study materials have been employed. One possibility is that across these studies, at least two frontal effects have been observed – one right-lateralised effect reflecting generic content-independent post-retrieval processes, and another less right-lateralised effect that may be content-dependent. If, therefore, across experiments these effects are engaged to differing degrees as a result of differences in task design then, because of the summation of electrical activity at the scalp, differential sensitivities to certain manipulations may be observed, such as the accuracy of source judgments. This is very likely to have contributed to the difficulties of providing an account capable of reconciling the majority of published data points.

9.3.2 The Effects of Time on Task

A serendipitous finding which was not related to any pre-experimental hypotheses concerns the differential contribution of late frontal ERPs over the course of a retrieval task. In Experiment Three, from 800-1100ms post-stimulus, the ERPs associated with correct source judgments separated according to confidence were both associated with reliable frontal old/new effects. However, only the low confidence correct source old/new effect was reliably right-lateralised. The high confidence effect was distributed bilaterally. Crucially, this difference between distributions remained after the data were rescaled, which implies that not entirely overlapping regions of cortex were responsible for the generation of the two effects (Rugg & Coles, 1995). This result was interpreted as reflecting a right-frontal old/new effect for both classes of correct source judgment, and a left-frontal old/new effect for high confidence judgments only.

Experiment Four was designed in order to determine whether this left-frontal old/new effect reflected processes associated specifically with the retrieval of visual/colour information or with more general processing associated with high confidence correct source judgments. The task was identical to that in Experiment Three with the exception that the source information to be retrieved at test was the voice in which the word was spoken at study (male/female). Unlike the results of Experiment Three, frontal old/new effects were right-lateralised for both high and low confidence correct source judgments in Experiment Four and did not differ reliably. This difference can be seen clearly in a comparison of Figures 6.2 and 7.2 (pages 104 & 131). The absence of a left-frontal old/new effect for high confidence correct source judgments in this study therefore argued for a content-specific role for this process observed in Experiment Three. In order to provide more robust support for this claim, Experiment Five contrasted the tasks employed in Experiments Three and Four in a within participants design.

However, the results of Experiment Five provided no evidence for a left-frontal old/new effect associated with high confidence correct judgments for visual source information (word colour at study), as had been observed in Experiment Three. Figure 9.1 (overleaf) highlights very well the focal right-lateralised distribution of the frontal old/new effect from 800-1100ms in Experiment Five compared with the bilateral distribution in Experiment Three. This result argues strongly against a content-specific account for the left-frontal old/new effect. It was noted, however, that the task in Experiment Three involved the completion of a greater number of study-test blocks than the analogous condition in Experiment Five (the *Visual* condition). This generated the hypothesis that the bilateral distribution in the average from Experiment Three was driven primarily by activity generated in the later test phases only, and therefore was not observed in Experiment Five.

The data from Experiment Three were therefore separated into two blocks – data from the first three (of six) test phases of the experiment, and data from the last three test phases. Comparison of the high confidence correct source judgment old/new effects across the first and second half of the experiment revealed that this old/new effect was right-lateralised during the first three test blocks from 800-1100ms and reliably more left-lateralised in the same time-period in the latter three test-blocks. Hence the high confidence correct source old/new effect in Experiment Three appears to be bilaterally distributed, when in reality it reflects the summation of two distinct frontal effects with different degrees of laterality dependent upon which periods of data acquisition are inspected.

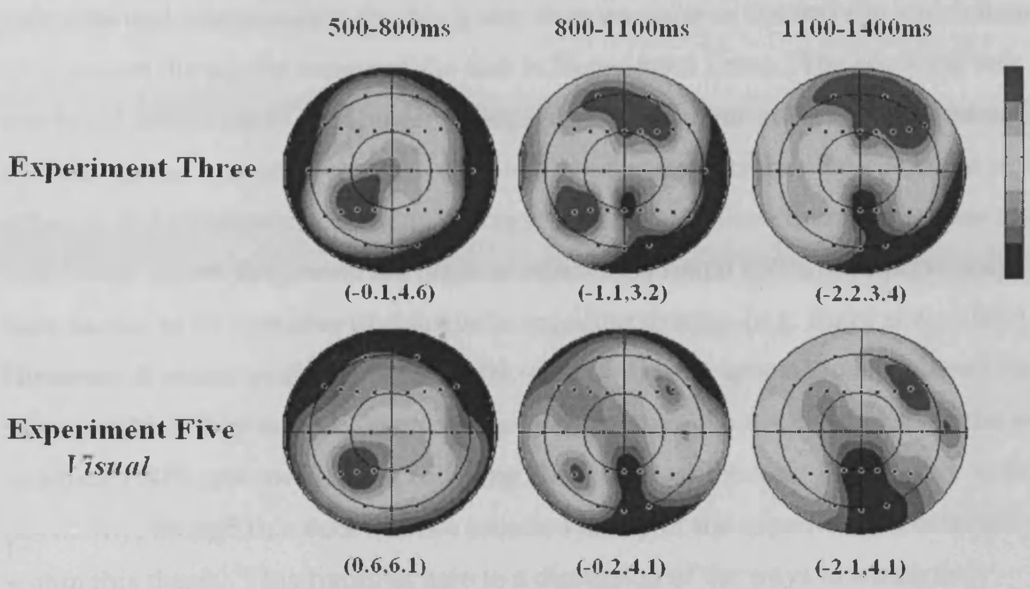


Figure 9.1: Scalp distributions of the high confidence hit/hit old/new effects in Experiment Three and Experiment Five (*Visual* condition). The distributional differences at frontal sites are clear to see in the 800-1100ms and 1100-1400ms time-windows.

This evidence that bilaterally distributed old/new effects across blocks are a result of averaging two effects with different degrees of laterality that vary over the course of a retrieval task may also be a reason for inconsistencies in the behaviour and scalp distributions of frontal old/new effects across published studies. As highlighted in Chapter One, the degree to which late frontal old/new effects are right-lateralised varies (cf. Senkfor & Van Petten, 1998; Wilding & Rugg, 1996). Reliably right-lateralised late frontal effects have been reported in studies which employed relatively shorter tasks (between 3 and 6 study-test blocks: Wilding, 1999; Wilding & Rugg, 1996, 1997a, 1997b) than those employed in studies reporting bilateral late-frontal old/new effects (between 9 and 16 study-test blocks: Senkfor & Van Petten, 1998; Van Petten et al., 2000). One way of reconciling these findings is to argue that a left-frontal old/new effect is engaged to a greater degree in the later stages of a retrieval task, hence the reason for frontal old/new effects that are less right-lateralised in longer tasks.

One potential interpretation for this is that changes occur in the ways in which items are encoded during the course of the task in Experiment Three. The encoding task employed in that study was simply a judgment of the colour in which the word was written. In the later study phases of the task the participants may have adopted a more efficient and elaborative encoding strategy which would allow them to increase the speed with which judgments are made at retrieval. Frontal ERPs have previously been shown to be sensitive to changes in encoding strategy (e.g. Rugg et al., 2000). However, it seems unlikely that all participants will have spontaneously altered the ways in which they encoded items in the later stages of the task. Analysis of the ways in which ERPs recorded during encoding change across the task would speak to this possibility, though this data was not acquired in any of the experiments contained within this thesis. This limits us here to a discussion of the ways in which the demands of retrieval change across a *retrieval* task and how these relate to the changes in frontal ERPs.

One candidate interpretation is that the left-frontal activity seen only in the later phases of a retrieval task reflects processes involved in the resolution of interference due to the increased number of preceding stimuli, a role with which the PFC has been implicated in previous studies (Dobbins & Wagner, 2005; Henson et al., 2002; Sohn et al., 2003). Kuo and Van Petten (2008) reported a functionally similar bilaterally distributed fronto-polar ERP old/new effect with a similar time-course (from 800-1200ms post-stimulus) which was larger for whichever of two perceptual source tasks were completed second, and was interpreted by the authors as reflecting a change in retrieval strategy to reduce interference. In an earlier source memory study in which test items were presented in the same/different colour at test and at study, Kuo and Van Petten (2006) reported reliably more positive left-frontal ERPs associated with correct 'different' judgments than 'same' judgments from 800ms, consistent with the interference resolution account for left-frontal ERPs in this time period since items presented in a familiar but incorrect context are considered to be associated with higher levels of interference from other memory traces than those presented in the same context as at study (Dodson, 2007; Dodson & Shimamura, 2000).

The fact that this left-frontal old/new effect also differentiated between high and low confidence correct source judgments in Experiment Three implicates it in processes which operate on the products of retrieval. The ERPs associated with low confidence correct source judgments in that experiment were also associated with a small (statistically non-significant) left-parietal old/new effect relative to the far larger high confidence effect (see Figure 6.2, page 104). A large body of evidence ties the left-parietal old/new effect to recollection (Duarte et al., 2004; Duzel et al., 1997; Smith, 1993; Wilding, 2000; Wilding & Rugg, 1996; Wilding et al., 1995). The lack of a reliable left-parietal effect for low confidence correct source judgments therefore indicates that these items were associated with very low levels of contextual retrieval, and may not have been correctly identified as old on the basis of this information, but perhaps on the basis of familiarity[4]. It is plausible that the greater amount of contextual information associated with items attracting high confidence correct source judgments, as indexed by the large left-parietal effect for this response category, required the engagement of processes to resolve interference and select the appropriate piece of information from amongst other competing products of retrieval, whereas the considerably lower levels of recollected detail associated with items attracting low confidence correct source judgments did not engage such processing. The timing of this effect, extending later in time than the left-parietal index of recollection (800ms+), is consistent with this interpretation.

A similar argument can be applied to aspects of the data from Experiment One. In that experiment, the difficulty of retrieval was manipulated by increasing the number of items which were to be learned in some study lists such that lists in the Difficult condition were three times longer than those in the Easy condition. While there were

[4] While no analyses of ERPs in the 300-500ms time-window are reported in this thesis, the current issue is directly testable with analyses at frontal sites in this time-window, since the FN400 has been linked by some to the familiarity component of dual-process models of recognition memory (Curran, 2000; although see, Paller, Voss, & Boehm, 2007). Subsidiary analyses on the current data did not reveal significant frontal old/new effects for either high- or low-confidence responses in the 300-500ms time-period which did not differ from one another. This lack of reliable effects does, therefore, not add anything to this possible interpretation. As discussed in Chapter Three, source retrieval tasks may not be the best approach to investigating the contributions of familiarity due to other large frontal effects which are associated with retrieval in these tasks. Previous studies which have also demonstrated patterns of late frontal effects which may be explained in terms of the variable contribution of familiarity, have not reported analyses on the FN400 (e.g. Senkfor & Van Petten, 1998; Van Petten et al., 2000).

no reliable differences between the frontal old/new effects associated with correct source judgments in the Easy and Difficult conditions, the late frontal old/new effect (1100-1400ms) was bilaterally distributed in the Easy condition and right-lateralised in the Difficult condition, similar to the high/low confidence correct source judgment distinction in the ERP data from Experiment Three (see Appendix A). From an interference resolution perspective, the fewer intervening items between the study lists in the Easy condition may have resulted in greater inter-list interference for this condition and therefore have led to the engagement of the left-frontal effect for this condition only, contributing to the bilateral distribution. Equally, however, it may be argued that the longer lists employed in the Difficult condition will have resulted in greater intra-list interference which will also have required the engagement of such resolution processes. It is unclear how the cognitive processes involved in the resolution of inter-list versus intra-list interference would differ here. This result from Experiment One, therefore, is broadly consistent with the resolution and selection account for the differences between high/low confidence correct source judgment effects in Experiment Three. Though statistically unreliable, the attenuated left-parietal old/new effect in the Difficult condition relative to the Easy condition can also be accommodated by this account.

The differences between the high/low confidence correct source frontal old/new effects in Experiment Three are reminiscent of an effect reported in a study by Woodruff and colleagues (2006) discussed above in which participants completed a modified Remember/Know procedure which required a confidence rating (high/low) for Know and New responses. The ERPs associated with Remember responses diverged from those associated with high confidence Know responses from 800ms at frontal and fronto-polar sites. The distribution of this late frontal Remember effect differed reliably from the right-lateralised late frontal high confidence Know effect after rescaling. There was no reliable left-parietal old/new effect obtained for high confidence Know responses, consistent with the claim that these responses are made on the basis of familiarity rather than recollection. In so far as high confidence correct source judgments in Experiment Three were made on the basis of recollection to a far greater extent than those made with low confidence, the qualitatively different patterns of frontal activity between these two response categories are consistent with the differences observed by Woodruff and colleagues (2006) between ERPs associated with remember and high confidence Know responses. Woodruff and colleagues (2006) offered little discussion regarding this effect other than to associate it with processes linked to recollection. The apparent content-dependence of the left-frontal old/new effect, demonstrated by its absence from the ERPs in an identical study for which study stimuli were auditory rather than visual (Experiment Four), argues, however, against a general role for this effect in recollection and provides more support for an interference resolution interpretation.

The task employed in Experiment Four was identical in length to that employed in Experiment Three, and yet no evidence for a left-frontal old/new effect was observed, indicating that it is not merely related to the amount of time spent performing the task, or the number of preceding stimuli encountered. It is possible that across the auditory study stimuli employed in Experiment Four there was greater perceptual variability as a result of variations in the inflection of the voice or the length of time taken to speak each study word. Study stimuli in Experiment Three, however, were simply presented in one of two colours for a fixed length of time (300ms). The greater perceptual overlap between visual study items relative to the auditory stimuli in Experiment Four may have resulted in relatively higher levels of interference from previous stimuli in the former condition, and therefore have required the engagement of the resolution processes ostensibly indexed by the left-frontal effect to a greater extent. The task employed by Woodruff and colleagues (2006) comprised one study list of 150 visually presented words, followed by a test list containing all old words and an equal number of visually presented new words. It is possible that test cues in that study were associated with particularly high levels of interference from the high number of preceding stimuli, resulting in the observation of what may be the same effect at fronto-polar sites from 800ms.

A further important point to note is that demonstrations of variations in the distributions of ERP old/new effects over the course of a retrieval task have critical implications for claims made on the basis of averaged measures of neural activity. In the case of ERPs, this result highlights the fact that the averaged scalp distribution of an effect is not necessarily reflective of the neural generators or processes engaged throughout the task. As for haemodynamic imaging techniques such as fMRI, this result suggests that the brain regions identified as being active during retrieval may only support retrieval processing under some circumstances. In particular, these issues apply to studies employing lengthy retrieval tasks, or those in which the order of task completion is not adequately counter-balanced.

Data relevant to this issue were touched on by Buckner (2003) when reviewing the contribution of fronto-polar regions of PFC to memory control processes. He noted that early fMRI paradigms which, due to methodological limitations, averaged activity over extended periods during retrieval tasks regularly identified activity in right fronto-polar PFC (see also Buckner, 1996). However, more recent event-related fMRI paradigms which do not require averaging over such extended periods, observe activity in this region with less regularity. Buckner argued that the constraints imposed by blocked designs may have led to misleading or at best incomplete accounts of the roles played by fronto-polar regions of PFC during retrieval. The ERP findings in this thesis might be seen to argue for the inclusion in future studies of an initial level of analyses – even in event-related imaging studies – which include some means of assessing changes in levels of activity within regions at selected time points during a task.

9.4 Other Electrophysiological Effects of Interest

While not the focus of the work contained in this thesis, the data obtained in these five experiments also provide some insights into two well-documented posteriorly-distributed old/new effects. These are discussed in turn in the following section, beginning with data relevant to a putative electrophysiological index of recollection.

9.4.1 The Left-Parietal Old/New Effect

This effect, onsetting at around 500ms post-stimulus and lasting for several hundred milliseconds, is widely considered to index the recollection component of dual-process models of recognition memory. This view has stemmed from the fact that the effect is larger for Remember responses relative to Know responses in studies employing Remember/Know paradigms (Duarte et al., 2004; Duzel et al., 1997) and is larger for items attracting correct relative to incorrect source judgments (Wilding & Rugg, 1996; Wilding et al., 1995). The effect has also been shown to be absent in

Alzheimer's patients unable to accurately recollect contextual information from a study event (Tendolkar et al., 1999) and to be attenuated in older adults (e.g. Ally et al., 2008; Morcom & Rugg, 2004) who demonstrate a selective impairment of recollection in recognition memory tasks (e.g. Howard et al., 2006; Prull et al., 2006). It has also been shown that the effect indexes recollection in a graded manner such that the greater quantity of the contents of recollection is reflected in effects of greater magnitude (Vilberg et al., 2006; Wilding, 1999).

Across the five experiments in this thesis, the left-parietal old/new effect, obtained in the analyses between 500-800ms at posterior, behaved in a way consistent with a recollection account. The analyses in Experiments One to Four included comparisons of the ERPs associated with correct and incorrect source judgments and showed that in each case the left-parietal old/new effect was reliably larger for the former category of responses (although this only tended towards significance in Experiment Two, see Figure 5.2, page 89) consistent with previous findings (Wilding & Rugg, 1996; Wilding et al., 1995). In both Experiments Three and Four sufficient trials were available to contrast the ERPs associated with correct source judgments separated according to confidence (high/low). In both cases, these left-parietal old/new effects were strikingly large in the case of high confidence judgments relative to the small and statistically unreliable effects associated with low confidence judgments. In so far as a correct source judgment requires the contribution of recollection in these tasks, the large left-parietal old/new effects for these judgments made with high confidence is consistent with a recollection account. The lack of reliable effects associated with low confidence judgments therefore indicates that these items were associated with very low levels of recollection of contextual detail and suggests that perhaps these source judgments were guesses following an old decision made on the basis of familiarity.

A further intriguing result relates to the reliable hit/miss left-parietal old/new effects in Experiments Three and Four, but unreliable low-confidence hit/hit old/new effects. Low-confidence correct source judgments, however, would be expected to be associated with recollection to a greater extent than incorrect source judgments, and therefore to elicit larger left-parietal old/new effects than hit/miss responses. It is possible that hit/miss responses in these tasks were associated with a below-criterial level of recollection, and therefore a small, reliable left-parietal effect, whereas low-confidence hit/hit responses attracted guesses to a greater extent. While this cannot be directly tested here, this result could be verified in future studies in which a 'guess' option is provided as a test response.

It has been argued by some that parietal old/new effects in recognition memory tasks are not reflective of recollection but rather are a result of contributions from other posteriorly distributed positive-going activity with a similar time-course, such as the P300 (Spencer et al., 2000) which is sensitive to the requirement to attend or discriminate between stimuli and is maximal at midline posterior sites in other non-mnemonic tasks (for a review, see Polich & Kok, 1995). However, the reliable left-lateralisation of the old/new effects associated with high confidence correct source judgments in Experiments Three and Five argues strongly that these are not simple manifestations of the non-lateralised P300. This is not to say, however, that the P300 may not have contributed to parietal amplitudes in the 500-800ms time-window for some response categories in this thesis since not all effects associated with correct source judgments in this time-window were reliably left-lateralised (see, for example, Figures 4.1, 5.1, and 7.1, pages 65, 85, & 127). However, more generally, evidence that left-parietal amplitudes in recognition memory tasks in this time-window are insensitive to simple effects of stimulus probability (Herron, Quayle, & Rugg, 2003) or response confidence (Curran, 2004), which are both known to affect the amplitude of the P300 in non-mnemonic tasks, provides strong evidence that left-parietal old/new effects do not reduce solely to explanations about P300 sensitivities..

9.4.2 The Late Posterior Negativity

A second, posteriorly-distributed old/new effect obtained throughout the experiments in this thesis, as well as in previous source memory studies, comprises a greater negativity for correctly identified old items relative to correctly identified new items at bilateral posterior parietal sites. This negative-going effect, known as the late posterior negativity (LPN), which onsets around the time of responding in retrieval tasks and lasts for several hundred milliseconds, is often larger in episodic memory tasks requiring source judgments relative to those requiring only old/new judgments (Johansson et al., 2002; Senkfor & Van Petten, 1998).

Herron (2007) proposed the separation of the LPN into two distinct components: one early and one late. An early LPN, from 600-1200ms, was considered to reflect the search for contextual information from the posterior cortical regions which processed the stimulus at encoding. This effect was thought to be sensitive to the difficulty with which the search was conducted, such that a more difficult search would be associated with a larger early LPN. A second LPN, from 1200-1900ms, was thought to reflect the maintenance of the retrieved episode 'in mind' while subjected to evaluation. Johansson and Mecklinger (2003) made a similar proposal regarding observations of the LPN in source retrieval studies. They argued that, following an old judgment but prior to a source judgment, a test item may be imaged or re-experienced in a particular study context – i.e. internally spoken in a particular voice – in order to inform the source attribution, and that the processes involved in the formation and maintenance of this reconstruction of the prior episode may be indexed by the LPN.

The time-windows and electrode locations selected for the analyses in this thesis were chosen to allow for the investigation of known old/new effects with different left/right lateralisation and anterior/posterior distributions, and as such are not ideally placed to allow for any robust claims regarding the behaviour of the LPN. In particular, this issue relates to the absence of data from midline posterior and occipital sites in the analyses, at which the LPN is typically maximal (Herron, 2007). However, the experiments in this thesis provide several data points relevant to accounts of the functional significance of the LPN.

First, in Experiments One, Two, and Three there were no reliable differences between the magnitudes of the LPNs (analysed at posterior sites from 1100-1400ms) associated with correct and incorrect source judgments, in keeping with previous findings (Mecklinger, Johansson, Parra, & Hanslmayr, 2007; Senkfor & Van Petten, 1998; Wilding & Rugg, 1996). In Experiment One, a reliable LPN was only evident for correct source judgments in the Easy condition (see Appendix A). The ERPs associated with correct source judgments in the Difficult condition did not differ from those associated with correct rejections and were reliably less negative-going than those in the Easy condition. This result is not consistent with the search account proposed by Herron (2007) since a search for related contextual information would be considered to have been more effortful in the Difficult than in the Easy condition.

The reliably larger LPN associated with low confidence correct source judgments relative to high confidence judgments in Experiment Three is compatible with the difficulty of search account as proposed by Herron (2007), however, since items attracting low confidence responses are likely to have been associated with a more effortful search for the relevant piece of contextual information from the posterior cortical regions which processed the event at study. This pattern was not replicated in the same comparison in Experiment Four, however. In that experiment, which required the retrieval of auditory source information, the ERPs associated with high and low confidence correct source judgments were statistically indistinguishable at posterior sites in the latest epoch (1100-1400ms). Also inconsistent with the findings in Experiment Three, the LPN associated with correct source judgments was reliably more negative than that associated with incorrect source judgments. Since the contextual information to be retrieved from the study episode in this experiment was auditory rather than visual (as was the case in Experiment Three), the posterior cortical regions primarily involved in processing the stimuli at study will have been different across experiments – i.e. the visual cortices in Experiment Three and auditory cortices in Experiment Four. This difference in the regions of cortex in which a search will purportedly be engaged may be responsible for the disparate results across the two experiments. Johansson and Mecklinger (2003) argued that the topography of the LPN may be sensitive to the modality which is queried during retrieval. The design of Experiment Five allowed for an investigation of this possibility in the contrast of the ERPs associated with high confidence retrieval of visual and auditory source information. This contrast revealed no reliable differences between these response categories at posterior sites in any time-window between 500 and 1400ms post-stimulus. The results of Experiment Five therefore argue against the proposed variation of the LPN alongside the modality of retrieved content (Johansson & Mecklinger, 2003).

9.5 Outstanding Issues, Caveats, and Future Directions

A provocative finding reported in this thesis with implications for both ERP and fMRI studies is that the averaged scalp distribution of an ERP old/new effect across a retrieval task is not necessarily reflective of the neural activity engaged throughout the task. This outcome, however, comes from post-hoc analyses of data from a group of participants, some of whom contributed as few as 6 trials to the response categories of interest (16 trials is the minimum used in all other analyses in this thesis). Therefore, further weight would be added to this argument by observing a similar pattern across time in a paradigm designed to maximise the numbers of trials per participant available for averaging. In addition, if the frontal effects shown here are in fact due to interference, then it should be possible to observe these effects independently of the length of retrieval tasks by manipulating the degree to which stimuli are likely to interfere. A simple means of doing this would be, for example, to increase the number of colours in which words were shown. The augmentation of left-frontal ERP old/new effects alongside increases in the number of study sources could be interpreted in a way consistent with an interference account.

The data reported in this thesis have ruled out the contributions of the presence or absence of copy cues at test, as well as the form of response options (two-stage versus three-way) to the circumstances under which right-frontal ERP old/new effects will predict correct source judgments. The results of Experiment Four, however, suggest that the correspondence between the modality of study and test cues may contribute to the conditions under which the magnitudes of right-frontal ERPs predict the accuracy of source judgments. In that experiment, as with the source memory studies by Wilding and colleagues (Wilding, 1999; Wilding & Rugg, 1996) in which late right-frontal ERPs were also reliably more positive for correct relative to incorrect source judgments, study words were spoken in a male/female voice and test items presented visually. This mismatch between study and test modality is in contrast to the tasks employed in Experiments One to Three, and other published studies (Senkfor & Van Petten, 1998; Van Petten et al., 2000), in which both study and test items were presented in the same modality and late right-frontal ERPs were of equivalent magnitude for correct and incorrect source judgments. Unfortunately, the tasks employed in Experiment Five did not provide sufficient trials for the incorrect source judgment categories and therefore precluded a within-subjects test of the possible contribution of study-test modality correspondence to the relative magnitudes of these old/new effects. A within-subjects demonstration of differences between the relative magnitudes of the correct and incorrect source ERPs across two tasks in which the correspondence between study and test modality is varied in a way similar to Experiment Five would provide support for the contribution of this factor and would contribute to an understanding of the processes indexed by this effect.

Finally, it is important to acknowledge that the frontally-distributed ERP effects reported in this thesis are not necessarily reflective of activity generated solely within the PFC. The *inverse problem* states that for any given pattern of scalp-recorded activity there is no unique solution in terms of its neural generators (Nunez, 1981; Wood, 1982), clearly providing a note of caution for inferences regarding the frontal generators of a frontally-distributed ERP. As discussed in Chapter One, however, the converging evidence from haemodynamic imaging and lesion studies for a role of the PFC in source memory retrieval ties the larger frontal ERP effects obtained in source memory tasks, like those contained in this thesis, relative to those obtained in old/new recognition tasks, to activity generated within the PFC. While an accurate identification of the particular regions of PFC responsible for the generation of the frontal effects reported in this thesis is not possible, the large magnitude (~3.5μV) and focal frontal distribution of these effects (see, for example, Figures 6.2 and 7.2, pages 104 & 131) argues for a primary contribution from generators within the frontal lobes (for a similar argument, see footnote 2 on page 2245, in Kuo & Van Petten, 2008). None the less, the low spatial resolution of this electrophysiological technique highlights the need to compliment data from ERP studies of episodic memory retrieval processes with data from haemodynamic imaging (and possibly transcranial magnetic stimulation [TMS]) studies in order to determine the time points over which retrieval processes operate as well as the brain regions which support them. Together these data will contribute to a more precise characterisation of the functional roles of the PFC during episodic retrieval than is available currently.

9.6 Concluding Remarks

This thesis comprises five experiments designed to contribute to an understanding of the PFC-supported processes engaged during source retrieval. The data provide for the first time evidence that the electrical record is sensitive to multiple neurally, functionally, and temporally distinct PFC-supported processes which operate during source retrieval. In combination, these data points have demonstrated that the term *the right-frontal old/new effect* used for some time in the ERP source memory literature when characterising late frontal activity is at best inaccurate. There are at least two electrophysiologically and functionally dissociable frontal ERP old/new effects.

Aspects of the data in this thesis also have valuable implications for conclusions made on the basis of averaged measures of neural activity. The evidence for changes in cortical activity as time spent performing a retrieval task increases demonstrates that the averaged patterns of activity obtained in both ERP and fMRI studies are not necessarily reflective of activity in these brain regions throughout the task, and encourages caution in the design of lengthy retrieval tasks and the interpretation of data obtained in such studies.

In summary, the work contained in this thesis has highlighted the utility of the ERP technique in contributing to an understanding of the retrieval processes supported by the PFC. Complimenting further ERP investigations with fMRI measures will facilitate separation of the regions of PFC which support these processes as well as the time-periods over which they operate.

Appendix A

A.1 Re-analyses of Experiment One – Easy and Difficult old/new effects

The following exploratory analyses were conducted on the ERPs associated with correct rejections and hit/hits from the Easy and Difficult conditions of Experiment One separately. These contrasts were not conducted in the first instance, and are not reported in Chapter Four, due to the lack of reliable interaction terms involving the factor of difficulty in the initial global analyses. The results of Experiment Three provided evidence for reliable differences in the degree to which frontal old/new effects were right-lateralised for high and low confidence hit/hits. The following analyses were therefore conducted in order to determine the extent to which the frontal old/new effects in the Easy and Difficult conditions of Experiment One were right-lateralised.

ERPs were analysed for 3 post-stimulus time windows: 500-800, 800-1100 and 1100-1400ms. Initial global ANOVAs were conducted including the factors of response category (4 levels: easy hit/hit, easy correct rejection, difficult hit/hit, difficult correct rejection), the anterior/posterior dimension (2 levels), hemisphere (2 levels), and electrode site (5 levels).

The initial global ANOVAs revealed reliable interactions between response category and the anterior/posterior dimension for the 500-800ms period ($F(3,45) = 10.62$, $p<.001$, $e = 0.63$) and between response category, the anterior/posterior dimension and hemisphere the later time windows (800-1100ms: $F(3,45) = 7.37$, $p<.01$, $e = 0.82$; 1100-1400ms: $F(3,45) = 9.87$, $p<.001$, $e = 0.70$). The outcomes of the subsequent separate paired contrasts at anterior and posterior sites can be seen in Table A.1 (page 205), which shows that there are reliable old/new effects for Easy hit/hits in all time windows, and in the 500-800ms and 1100-1400ms time-windows for Difficult hit/hits.

The results at anterior locations are described first. The main effect of response category from 500-1400ms for Easy hit/hits reflects the broad bilateral distribution of this effect throughout this extended epoch. The category by hemisphere interaction from 1100-1400ms for the Difficult hit/hit old/new effect reflects the right-lateralisation of this effect in this time-window. Despite the interaction with hemisphere in the Difficult condition only, there were no differences between the Easy and Difficult old/new effects in this late epoch or indeed in the earlier epochs (these analyses were conducted on subtraction scores calculated by subtracting the mean amplitudes associated with correct rejections in each condition from the respective hit/hit amplitudes: all other factors were as described previously).

At posterior sites, the category by site interactions from 500-1100ms for the Easy hit/hit old/new effects reflects the mid-lateral maxima of these effects, while the category by hemisphere interactions from 800-1400ms reflect the left-lateralisation of this effect. The category by site interaction in the late time-window (1100-1400ms) reflects the greater positivity of correct rejections relative to hit/hits at superior electrode sites. For the Difficult hit/hit old/new effect, the category by site interaction in the 500-800ms time-window comes about for the same reasons as the Easy old/new effect. The category by site interaction in the comparison of the Easy and Difficult effects in the 1100-1400ms time-window reflects the larger negative-going Easy old/new effect at superior sites.

In summary, frontal hit/hit old/new effects in the Easy condition were bilaterally distributed from 500-1400ms, whereas the same effect in the Difficult condition was reliably right-lateralised from 1100-1400ms. While there are no reliable differences between these effects, the pattern is consistent with that discussed in Chapter Six (Section 6.4.3).

Table A.1: F-values and significance levels for the paired comparisons between the mean amplitudes associated with the hit/hit and correct rejection (CR) response categories in the Easy and Difficult conditions over the 500-800, 800-1100, and 1100-1400ms epochs at anterior and posterior sites separately. Data submitted to comparisons between old/new effects (O/N) are subtraction scores generated by subtracting ERPs associated with correct rejections from those associated with hit/hit responses. Only effects involving response category that were reliable in at least one contrast are shown. RC = response category, HM = hemisphere, ST = site. * = p<.05, ** = p<.01, *** = p<.001, ns. = non-significant (p>.05). Full dfs are shown on the left with epsilon values in brackets alongside each associated F-value.

	500-800ms		**800-1100ms**		**1100-1400ms**	
	Anterior	**Posterior**	**Anterior**	**Posterior**	**Anterior**	**Posterior**
Easy Hit/Hit vs. CR						
RC (1,15)	5.39 *	71.12 ***	9.62 **	7.22 *	7.87 *	ns.
RC x HM (1,15)	ns.	ns.	ns.	7.75 *	ns.	7.31 *
RC x ST (4,60)	ns.	7.94 *** (0.66)	ns.	3.89 * (0.80)	ns.	5.85 *** (0.89)
Difficult Hit/Hit vs. CR						
RC (1,15)	ns.	26.31 ***	ns.	ns.	ns.	ns.
RC x HM (1,15)	ns.	ns.	ns.	ns.	14.72 **	ns.
RC x ST (4,60)	ns.	10.46 *** (0.72)	ns.	ns.	ns.	ns.
Easy Hit/Hit O/N vs. Difficult Hit/Hit O/N						
RC x ST (4,60)	ns.	ns.	ns.	ns.	ns.	3.75 * (0.60)

References

Allan, K., Wilding, E. L., & Rugg, M. D. (1998). Electrophysiological evidence for dissociable processes contributing to recollection. *Acta Psychologica, 98*, 231-252.

Ally, B. A., Simons, J. S., McKeever, J. D., Peers, P. V., & Budson, A. E. (2008). Parietal contributions to recollection: Electrophysiological evidence from aging and patients with parietal lesions. *Neuropsychologia, 46*, 1800-1812.

Anderson, M. C. (2003). Rethinking interference theory: Executive control and the mechanisms of forgetting. *Journal of Memory and Language, 49*, 415-445.

Azimian-Faridani, N., & Wilding, E. L. (2006). The influence of criterion shifts on electrophysiological correlates of recognition memory. *Journal of Cognitive Neuroscience, 18*, 1075-1086.

Badre, D., & Wagner, A. D. (2007). Left ventrolateral prefrontal cortex and the cognitive control of memory. *Neuropsychologia, 45*, 2883-2901.

Banks, W. P. (1970). Signal detection theory and human memory. *Psychological Bulletin, 74*, 81-99.

Barrett, G., Blumhardt, L., Halliday, A. M., Halliday, E., & Kriss, A. (1976). Paradox in Lateralization of Visual Evoked-Response. *Nature, 261*, 253-255.

Berger, H. (1929). Electroencephalogram in humans. *Archiv fur Psychiatrie und Nervenkrankheiten, 87*, 527-570.

Brunia, C. H. M., & Vingerhoets, A. (1981). Opposite Hemisphere Differences in Movement Related Potentials Preceding Foot and Finger Flexions. *Biological Psychology, 13*, 261-269.

Buckner, R. L. (1996). Beyond HERA: contributions of specific prefrontal brain areas to long-term memory retrieval. *Psychonomic Bulletin and Review, 3*, 149-158.

Buckner, R. L. (2003). Functional-Anatomic Correlates of Control Processes in Memory. *The Journal of Neuroscience, 23*, 3999-4004.

Burgess, P. W., & Shallice, T. (1996). Confabulation and the control of recollection. *Memory, 4*, 359-411.

Cabeza, R., Anderson, N. D., Locantore, J. K., & McIntosh, A. R. (2002). Aging gracefully: Compensatory brain activity in high-performing older adults. *Neuroimage, 17*, 1394-1402.

Cabeza, R., Locantore, J. K., & Anderson, N. D. (2003). Lateralisation of Prefrontal Activity during Episodic Memory Retrieval: Evidence for the Production-Monitoring Hypothesis. *Journal of Cognitive Neuroscience, 15*, 249-259.

Casasanto, D. (2003). Hemispheric specialization in prefrontal cortex: effects of verbalizability, imageability and meaning. *Journal of Neurolinguistics, 16*, 361-382.

Coles, M. G. H., & Rugg, M. D. (1995). Event-related brain potentials: an introduction. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of mind. Event-related brain potentials and cognition.* (pp. 1-26). New York: Oxford University Press.

Coltheart, M. (1981). The MRC Psycholinguistic Database. *Quarterly Journal of Experimental Psychology: A, 33*, 497-505.

Conway, M. A. (2001). Sensory-perceptual episodic memory and its context: autobiographical memory. *Philosophical Transactions of the Royal Society B-Biological Sciences, 356*, 1375-1384.

Cruse, D., & Wilding, E. L. (In Press). Prefrontal cortex contributions to episodic retrieval monitoring and evaluation. *Neuropsychologia, In Press, Corrected Proof.*
Curran, T. (2000). Brain potentials of recollection and familiarity. *Memory and Cognition, 28*, 923-938.
Curran, T. (2004). Effects of attention and confidence on the hypothesized ERP correlates of recollection and familiarity. *Neuropsychologia, 42*, 1088-1106.
Curran, T., DeBuse, C., & Leynes, P. A. (2007). Conflict and Criterion Setting in Recognition Memory. *Journal of Experimental Psychology: Learning, Memory and Cognition, 33*, 2-17.
Cycowicz, Y. M., Friedman, D., & Snodgrass, J. G. (2001). Remembering the colour of objects: An ERP investigation of source memory. *Cerebral Cortex, 11*, 322-334.
Diana, R. A., Yonelinas, A. P., & Ranganath, C. (2008). The effects of unitization on familiarity-based source memory: Testing a behavioral prediction derived from neuroimaging data. *Journal of Experimental Psychology-Learning Memory and Cognition, 34*, 730-740.
Dobbins, I. G., & Han, S. (2006). Isolating Rule- versus Evidence-Based Prefrontal Activity during Episodic and Lexical Discrimination: an fMRI Investigation of Detection Theory Distinctions. *Cerebral Cortex, 16*, 1614-1622.
Dobbins, I. G., Simons, J. S., & Schacter, D. L. (2004). fMRI evidence for separable and lateralized prefrontal memory monitoring processes. *Journal of Cognitive Neuroscience, 16*, 908-920.
Dobbins, I. G., & Wagner, A. D. (2005). Domain-general and domain-sensitive prefrontal mechanisms for recollecting events and detecting novelty *Cerebral Cortex, 15*, 1768-1778.
Dodson, C. S. (2007). Retrieval-based illusory recollections: Why study-test contextual changes impair source memory. *Memory & Cognition, 35*, 1211-1221.
Dodson, C. S., & Shimamura, A. P. (2000). Differential effects of cue dependency on item and source memory. *Journal of Experimental Psychology-Learning Memory and Cognition, 26*, 1023-1044.
Donaldson, D. I., Peterson, S. E., Ollinger, J. M., & Bucker, R. L. (2001). Dissociating state and item components of recognition memory using fMRI. *Neuroimage, 13*, 129-142.
Duarte, A., Ranganath, C., Winward, L., Hayward, D., & Knight, R. T. (2004). Dissociable neural correlates for familiarity and recollection during the encoding and retrieval of pictures. *Cognitive Brain Research, 18*, 255-272.
Duzel, E., Cabeza, R., Picton, T. W., Yonelinas, A. P., Scheich, H., Heinze, H. J., et al. (1999). Task-related and item-related brain processes of memory retrieval. *Proceedings of the National Academy of Sciences: USA, 96*, 1794-1799.
Duzel, E., Picton, T. W., Cabeza, R., Yonelinas, A. P., Scheich, H., Heinze, H. J., et al. (2001). Comparing electrophysiological and hemodynamic measures of neural activation during memory retrieval. *Human Brain Mapping, 13*, 104-123.
Duzel, E., Vargha-Khadem, F., Heinze, H. J., & Mishkin, M. (2001). Brain activity evidence for recognition without recollection after early hippocampal damage. *Proceedings of the National Academy of Sciences: USA, 98*, 8101-8106.
Duzel, E., Yonelinas, A. P., Mangun, G. R., Heinze, H. J., & Tulving, E. (1997). Event-related brain potential correlates of two states of conscious awareness in

memory. *Proceedings of the National Academy of Sciences: USA, 94*, 5973-5978.

Fletcher, P. C., & Henson, R. N. A. (2001). Frontal lobes and human memory: Insights from functional neuroimaging. *Brain, 124*, 849-881.

Friedman, D., & Johnson, R. (2000). Event-related potential (ERP) studies of memory encoding and retrieval: A selective review. *Microscopy Research and Techniques, 51*, 6-28.

Gold, B. T., & Buckner, R. L. (2002). Common prefrontal regions coactivate with dissociable posterior regions during controlled semantic and phonological tasks. *Neuron, 35*, 803-812.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. New York: Wiley.

Greenhouse, G. W., & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika, 49*, 95-112.

Han, S., Huettel, S. A., & Dobbins, I. G. (2009). Rule-dependent Prefrontal Cortex Activity across Episodic and Perceptual Decisions: An fMRI Investigation of the Criterial Classification Account. *Journal of Cognitive Neuroscience, 21*, 922-937.

Hayama, H. R., Johnson, J. D., & Rugg, M. D. (2008). The relationship between the right frontal old/new ERP effect and post-retrieval monitoring: Specific or non-specific. *Neuropsychologia, 46*, 1211-1223.

Hayama, H. R., & Rugg, M. D. (2009). Right dorsolateral prefrontal cortex is engaged during post-retrieval processing of both episodic and semantic information. *Neuropsychologia, 47*, 2409-2416.

Henson, R. N. A., Rugg, M., Shallice, T., & Dolan, R. J. (2000). Confidence in recognition memory for words: dissociating right prefrontal roles in episodic retrieval. *Journal of Cognitive Neuroscience., 12*, 913-923.

Henson, R. N. A., Rugg, M. D., Shallice, T., Josephs, O., & Dolan, R. J. (1999). Recollection and familiarity in recognition memory: An event-related functional magnetic resonance imaging study. *Journal of Neuroscience, 19*, 3962-3972.

Henson, R. N. A., Shallice, T., & Dolan, R. J. (1999). Right prefrontal cortex and episodic memory retrieval: a functional MRI test of the monitoring hypothesis. *Brain, 122* 1367-1381.

Henson, R. N. A., Shallice, T., Josephs, O., & Dolan, R. J. (2002). Functional magnetic resonance imaging of proactive interference during spoken cued recall. *Neuroimage, 17*, 543-558.

Herron, J. E. (2007). Decomposition of the ERP late posterior negativity: effects of retrieval and response fluency. *Psychophysiology, 44*, 233-244.

Herron, J. E., Quayle, A. H., & Rugg, M. D. (2003). Probability effects on event-related potential correlates of recognition memory. *Cognitive Brain Research, 16*, 66-73.

Howard, M. W., Bessette-Symons, B., Zhang, Y. F., & Hoyer, W. J. (2006). Aging selectively impairs recollection in recognition memory for pictures: Evidence from modeling and receiver operating characteristic curves. *Psychology and Aging, 21*, 96-106.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language, 30*, 513-541.

Janowsky, J. S., Shimamura, A. P., & Squire, L. R. (1989). Source memory impairment in patients with frontal lobe lesions. *Neuropsychologia, 27*, 1043-1056.

Jasper, H. A. (1958). The ten-twenty system of the international federation. *Electroencephalography and Clinical Neurophysiology, 10*, 371-375.

Johansson, M., & Mecklinger, A. (2003). The late posterior negativity in ERP studies of episodic memory: action monitoring and retrieval of attribute conjunctions. *Biological Psychology, 64*, 91-117.

Johansson, M., Stenberg, G., Lindberg, M., & Rosen, I. (2002). Memory for perceived and imagined pictures - an event-related potential study. *Neuropsychologia, 40*, 986-1002.

Johnson, J. D., Minton, B. R., & Rugg, M. D. (2008). Content dependence of the electrophysiological correlates of recollection. *Neuroimage, 39*, 406-416.

Johnson, M. K. (1992). MEM: Mechanisms of Recollection. *Journal of Cognitive Neuroscience, 4*, 268-280.

Johnson, M. K., Hashtroudi, S., & Lindsay, D. S. (1993). A source monitoring framework. *Psychological Bulletin, 114*, 3-28.

Johnson, M. K., Kounios, J., & Nolde, S. F. (1996). Electrophysiological brain activity and memory source monitoring. *Neuroreport, 7*, 2929-2932.

Johnson, M. K., Kounios, J., & Nolde, S. F. (1997). Electrophysiological brain activity and memory source monitoring. *Neuroreport, 8*, 1317-1320.

Johnson, M. K., Oconnor, M., & Cantor, J. (1997). Confabulation, memory deficits, and frontal dysfunction. *Brain and Cognition, 34*, 189-206.

Joyce, C. A., Paller, K. A., McIsaac, H. K., & Kutas, M. (1998). Memory changes with normal aging: Behavioral and electrophysiological measures. *Psychophysiology, 35*, 669-678.

Kelley, C. M., Jacoby, L. L., & Hollingshead, A. (1989). Direct versus indirect tests of memory for source: Judgements of modality. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*, 1101-1108.

Kuo, T. Y., & Van Petten, C. (2006). Prefrontal engagment during source memory retrieval depends upon the prior encoding context. *Journal of Cognitive Neuroscience, 18*, 1133-1146.

Kuo, T. Y., & Van Petten, C. (2008). Perceptual difficulty in source memory encoding and retrieval: Prefrontal versus parietal electrical brain activity. *Neuropsychologia, 46*, 2243-2257.

Kutas, M., & Dale, A. M. (1997). Electrical and magnetic readings of mental functions. In M. D. Rugg (Ed.), *Cognitive Neuroscience* (pp. 197-242). Cambridge, MA: MIT Press.

Lee, A. C. H., Robbins, T. W., Pickard, J. D., & Owen, A. M. (2000). Asymmetric frontal activation during episodic memory: the effects of stimulus type on encoding and retrieval. *Neuropsychologia, 38*, 677-692.

Lepage, M., Ghaffar, O., Nyberg, L., & Tulving, E. (2000). Prefrontal cortex and episodic memory retrieval mode. *Proceedings of the National Academy of Sciences: USA, 97*, 506-511.

Lins, O. G., Picton, T. W., Berg, P., & Scherg, M. (1993). Ocular artifacts in EEG and event-related potentials. 1. Scalp Topography. *Brain Topography, 6*, 51-63.

Luck, S. J. (2005). *An Introduction to the Event-Related Potential Technique*. London: The MIT Press.

Lundstrom, B. N., Ingvar, M., & Petersson, K. M. (2005). The role of precuneus and left inferior frontal cortex during source memory episodic retrieval. *Neuroimage, 27*, 824-834.

MacKenzie, G., & Donaldson, D. I. (In Press). Examining the neural basis of episodic memory: ERP evidence that faces are recollected differently from names. *Neuropsychologia, In Press, Corrected Proof.*

Mandler, G. (1980). Recognising: The judgment of previous occurrence. *Psychological Review, 87*, 252-271.

Mark, R. E., & Rugg, M. D. (1998). Age effects on brain activity associated with episodic memory retrieval. An electrophysiological study. *Brain, 121*, 861-873.

McCarthy, G., & Wood, C. C. (1985). Scalp distributions of event-related potentials: An ambiguity associated with analysis of variance models. *Electroencephalography and Clinical Neurophysiology, 62*, 203-208.

McDermott, K. B., Buckner, R. L., Petersen, S. E., Kelley, W. M., & Sanders, A. L. (1999). Set- and code-specific activation in the frontal cortex: An fMRI study of encoding and retrieval of faces and words. *Journal of Cognitive Neuroscience, 11*, 631-640.

Mecklinger, A. (2000). Interfacing mind and brain: A neurocognitive model of recognition memory. *Psychophysiology, 37*, 565-582.

Mecklinger, A., Johansson, M., Parra, M., & Hanslmayr, S. (2007). Source-retrieval requirements influence late ERP and EEG memory effects. *Brain Research, 1172*, 110-123.

Mecklinger, A., von Cramon, D. Y., & Matthes-von Cramon, G. (1998). Event-related potential evidence for a specific recognition memory deficit in adult survivors of cerebral hypoxia. *Brain, 121*, 1919-1935.

Mitchell, K. J., & Johnson, M. K. (2009). Source Monitoring 15 Years Later: What Have We Learned From fMRI About the Neural Mechanisms of Source Memory? *Psychological Bulletin, 135*, 638-677.

Morcom, A. M., & Rugg, M. D. (2004). Effects of age on retrieval cue processing as revealed by ERPs. *Neuropsychologia, 42*, 1525-1542.

Moscovitch, M. (1989). Confabulation and the Frontal Systems: Strategic versus Associated Retrieval in Neuropsychological Theories of Memory. In H. L. Roediger & F. I. M. Craik (Eds.), *Varieties of Memory and Consciousness: Essays in Honour of Endel Tulving*. London: Lawrence Erlbaum Associates.

Moscovitch, M. (1992). Memory and working-with-memory: A component process model based on modules and central systems. *Journal of Cognitive Neuroscience, 4*, 257-267.

Moscovitch, M., & Melo, B. (1997). Strategic retrieval and the frontal lobes: Evidence from confabulation and amnesia. *Neuropsychologia, 35*, 1017-1034.

Murdock, B. B. (1965). Signal-Detection-Theory and Short-Term-Memory. *Journal of Experimental Psychology, 70*, 443-447.

Nelson, K. (1993). The Psychological and Social Origins of Autobiographical Memory. *Psychological Science, 4*, 7-13.

Nolde, S. F., Johnson, M. K., & D'Esposito, M. (1998). Left prefrontal activitation during episodic memory: an event-related study. *Neuroreport, 9*, 3509-3514.

Nolde, S. F., Johnson, M. K., & Raye, C. L. (1998). The role of prefrontal cortex during tests of episodic memory. *Trends in Cognitive Sciences, 2*, 399-406.

Norman, D. A., & Bobrow, D. G. (1979). Descriptions: an intermediate stage in memory retrieval. *Cognitive Psychology, 11*, 107-123.

Nunez, P. L. (1981). *Electric fields of the brain: The neurophysics of EEG*. New York: Oxford University Press.

Nyberg, L., McIntosh, A. R., Cabeza, R., Habib, R., & Houle, S. (1996). General and specific brain regions involved in encoding and retrieval of events: What, where, and when. *Proceedings of the National Academy of Sciences, USA, 93*, 11280-11285.

Paller, K. A., & Kutas, M. (1992). Brain potentials during memory retrieval provide neurophysiological support for the distinction between conscious recollection and priming. *Journal of Cognitive Neuroscience, 4*, 375-391.

Paller, K. A., Voss, J. L., & Boehm, S. G. (2007). Validating neural correlates of familiarity. *Trends in Cognitive Sciences, 11*, 243-250.

Parkin, A. J. (1997). The neuropsychology of false memory. *Learning and Individual Differences, 9*, 341-357.

Parks, C. M., Yonelinas, A. P., & John, H. B. (2008). Theories of Recognition Memory. In *Learning and Memory: A Comprehensive Reference* (pp. 389-416). Oxford: Academic Press.

Picton, T. W., Lins, O. G., & Scherg, M. (1995). The recording and analysis of event-related potentials. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology, Volume 10* (Vol. 10, pp. 429-499): Elsevier.

Polich, J., & Kok, A. (1995). Cognitive and biological determinants of P300: an integrative review. *Biological Psychology, 41*, 103-146.

Prull, M. W., Dawes, L. L. C., Martin, A. M., Rosenberg, H. F., & Light, L. L. (2006). Recollection and familiarity in recognition memory: Adult age differences and neuropsychological test correlates. *Psychology and Aging, 21*, 107-118.

Qin, J., Raye, C. L., Johnson, M. K., & Mitchell, K. J. (2001). Source ROCs are (Typically) Curvilinear: Comment on Yonelinas (1999). *Journal of Experimental Psychology: Learning, Memory and Cognition, 27*, 1110-1115.

Ranganath, C. (2004). The 3-D prefrontal cortex: Hemispheric asymmetries in prefrontal activity and their relation to memory retrieval processes. *Journal of Cognitive Neuroscience, 16*, 903-907.

Ranganath, C., Heller, A. S., & Wilding, E. L. (2007). Dissociable correlates of two classes of retrieval processing in prefrontal cortex. *Neuroimage, 35*, 1663-1673.

Ranganath, C., Johnson, M. K., & D'Esposito, M. (2000). Left anterior prefrontal activation increases with demands to recall specific perceptual information. *Journal of Neuroscience, 20: RC108*, 1-6.

Ranganath, C., & Knight, R. T. (2003). Prefrontal cortex and episodic memory: Integrating findings from neuropsychology and event-related functional neuroimaging. In A. E. Parker, E. L. Wilding & T. Bussey (Eds.), *Memory encoding and retrieval: A Cognitive Neuroscience Perspective* (pp. 83-99). New York: Psychology Press.

Ranganath, C., & Paller, K. A. (2000). Neural correlates of memory retrieval and evaluation. *Cognitive Brain Research, 9*, 209-222.

Raye, C. L., Johnson, M. K., Mitchell, K. J., Nolde, S. F., & D'Esposito, M. (2000). fMRI investigations of left and right PFC contributions to episodic remembering. *Psychobiology, 28*, 197-206.

Rotello, C. M., Macmillan, N. A., Hicks, J. L., & Hautus, M. (2006). Interpreting the effects of response bias on remember-know judgments using signal-detection and threshold models. Memory & Cognition. *Memory & Cognition, 34*, 1598-1614.

Rugg, M. D. (1998). Converging approaches to electrophysiological and haemodynamic investigations of memory. *Human Brain Mapping, 6*, 394-398.

Rugg, M. D., Allan, K., & Birch, C. S. (2000). Electrophysiological evidence for the modulation of retrieval orientation by depth of study processing. *Journal of Cognitive Neuroscience, 12*, 664-678.

Rugg, M. D., Fletcher, P. C., Chua, P. M., & Dolan, R. J. (1999). The role of the prefrontal cortex in recognition memory and memory for source: an fMRI study. *Neuroimage, 10*, 520-529.

Rugg, M. D., & Henson, R. N. A. (2003). Episodic memory retrieval: an (event-related) functional neuroimaging perspective. In A. E. Parker, E. L. Wilding & T. J. Bussey (Eds.), *The Cognitive Neuroscience of Memory: Episodic encoding and retrieval* (pp. 5-38). Hove: Psychology Press.

Rugg, M. D., Henson, R. N. A., & Robb, W. G. K. (2003). Neural correlates of retrieval procesing in the prefrontal cortex during recognition and exclusion tasks. *Neuropsychologia, 41*, 40-52.

Rugg, M. D., Otten, L. J., & Henson, R. N. (2002). The neural basis of episodic memory: evidence from functional neuroimaging. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences., 357*, 1097-1110.

Rugg, M. D., & Wilding, E. L. (2000). Retrieval processing and episodic memory. *Trends in Cognitive Sciences, 4*, 108-115.

Schacter, D. L. (1987). Memory, amnesia and frontal lobe dysfunction. *Psychobiology, 15*, 21-36.

Schacter, D. L., Norman, K. A., & Koutstaal, W. (1998). The cognitive neuroscience of constructive memory. *Annual Review of Psychology, 49*, 289-318.

Semlitsch, H. V., Anderer, P., Schuster, P., & Presslich, O. (1986). A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. *Psychophysiology, 23*, 695-703.

Semon, R. S. (1921). *The Mneme*. London: George Allen & Unwin.

Senkfor, A. J., & Van Petten, C. (1998). Who said what: An event-related potential investigation of source and item memory. *Journal of Experimental Psychology: Learning, Memory and Cognition, 24*, 1005-1025.

Simons, J. S., Gilbert, S. J., Owen, A. M., Fletcher, P. C., & Burgess, P. W. (2005). Distinct Roles for Lateral and Medial Anterior Prefrontal Cortex in Contextual Recollection. *Journal of Neurophysiology, 94*, 813-820.

Slotnick, S. D., & Dodson, C. S. (2005). Support for a continuous (single-process) model of recognition memory and source memory. *Memory & Cognition, 33*, 151-170.

Smith, M. E. (1993). Neurophysiological manifestations of recollective experience during recognition memory judgements. *Journal of Cognitive Neuroscience, 5*, 1-13.

Snodgrass, J. G., & Corwin, J. (1988). Pragmatics of measuring recognition memory: Applications to dementia and amnesia. *Journal of Experimental Psychology: General, 117*, 34-50.

Sohn, M.-H., Goode, A., Stenger, V. A., Carter, C. S., & Anderson, J. R. (2003). Competition and representation during memory retrieval: Roles of the prefrontal cortex and the posterior parietal cortex. *Proceedings of the National Academy of Sciences, 100*, 7412-7417.

Spencer, K., Abad, E. V., & Donchin, E. (2000). On the search for the neurophysiological manifestation of recollective experience. *Psychophysiology, 37*, 494-506.

Squire, L. R., & Zola-Morgan, M. (1991). The medial temporal lobe memory system. *Science, 253*, 1380-1386.

Stuss, D. T., Eskes, G. A., & Foster, J. K. (1994). Experimental neuropsychological studies of frontal lobe functions. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology* (Vol. 9, pp. 149-183). New York: Elsevier.

Swick, D., Senkfor, A. J., & Van Petten, C. (2006). Source memory retrieval is affected by aging and prefrontal lesions: behavioral and ERP evidence. *Brain Research, 1107*, 161-176.

Tendolkar, I., & Rugg, M. D. (1998). Electrophysiological dissociation of recency and recognition memory. *Neuropsychologia, 36*, 477-490.

Tendolkar, I., Schoenfeld, A., Golz, G., Fernandez, G., Kuhl, K., Ferszt, R., et al. (1999). Neural correlates of recognition memory with and without recollection in patients with Alzheimer's disease and healthy controls. *Neuroscience Letters, 263*, 45-48.

Thompson-Schill, S. L., D'Esposito, M., Aguirre, G. K., & Farah, M. J. (1997). Role of left inferior prefrontal cortex in retrieval of semantic knowledge: A reevaluation. *Proceedings of the National Academy of Sciences of the United States of America, 94*, 14792-14797.

Trott, C. T., Friedman, D., Ritter, W., & Fabiani, M. (1997). Item and source memory: Differential age effects revealed by event-related potentials. *Neuroreport, 8*, 3373-3378.

Trott, C. T., Friedman, D., Ritter, W., Fabiani, M., & Snodgrass, J. G. (1999). Episodic priming and memory for temporal source: Event-related potentials reveal age-related differences in prefrontal functioning. *Psychology and Aging, 14*, 390-413.

Tulving, E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson (Eds.), *Organization of Memory* (pp. 381-403). New York: Academic Press.

Tulving, E. (1983). *Elements of Episodic Memory*. Oxford: Oxford University Press.

Tulving, E. (1985). Memory and consciousness. *Canadian Psychologist, 26*, 1-12.

Tulving, E., Kapur, S., Craik, F. I. M., Moscovitch, M., & Houle, S. (1994). Hemispheric encoding/retrieval asymmetry in episodic memory: Positron emission tomography findings. *Proceedings of the National Academy of Science, 91*, 2016-2020.

Ullsperger, M., Mecklinger, A., & Muller, U. (2000). An electrophysiological test of directed forgetting: The role of retrieval inhibition. *Journal of Cognitive Neuroscience, 12*, 924-940.

Urbach, T. P., & Kutas, M. (2002). The intractability of scaling scalp distributions to infer neuroelectric sources. *Psychophysiology, 39*, 791-808.

Vallesi, A., & Shallice, T. (2006). Prefrontal involvement in source memory: An electrophysiological investigation of accounts concerning confidence and accuracy. *Brain Research, 1124*, 111-125.

Van Petten, C., Senkfor, A. J., & Newberg, W. M. (2000). Memory for drawings in locations: Spatial source memory and event-related potentials. *Psychophysiology, 4*, 551-564.

Vilberg, K. L., Moosavi, R. F., & Rugg, M. D. (2006). The relationship between electrophysiological correlates of recollection and the amount of information retrieved. *Brain Research, 1122*, 161-170.

Wagner, A. D., Poldrack, R. A., Eldridge, L. L., Desmond, J. E., Glover, G. H., & Gabrieli, J. D. E. (1998). Material-specific lateralisation of prefrontal activation during episodic encoding and retrieval. *Neuroreport, 9*, 3711-3717.

Wegesin, D. J., Friedman, D., Varughese, N., & Stern, Y. (2002). Age-related changes in source memory retrieval: an ERP replication and extension. *Cognitive Brain Research, 13*, 323-328.

Wheeler, M. A., Petersen, S. E., & Buckner, R. L. (2000). Memory's echo: Vivid remembering reactivates sensory-specific cortex. *Proceedings of the National Academy of Sciences, USA, 97*, 11125-11129.

Wheeler, M. A., Stuss, D., & Tulving, E. (1997). Toward a theory of episodic memory: The frontal lobes and autonoetic consciousness. *Psychological Bulletin, 121*, 331-354.

Wilding, E. L. (1999). Separating retrieval strategies from retrieval success: An event-related potential study of source memory. *Neuropsychologia, 37*, 441-454.

Wilding, E. L. (2000). In what way does the parietal ERP old/new effect index recollection? *International Journal of Psychophysiology, 35*, 81-87.

Wilding, E. L. (2006). On the practice of rescaling scalp-recorded event-related potentials. *Biological Psychology, 72*, 325-332.

Wilding, E. L., Doyle, M. C., & Rugg, M. D. (1995). Recognition memory with and without retrieval of context: an event-related potential study. *Neuropsychologia, 33*, 743-767.

Wilding, E. L., Fraser, C. S., & Herron, J. E. (2005). Indexing strategic retrieval of colour information with event-related potentials. *Cognitive Brain Research, 25*, 19-32.

Wilding, E. L., & Rugg, M. D. (1996). An event-related potential study of recognition memory with and without retrieval of source. *Brain, 119*, 889-905.

Wilding, E. L., & Rugg, M. D. (1997a). An event-related potential study of memory for spoken and heard words. *Neuropsychologia, 35*, 1185-1195.

Wilding, E. L., & Rugg, M. D. (1997b). Event-related potentials and the recognition memory exclusion task. *Neuropsychologia, 35*, 119-128.

Wixted, J. T. (2007). Dual-Process Theory and Signal-Detection Theory of Recognition Memory. *Psychological Review, 114*, 152-176.

Wood, C. C. (1982). Application of dipole localization methods to source identification of human evoked potentials. *Annals of the New York Academy of Sciences, 388*, 139-155.

Woodruff, C. C., Hayama, H. R., & Rugg, M. D. (2006). Electrophysiological dissociation of the neural correlates of recollection and familiarity. *Brain Research, 1100*, 125-135.

Woodruff, C. C., Johnson, J. D., Uncapher, M. R., & Rugg, M. D. (2005). Content-specificity of the neural correlates of recollection. *Neuropsychologia, 43*, 1022-1032.

Yick, Y. Y., & Wilding, E. L. (2008). Material-specific neural correlates of memory retrieval. *Neuroreport, 19*, 1463-1467.

Yonelinas, A. P. (1994). Receiver-operating characteristics in recognition memory: Evidence for a dual-process model. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 1341-1354.

Yonelinas, A. P. (1999). The contribution of recollection and familiarity to recognition and source-memory judgements: A formal dual-process model and an analysis of receiver operating characteristics. *Journal of Experimental Psychology: Learning, Memory and Cognition., 25*, 1415-1434.

Yonelinas, A. P. (2001). Components of episodic memory: the contribution of recollection and familiarity. *Philosophical Transactions of the Royal Society of London, 356*, 1-12.
Yonelinas, A. P. (2002). The nature of recollection and familiarity: a review of the 30 years of research. *Journal of Memory and Language, 46*, 441-517.
Yonelinas, A. P., Otten, L. J., Shaw, K. N., & Rugg, M. D. (2005). Separating the brain regions involved in recollection and familiarity in recognition memory. *Journal of Neuroscience, 25*, 3002-3008.