Event-Related Potential Correlates of Controlled Retrieval Processing in Recognition Memory Exclusion Tasks

N.C. Bridson
2008

A thesis submitted to Cardiff University for the degree of Doctor of Philosophy in Psychology.

CARDIFF
UNIVERSITY
PRIFYSGOL
CAERDYDD

DECLARATION

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

Signed .... (candidate) Date ....4/8/08..........

STATEMENT 1

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

Signed .... (candidate) Date ....4/8/08..........

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 .... (candidate) Date ....4/8/08..........

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 .... (candidate) Date ....4/8/08..........

STATEMENT 4: PREVIOUSLY APPROVED BAR ON ACCESS

I hereby give consent for my thesis, if accepted, to be available for photocopying and for inter-library loans **after expiry of a bar on access previously approved by the Graduate Development Committee.**

Signed .... (candidate) Date ....4/8/08..........

SUMMARY OF THESIS: POSTGRADUATE RESEARCH DEGREES

Please return the completed form to:
School Research Office

Please TYPE or write in BLACK ink and use BLOCK capitals

SECTION A: TO BE COMPLETED BY THE CANDIDATE AND SUBMITTED WITH THE THESIS

Student ID Number:	**0438717**
Title:	**Please circle appropriate value** **Mr/ Miss/ Ms/ Mrs/ Dr/ Rev/ Other, please specify ....**
Surname:	**BRIDSON**
First Names:	**NICOLE CLARE**
School:	**PSYCHOLOGY**
Title of Degree:	**Please circle appropriate value** **EdD, EngD, DSW, DClinPsy, DHS, MCh, Md, MPhil, MPhil/PhD, MScD by Research, PhD/ Other, please specify ....**
Full Title of Thesis	Event-related potential correlates of controlled retrieval processing in recognition memory exclusion tasks.

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Student ID Number:	0438717

Summary of Thesis:

Natural intelligences appear to represent the world in ways which filter out irrelevant information and allow them to function in a challenging environment. Episodic memory is thought to be mediated by control processes that facilitate the retrieval of task-relevant information at the expense of irrelevant information. Six event-related potential (ERP) experiments were conducted to explore the factors facilitating this strategic recollection. All of the experiments employed a variant of the exclusion task first used by Jennings & Jacoby (1997), in which studied words (targets) are endorsed on one response key, whereas new words and new words which repeat after an intervening lag of 7-9 items (non-targets) are rejected on another key. In all of the experiments correct responses to targets and non-targets elicited reliable left-parietal ERP old/new effects. However, when target accuracy was high (experiments 4 and 5) the effect for non-targets was significantly attenuated. This pattern of data is consistent with previous suggestions that, when the likelihood of recollecting information about targets is high, participants use the success or failure of an attempt to recollect information about targets as the basis for distinguishing between targets and all other classes of test word. Importantly, the findings generalise those obtained in previous experiments to circumstances under which one class of 'old' test items comprises items repeated during the exclusion test phases. The findings in this set of experiments also highlight important considerations when employing exclusion task data in order to make estimates of the relative contributions of memory processes to task performance. Furthermore, an exploratory magnetoencephalography (MEG) experiment found likely functional correlates of ERP memory effects, as well an event-related field (ERF) to which there is no comparable modulation within the electrical record, therefore, highlighting the possible benefits for the use of MEG in the study of human recognition memory.

Abstract

Natural intelligences appear to represent the world in ways which filter out irrelevant information and allow them to function in a challenging environment. Episodic memory is thought to be mediated by control processes that facilitate the retrieval of task-relevant information at the expense of irrelevant information. Six event-related potential (ERP) experiments were conducted to explore the factors facilitating this strategic recollection. All of the experiments employed a variant of the exclusion task first used by Jennings & Jacoby (1997), in which studied words (targets) are endorsed on one response key, whereas new words and new words which repeat after an intervening lag of 7-9 items (non-targets) are rejected on another key. In all of the experiments correct responses to targets and non-targets elicited reliable left-parietal ERP old/new effects. However, when target accuracy was high (experiments 4 and 5) the effect for non-targets was significantly attenuated. This pattern of data is consistent with previous suggestions that, when the likelihood of recollecting information about targets is high, participants use the success or failure of an attempt to recollect information about targets as the basis for distinguishing between targets and all other classes of test word. Importantly, the findings generalise those obtained in previous experiments to circumstances under which one class of 'old' test items comprises items repeated during the exclusion test phases. The findings in this set of experiments also highlight important considerations when employing exclusion task data in order to make estimates of the relative contributions of memory processes to task performance. Furthermore, an exploratory magnetoencephalography (MEG) experiment found likely functional correlates of ERP memory effects, as well as an event-related field (ERF) to which there is no comparable modulation within the electrical record, therefore, highlighting the possible benefits for the use of MEG in the study of human recognition memory.

Acknowledgements

Many thanks to all the members of the Cognitive Electrophysiology Lab at Cardiff University, and in particular my supervisor, Dr. Ed Wilding for all his guidance during my PhD.

In addition I would like to take the opportunity to thank my family for always believing in me, and supporting me. Finally, a special thanks to my husband James who has made these three years such a wonderful time, no matter what hurdles were put in the way. Only the angels could have sent you.

Contents

List of Tables

List of Figures

Chapter One

Memory

Divisions in human memory

Psychologists began studying memory in the mid 19^{th} century; the first monograph, by Ebbinghaus, was published in 1885. Ebbinghaus assessed retention of lists of nonsense syllables, documenting very rapid forgetting in the first hour, which flattened out at about 30% for delays of up to two days. After that the rate of forgetting slowed markedly, but some forgetting was still apparent after a month (Ebbinghaus, 1913). The 1880s have been seen as a revolutionary decade for memory research because it marked the beginnings of the descriptions of memory processes. By the end of 1980s the view that memory comes in many different forms was relatively widespread.

Short term vs. long term memory

Dissociations between different measures of memory have been interpreted as evidence that memory is not a unitary system, but rather that it is comprised of separable and functionally distinct components (Squire, 2004; Tulving, 1972; Tulving & Craik, 2000). This view is supported by various findings in neuropsychological studies, which show contrasts between deficits on certain kinds of memory tasks and normal or near normal performance on others. In an attempt to account for these data, memory researchers have concentrated on determining the ways in which memory is fractionated. For the majority of the 1960s, memory research was focused on the differences between short-term and long-term memory.

This work culminated in a memory framework formulated by Atkinson & Shiffrin (1968). This framework specified three kinds of memory store: sensory registers, short-term memory and long-term memory. In essence, the framework assumes that input information is initially received by modality- specific stores (the sensory registers) that hold information in a relatively uninterrupted form for very short periods of time (not longer than a few seconds). From the information entering the sensory stores, a small fraction is attended to and selected for further processing in short-term memory. Information in short-term memory is processed actively and may be transferred into long-term memory during the time it is being rehearsed (Atkinson & Shiffrin, 1968).

Once short-term memory is seen as a mechanism for allocating attention it is clear that it is not just a passive repository for incoming information. Instead, information is actively selected and actively manipulated. In keeping with this observation, Baddeley & Hitch (1974) and Hitch & Baddeley (1976) proposed that the concept of a short-term store serving as a temporary repository for information should be replaced with the idea of a working memory system with a functional role in a wide range of cognitive tasks.

Baddeley & Hitch (1974) argued that working memory is a complex multi-component system, rather than a unitary store. The working memory model has evolved out of series of experiments in which hypotheses about its structure and operation have been tested and revised. The model as it is most well known is composed of three separate components: a modality free central executive, an articulatory loop, and a visuo-spatial sketch pad (Baddeley, 1990). The central executive is a supervisory system that controls cognitive processes, and is responsible for directing attention to relevant information, suppressing irrelevant information and inappropriate actions, and for coordinating cognitive processes when more than one task must be done at the same time. The articulatory loop stores phonological information and prevents its decay by rehearsing its contents, thereby refreshing the information in a rehearsal loop. The visuo-spatial sketch pad stores visual and spatial information. It can be further broken down into a visual subsystem (dealing with, for instance, shape, colour, and texture), and a spatial subsystem.

Baddeley (2000) extended the model by adding a fourth component, the episodic buffer, which holds representations that integrate phonological, visual, and spatial information, and possibly information not covered by the articulatory loop or visuo-spatial sketch pad (e.g., semantic information, musical information). The component is episodic because it is assumed to bind information into a unitary episodic representation. The episodic buffer resembles Tulving's (1972, 1983, 1985a) concept of episodic memory (which will be described in detail later), but it differs from long-term episodic memory in that the episodic buffer is a temporary store.

There is a body of neuropsychological evidence (Gainotti, Cappa, Perri, & Silveri, 1994; Gathercole, 1994; Shallice & Warrington, 1970; Smith & Jonides, 1995; Vallar & Shallice, 1990; Van der Linden, Coyette, & Seron, 1992) and neuroimaging studies (D'Esposito et al., 1998; D'Esposito et al., 1995; Smith & Jonides, 1999; Smith, Jonides, & Koeppe, 1996) which are generally consistent with the working memory model. In particular, there is some evidence from neuroimaging research indicating that the articulatory loop can be mapped to particular brain regions.

Specifically, it has been suggested that the left inferior parietal cortex supports storage, while a network of areas associated with speech production (left inferior frontal, premotor, supplementary motor, and cerebellar regions) mediate articulatory rehearsal (Awh et al., 1996; Jonides et al., 1998; Paulesu, Frith, & Frackowiak, 1993). However, the extent to which these conclusions account for both neuroimaging and neuropsychological results has been debated (Becker, MacAndrew, & Fiez, 1999; Fiez, 2001). In addition, it is worth noting that although the Baddeley and Hitch (1974) model is the most popular conceptualisation of working memory, there are several alternative theoretical approaches to working memory (see Cowan, 2005; Oberauer, 2002 for examples).

Long-term memory contrasts with short-term memory in that information can be stored for extended periods of time (Baddeley, 1990). Long-term memory allows retrieval of information decades after it is stored, and the limits of its capacity are not known. Storage in long-term memory is assumed to be primarily associative, relating different items to one another and relating items to attributes of the current situation.

The strongest evidence for a dissociation between long-term memory and short-term memory comes from neuropsychological studies. Scoville & Milner (1957) reported that the severely amnesic patient H.M., who underwent surgery in which the temporal lobe was removed in order to relieve severe epilepsy symptoms, had normal short-term verbal recall, as measured by a digit span task. However, he was unable to retain new information for more than a few minutes (Scoville & Milner, 1957). The reverse pattern of findings was reported by Shallice & Warrington (1970) in patient K.F., who could retain new information permanently but had a severely impaired digit span (Shallice & Warrington, 1970). The question of the relationship between short-term and long-term memory remains a mater of debate, however (e.g. Ranganath & Blumenfeld, 2006), but the focus in the remainder of this thesis is on long-term memory.

Models of long-term memory

Craik & Lockhart (1972) proposed a broad framework within which long-term memory phenomena could be understood. They assumed that the attentional and perceptual processes operating at the time of learning determine what information is stored in long-term memory. The theory postulates that there are a number of different levels of processing, ranging from shallow or physical analysis of a stimulus to deep or semantic analysis. Within this theory, depth is defined in terms of the meaningfulness extracted from the stimulus rather than on the number of analyses performed on it. Two key assumptions were made by Craik & Lockhart (1972). First, that the level or depth of processing of a stimulus has a substantial effect on its memorability. Second, that deeper levels of analysis produce more elaborate, longer lasting, and stronger memory traces than do shallow levels of analysis (Craik & Lockhart, 1972). There is evidence that disconfirms this second assumption. For example, Morris, Bransford & Franks (1977) argued that stored information is remembered only to the extent that it is of relevance to the memory test. They found that when participants are given an incidental judgment task in which they are shown a series of words (e.g. 'cat') and asked to make rhyme judgments on them (e.g. 'Does it rhyme with hat?') or semantic judgments (e.g. 'Does it have a tail'?) and the following day are required to either recognise the items, or were asked in each case whether the word rhymed with a word presented the previous day. On the incidental judgment task participants recalled more of the words that had been processed in terms of their meaning. However, when asked to recall words based on their judgment of rhyme (phonetics) the opposite result occurred – participants performed better on the words presented in the phonetic condition. Morris et al. (1977) argued that their findings supported a transfer-appropriate processing theory, whereby different kinds of processing lead to the acquisition of different kinds of information about a stimulus. The key point regarding a transfer-appropriate processing theory is that memory performance benefits from the extent of the similarity between the processes engaged at study and at test. Eysenck (1979) further addressed issues raised by the Craik & Lockhart theory by arguing that long-term memory is affected by distinctiveness of processing as well as by the depth and elaboration of processing. Eysenck & Eysenck (1980) tested this theory and found that words in a non-semantic, distinctive condition were better recognised than non-semantic, non-distinctive words, and almost as well as semantic words. A final problem with Craik & Lockhart's levels of processing theory is that they failed to give a detailed account of exactly why it is that deep processing is so effective.

In addition to his selective impairments being relevant to the short-term/long-term memory distinction, H.M. has also been influential with respect to questions concerning distinctions within long-term memory. H.M. was able to learn a hand-eye coordination skill (mirror drawing), whilst being unable to report any memory regarding the learning episode (Scoville & Milner, 1957). These findings suggest that long-term memory is not a unitary system. This hypothesis has been explored thoroughly more recently, with a number of further distinctions within the long-term memory system being identified. For a taxonomy of long-term memory systems, derived from Squire & Zola-Morgan (1991), see Figure 1.1. The following sections briefly review some of the distinctions shown in Figure 1.1.

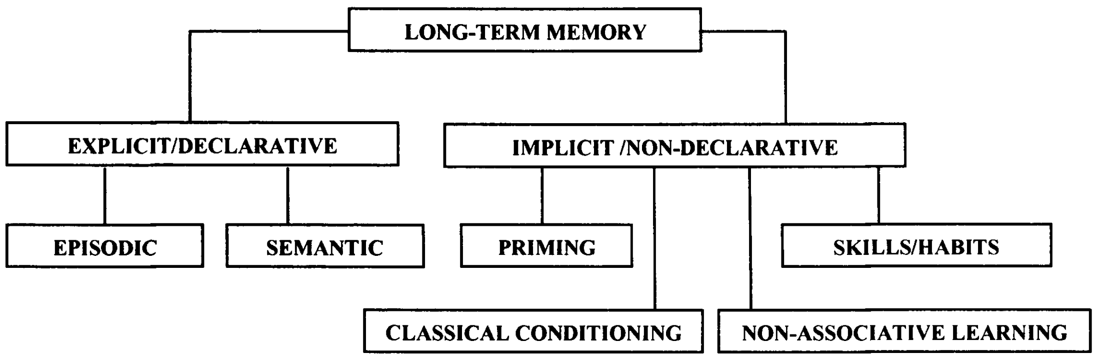


Figure 1.1. Taxonomy of long-term memory systems, derived from Squire & Zola-Morgan (1991).

Implicit/Declarative vs. Explicit/Non-declarative memory

Numerous findings suggest that long term memory is comprised of at least two components, one of which is a conscious form of memory for facts and events while the other is a non-conscious form of memory which manifests itself by influencing behaviour. This dichotomy has been expressed primarily in two different ways; the explicit vs. implicit distinction (Graf & Schacter, 1985; Schacter, 1987) and the declarative vs. non-declarative distinction (Squire & Zola-Morgan, 1991). Explicit or declarative memory is conceptualised as a conscious form of memory retrieval, as one can introspect on and report the contents of the memory. Implicit or non-declarative memory is characterised as memory which influences behaviour in the absence of awareness. Whichever dichotomy is employed for defining these two distinct sets of processes, be it explicit vs. implicit or declarative vs. non-declarative memory, there is little difference in the functional and behavioural processes associated with either. There are different theories that can account for dissociations between explicit/declarative and implicit/non-declarative memory. The following section reviews the various data and theories supporting this dissociation between memory components. These sections are presented using the declarative vs. non-declarative memory terminology throughout.

Declarative vs. Non-declarative memory

Beginning in the mid 1980s, the dominant perspective in memory research was that of a framework that accommodated multiple memory systems (see for example, Tulving, 1985b). At that time, the term ''non-declarative'' was introduced, as a modification of the earlier declarative vs. procedural distinction, with the idea that declarative memory refers to one memory system and that "non-declarative memory" is an umbrella term referring to several additional memory systems (Squire & Zola-Morgan, 1988).

Declarative memory is the kind of memory that is meant when the term ''memory'' is used in everyday language. It refers to the capacity for conscious recollection about facts and events and is the kind of memory that is impaired in amnesia and dependent on structures in the medial temporal lobe and midline diencephalon (Squire, 2004). Declarative memory supports the on-demand accumulation, storage, and retrieval of new data about facts and events—the information that we capture from our experiences through our representations of it.

There is substantial evidence that declarative and non-declarative memory systems differ in the degree to which the knowledge that they support can be generalised. Non-declarative memory includes classical conditioning and procedural memory (motor skills and habits such as tying up shoelaces). These forms of memory are difficult to describe verbally – they can be 'encoded' and 'retrieved' with little or no conscious awareness. Unlike declarative memory, non-declarative memory is inflexible and bound to the modality of the original response systems (Squire & Knowlton, 1995). This arises directly from the fact that non-declarative memory is tied in many cases to the specific processing operations involved in behaviour.

Typically, declarative memory is assessed via recall and recognition tasks which require intentional retrieval of information from previous experiences, or the successful identification of the previously studied material, respectively. As the task instructions refer the subject to a specific spatiotemporal context, these tasks have been variously described as autobiographical (Jacoby & Dallas, 1981), direct (Johnson & Hasher, 1987), episodic (Tulving, 1972, 1983, 1985), and intentional (Jacoby, 1984), declarative (Squire, 1987), or explicit (Graf & Schacter, 1985). An alternative set of tasks which involve no reference to previous events have been described as implicit (Graf & Schacter, 1985), indirect (Johnson & Hasher, 1987), or incidental (Jacoby, 1984).

A distinction should be made between using terms that refer only to task demands (e.g. direct/indirect) and terms that confound task demands with terms often used to describe classes of process or distinct kinds of memories (e.g. declarative). This is so that the use of certain terms to describe tasks does not automatically carry the assumption that the tasks exclusively tap into only one memory process or system.

One source of evidence for the brain mechanisms involved in declarative memory comes from recent neuroimaging studies using functional magnetic resonance imaging (fMRI) that have examined the degree to which distinct subregions of human hippocampus and the surrounding medial temporal lobe (MTL) differentially support particular aspects of declarative memory (see Cansino, Maquet, Dolan, & Rugg, 2002; Davachi, Mitchell, & Wagner, 2003; Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000; Henson, Cansino, Herron, Robb, & Rugg, 2003; Ranganath et al., 2004; Yonelinas, Hopfinger, Buonocore, Kroll, & Baynes, 2001).

Furthermore, lesion studies demonstrate that certain types of brain damage only impair non-declarative memory, while others only impair declarative (Exner, Weniger, & Irle, 2001; Gabrieli, Fleischman, Keane, Reminger, & Morrell, 1995; Keane, Gabrieli, Mapstone, Johnson, & Corkin, 1995). Findings in neuroimaging studies therefore emphasise differences between non-declarative and declarative memory. These neural dissociations comprise distinct neural correlates of non-declarative and declarative retrieval. For example, event-related potentials (ERPs) have revealed different spatiotemporal signatures of non-declarative and declarative retrieval (for example, Paller, Hutson, Miller, & Boehm, 2003; Schott, Richardson-Klavehn, Heinze, & Duzel, 2002). Functional magnetic resonance imaging (fMRI) has helped localise neuroanatomical differences between non-declarative and declarative memory. In one study, for example, non-declarative memory retrieval recruited prefrontal, fusiform, and extrastriate regions, while declarative memory retrieval recruited the posterior cingulate, precuneus, and inferior parietal lobule (Schott et al., 2005); many other studies have revealed frontal involvement in declarative memory retrieval as well (e.g. Buckner & Koutstaal, 1998).

The distinction between declarative and non-declarative memory has also been conceptualised in terms of the degree to which retrieval is dependent on conscious voluntary procedures (declarative memory) rather than an automatic processes (non-declarative memory). For example, Graf, Squire, & Mandler (1984) demonstrated that amnesic patients only showed benefits from cues in a word-completion task if they were encouraged to guess rather than when they attempted active recall. It has also been shown that patients with global amnesia perform poorly on tasks that rely primarily on declarative memory (Scoville & Milner, 1957) but these same participants perform normally on tasks that rely primarily on non-declarative memory (Corkin, 1968; Warrington & Weiskrantz, 1970).

Declarative – episodic and semantic memory

There have also been proposals that declarative memory contains sub-divisions. Tulving (1983, 1985) distinguished between episodic and semantic memory. Episodic memory mediates conscious recollection of previously experienced events, whereas semantic memory involves general symbolic knowledge and facts. The retrieval of semantic memories does not require recall of the contextual details surrounding their acquisition. Tulving (1985) associated episodic and semantic memory with autonoetic and noetic consciousness, respectively. Noetic consciousness refers to awareness of knowledge without a specific re-experience of the learning event (e.g., knowing that the capital of France is Paris). Conversely, autonoetic consciousness correlates with episodic memory and is necessary for the knowledge that an event was personally experienced in a particular spatio-temporal context (e.g., details of a personal trip to Paris).

There is clear evidence of important differences between episodic and semantic memory. First, different parts of the brain are relatively more active for both coding and retrieval of episodic and semantic memories (Wheeler, Stuss, & Tulving, 1997). Second, episodic retrieval leads to greater activation in the frontal lobes, particularly in the prefrontal cortex (Lepage, Ghaffar, Nyberg, & Tulving, 2000). There is also support for Tulving's view that episodic memory is more vulnerable to damage than semantic memory from Vargha-Khadem et al.'s (1997) studies of amnesic patients in which patients exhibited selecitve episodic memory deficits alongside intact semantic memory.

In overall summary, the understanding of the cognitive structure and dynamics of human memory has undergone a dramatic transformation over recent decades. Central to this transformation has been the accumulation of evidence suggesting that memory is not a single entity but rather consists of several dissociable (albeit interacting) systems, each fulfilling specific functions (Graf & Schacter, 1985; Tulving, 1983; Tulving & Schacter, 1990). Many characteristics of these proposed memory systems, including their precise definitions, functions, neuroanatomy, and the temporal parameters of their component processes are yet to be delineated clearly.

Models of recognition memory

The primary focus in this thesis is declarative memory processes, and more specifically, processes that are engaged in tasks where participants must make judgments about the prior occurrence of items. The term 'recognition memory' refers to the form of memory that enables one to distinguish between items encountered previously and those that are being encountered for the first time.

Recognition memory has been explained from two different perspectives, where it is thought that it is either supported by one or two processes (Gillund & Shiffrin, 1984; Hintzman, 1984, 1986, 1988; Jacoby & Dallas, 1981; Jacoby & Kelley, 1992; Mandler, 1980; Murdock, 1982, 1983, 1993; Yonelinas, 1994). From a dual-process position, the assumption is that two dissociable processes contribute to recogntiion memory. A single-process view assumes that there is a continuous strength based process which is the sole underlying mechanism for recognition memory.

Single process models of recognition memory

Global matching models

A class of recognition memory models referred to as 'global matching models' are based on the assumption that recognition memory is comprised of a single process as opposed to two distinct processes (Gillund & Shiffrin, 1984; Hintzman, 1984; Murdock, 1982). Global matching models have evolved as a result of combining features from two earlier types of models; direct-access models and search models. Search models (Tulving, 1976) assumed that events are stored in memory separately and that each item is retrieved sequentially and compared against the test cue. However, such a process would only produce correct rejections of new items after an exhaustive search, and it had been reported that correct rejections can be made very rapidly and confidently (Atkinson & Juola, 1974). Direct-access models (Kintsch, 1970) were formulated within the framework of associative networks, in which items are represented as nodes and relations between items are conceptualised as pathways between nodes. According to direct-access models, recognition occurs when the test item gains direct access to the relevant node. The strength of information at this node is then used to make a recognition judgment. This model circumvents the factor of response speed that proved problematic for search models as it does not require a search process prior to responding, but it does not allow for the influence either of other items in memory or of non-targets and new items presented at test on recognition. As it had been reported that factors such as list length (Bowles & Glanzer, 1983) and inter-item similarity (Posner & Keele, 1970) influence recognition, it is clear that any model of memory must be able to account for the influence of other items. Search models can, however, account for these phenomena.

Global matching models were developed from the congruence between search models and direct-access models in terms of processing speed and being able to account for the influence of other items on recognition. Gillund & Shiffrin (1984) conducted a series of experiments examining whether recognition is comprised of both a direct-access component and a search component or whether it is comprised of a single process. They argued that fast responses should reduce the contribution of a search component while leaving direct-access unaffected, whereas the relative contribution of search processes should increase for slow responses (Gillund &

Shiffrin, 1984). Variables thought to differentially engage search processes (e.g. list length, orienting task) should therefore show interactions with experimental manipulations that selectively reduce or eliminate the search component (Gillund & Shiffrin, 1984). However, although speeded performance decreased the accuracy of memory judgments, no such dissociations were observed. Therefore, the search of associative memory model (SAM) was developed as a single-process model of recognition memory (Gillund & Shiffrin, 1984). SAM, together with other global matching models, accounts both for the sensitivity of recognition performance to other items in memory, and for the production of relatively fast responses.

There are a number of single-process global-matching models. The three most influential are: search of associative memory models, or SAM (Gillund & Shiffrin, 1984), MINERVA 2 (Hintzman, 1984, 1986, 1988), and theory of distributed associate memory, or TODAM (Murdock, 1982; 1983; 1993). These will be reviewed briefly here. Although these three models do differ in detail, they share some commonalities. First and foremost, recognition is modelled as a single signal detection process based on global familiarity, which represents the total activation in memory in response to a test cue. They also a share two other underlying assumptions; a test cue is combined with its context into a single probe of memory (the interactive cue assumption), and the cue is simultaneously matched against all events in memory activating multiple events in parallel (the global matching assumption) rather than being used to retrieve a specific item (Clark & Gronlund, 1996). Global matching results in a value which can be conceptualised as item familiarity, the match of item to memory, or the activation of memory produced by the item (Clark & Gronlund, 1996). This value is generally perceived as an index of global familiarity (Ratcliffe, Van Zandt, & McKoon, 1995). A familiarity value above a certain criterion leads to the judgment that the item occurred previously whereas a value below criterion leads to a negative response.

Although the outcome (a strength based signal) is the same in the three models, there are several key differences between them. SAM assumes that, during encoding, the strength between items is developed, and that item-specific and associative information are stored separately. Item-specific information reflects the 'strength' between the test cue and its representation in memory, while associative information reflects the strength between the test cue and the remaining items in memory. Importantly, although item-specific and associative information are stored separately, their contribution is combined at retrieval and both influence the overall familiarity value that arises. Both Minerva 2 and TODAM assume items are represented as vectors. TODAM assumes that an item is composed of numbers of vectors of attributes which are stored in a common memory vector. During memory recognition, the familiarity product between test item vector and memory vector will produce the match value. In MINERVA 2, items are also thought of as being vectors of attributes and the familiarity product between the vector of the test item and the vector of each item in the memory is matched at recognition. Consequently, the greater the number of shared attributes the greater the level of activation. Thus, although all global matching models specify a single retrieval process, the assumptions underlying retrieval vary substantially.

Signal-detection theory

A number of single-process models of recognition memory employing signal detection theory (Green & Swets, 1966) were developed from classical signal detection models of yes/no recognition memory (Banks, 1970; Glanzer, Adams, Iverson, & Kim, 1993). Similar to global matching models, signal detection models of recognition memory specify a single continuously distributed familiarity process, and normal distributions represent the overlapping familiarity distributions of old and new words (see Figure 1.2). The mean of the old item familiarity distribution is higher than the mean of the new item familiarity distribution. The distance between the two means is denoted as d′, which provides an index of discrimination of old from new items free from response bias, and which assumes that the standard deviations of the old item and new item distributions are equal (Swets, 1986).

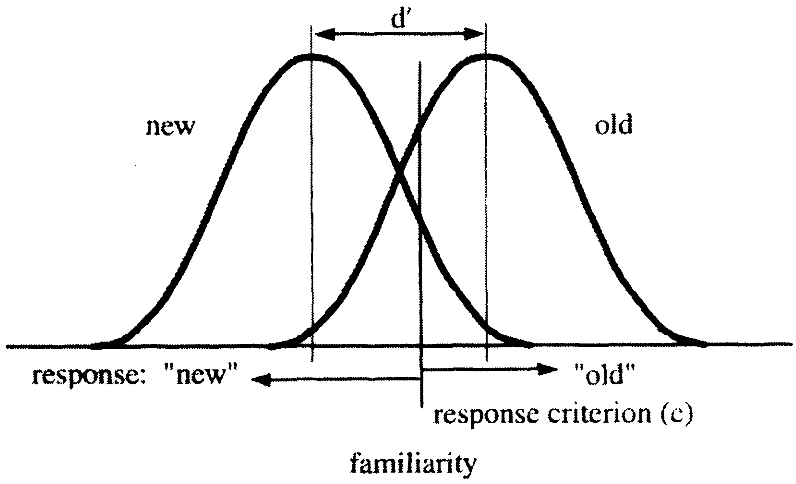


Figure 1.2. An equal-variance signal detection model illustrating familiarity distributions associated with studied and unstudied items. Adapted from Yonelinas (2002).

In the context of recognition memory, the signal detection models consists of two parts: the distribution of old and new items along a familiarity strength axis, and the placement of a decision criterion. It is considered that all test items have some level of familiarity value. Studying a list of items will temporarily increase their level of familiarity. Old items will therefore on average have a higher familiarity value than new items. However, because the distribution of old and new items interact, the overlap will therefore produce correct responses to old (hits) and new (correct rejections) items, as well as incorrect responses to both old (false alarms) and new (misses) items.

It is assumed that participants cannot determine directly whether an item is old or new, but that they are aware of the test item's familiarity value (Snodgrass & Corwin, 1988). Hence, participants must set a criterion, and whether an item will receive an old or new response will depend on where the decision criterion is placed: for an old item to receive an old response, its familiarity ($\mathbf{F_o}$) must exceed the set criterion (C, see Figure 1.2).

$$P(\text{“old”} \mid \text{old}) = (\mathbf{F_o} > \mathbf{C})$$

Similarly, in order for a new item to receive an old response, its familiarity value ($\mathbf{F_n}$) must also exceed the set criterion.

Dual-process theory holds that some recognition memory decisions are based on the recollection of contextual detail, whereas other decisions are based on a sense of familiarity unaccompanied by contextual information (Curran & Hintzman, 1995; Mandler, 1980). One technique that is designed to measure these two processes is the remember/know procedure, which simply involves asking participants to say ''remember'' (R) for recollection based decisions and ''know'' (K) for familiarity-based decisions (Gardiner, Richardson-Klavehn, & Ramponi, 1997) (the R/K procedure is addressed in more detail in a subsequent section of this thesis). Signal detection theory has been used to understand aspects of the R/K procedure, by the use of a two-criteria signal detection model in which a further criterion is placed above the old/new criterion, and this is used to make Remember/Know judgments (see Figure 1.3); items whose familiarity lies above this second criterion will attract a Remember response, whereas those that fall between this criterion and the lower yes/no criterion will attract a Know response (Donaldson, 1996; Hirshman & Master, 1997; Inoue & Bellezza, 1998). Increasing the old/new criterion (i.e. in a more lenient direction) should increase the rate of Know responses but leave Remember responses unaffected. Therefore, the placement of the old/new criterion and the proportion of Know responses should be positively correlated (Donaldson, 1996).

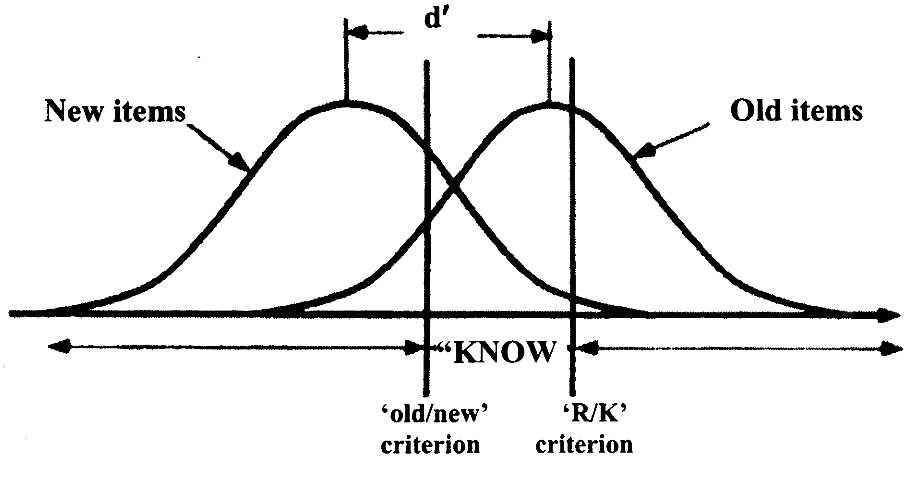


Figure 1.3. An equal-variance signal detection model of Remember and Know responses, illustrating familiarity distributions associated with studied and unstudied items and the placement of the yes/no and Remember/Know (R/K) response criteria. Adapted from Inoue and Bellezza (1998).

Two-criteria signal detection models have been used to demonstrate that a number of Remember/Know dissociations cited to support the dual-process approach can also be explained within a single-process model (Ratcliffe, Van Zandt, & McKoon, 1995). Some researchers adopting the two-criteria single-process model do not claim that all dual-process dissociations can be accounted for within a single-process model, but rather argue that Know responses are an unreliable estimate of familiarity as this measurement relies strongly on the placement of the second decision criterion (Donaldson, 1996). Or that the processes of recognition and familiarity represent instead strong and weak memories (Squire, Wixted & Clark, 2007).

In a review of signal-detection models, and in particular the unequal variance signal detection model, Wixted (2007) concludes that they are much more viable than alternative theories that currently guide investigations into the brain basis of recognition memory, such as the dual-process models and the theory that remember–know judgments capture recollection and familiarity.

Dual-process theories of recognition memory

In opposition to these unitary models of recognition memory, dual-process models propose that, in addition to an assessment of strength or familiarity, recognition judgments can be made on the basis of retrieval of the prior occurrence of the test item - the learning episode (Atkinson & Juola, 1974; Humphreys, Bain & Pike, 1989; Jacoby & Dallas, 1981; Jacoby & Kelley, 1992; Mandler, 1980). These models distinguish between processes supporting recognition with and without retrieval of context, since both familiarity and retrieval of the learning episode support recognition memory judgments, but only the latter supports context judgments.

One of the first dual process accounts of recognition memory was proposed as a result of findings from a sorting/recall paradigm (Mandler, Pearlstone, & Koopsman, 1969). It was demonstrated that the number of categories into which items were sorted at study (referred to as an 'organisational variable') dissociated performance on two measures of memory retrieval; whereas immediate recall was positively correlated with the number of sorting categories but then declined, immediate recognition remained unaffected but then substantially improved over time as a function of this variable. Mandler et al. (1969) proposed that immediate recognition initially depended on 'occurrence information' (i.e. awareness that the item had previously been encountered), and that a retrieval check was only performed if this failed. The underlying assumption was that occurrence information decays more rapidly over time than organised structural effects. This theory was extended to assert that organisational variables relate to slower recognition responses, and that faster responses are made primarily on the basis of occurrence information, for which the term 'familiarity' was adopted (Mandler & Boeck, 1974). Juola, Fischler, Wood & Atkinson (1971) proposed a similar account in which familiarity was conceptualised as being continuously distributed, and in which participants adopted two response criteria; all items eliciting familiarity above the high criterion were judged 'old' (i.e. studied), and all items which elicited familiarity below the low criterion were judged 'new' (i.e. unstudied). It was hypothesised that a second search process is initiated if familiarity elicited by an item falls between these two criteria, and that this results in a slower response (Juola, Fischler, Wood, & Atkinson, 1971).

In what is now perhaps the dual-process model to which most attention is paid (Jacoby, 1991; Yonelinas 1994, 1997, 1999, 2001a, 2001b), the two processes are known as familiarity and recollection. Familiarity is thought of as being relatively automatic and fast-acting, and reflects the outcome and assessment of a continuous index of memory strength. Recollection, on the other hand, is thought of as being slow and intentional, and is characterised by the retrieval of qualitative information about a prior event. These characterisations of the two processes differ somewhat among models. For example, in the influential early work of Mandler (1980), the two processes were referred to as Integration and Elaboration. However, the commonalities between the ways in which the terms are used outweigh the differences.

It has been proposed that the relationship between recollection and familiarity is one of independence, redundancy, or exclusivity (Jones, 1987). An independence relationship predicts that recollection and familiarity can occur simultaneously or separately. Redundancy refers to the possibility of familiarity occurring with or without recollection; however, recollection cannot occur without familiarity. From an exclusivity point of view, the two processes would never occur simultaneously (see Figure 1.4).

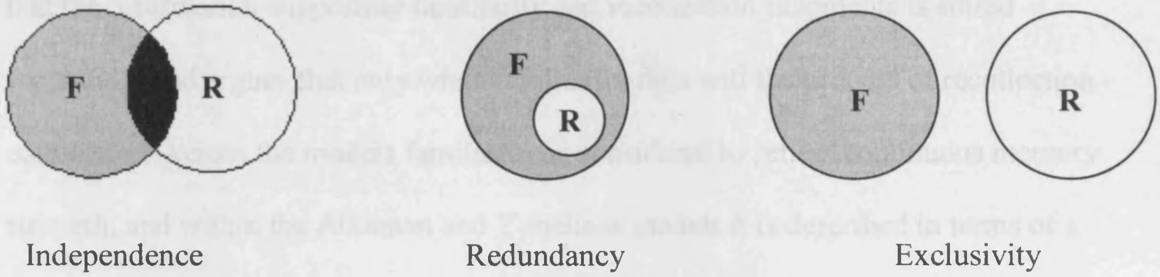


Figure 1.4. Three possible relationships between familiarity (**F**) and recollection (**R**).

There are a number of dual-process models that have been developed on the assumption that recognition memory consists of two separate mnemonic processes: the Atkinson Model, (Atkinson & Juola, 1973, 1974), the Mandler Model (Mandler, 1980, 1991), the Jacoby Model (Jacoby, 1991; Jacoby & Dallas, 1981; Jacoby & Kelley, 1992) the Tulving Model (Tulving, 1985b; Tulving & Schacter, 1990) and the Yonelinas Model (Yonelinas, 1994, 1997, 1999, 2001a, 2001b). The assumption that recognition memory is supported by two processes is central for all the models therefore they are relatively similar to one another. Furthermore, all the models assume that familiarity is a faster process than recollection, and that generally familiarity is considered to be relatively automatic, and recollection to be a process that can be controlled to a greater degree. However, there are some differences across the models with regard to some of their individual underlying assumptions.

For example, all the models, with the exception of the Atkinson model, assume the two processes operate independently. The Atkinson model (Atkinson & Juola, 1973, 1974) argues that familiarity is completed prior to recollection. Therefore, in the other models, in order for recollection to be available, or used, no prior assumptions need to be made with regards to familiarity. Atkinson, on the other hand, assumes that the information supporting familiarity and recollection judgments is stored separately, and argues that only when familiarity fails will the process of recollection commence. Across the models familiarity is considered to reflect continuous memory strength, and within the Atkinson and Yonelinas models it is described in terms of a signal detection framework. Recollection, meanwhile, is described by Yonelinas as a threshold process. Another differing assumption is that, while Jacoby (Jacoby & Dallas, 1981; Jacoby & Kelley, 1992) argues that familiarity is related to implicit memory processes (in particular, conceptual and perceptual priming), Tulving (1985a) argues that familiarity is linked to semantic memory. By contrast, both Atkinson and Mandler claim that familiarity and recollection are influenced by conceptual as well as perceptual processing operations. In addition, some of the models predict different rates of forgetting for the two processes, with Mandler and Atkinson claiming familiarity should decline more rapidly than recollection (Gardiner, 1988; Gardiner & Java, 1991; Yonelinas & Levy, 2002; but also see Bornstein & LeCompte, 1995).

Dissociating the processes in recognition memory

Several behavioural paradigms are currently widely employed as mechanisms for measuring the processes of recollection and familiarity in recognition memory. These include the Remember/Know paradigm (Gardiner, 1988; Gardiner & Java, 1990; Tulving, 1985a), calculated receiver operating characteristics (ROC: Yonelinas, 1994; Yonelinas, Dobbins, Szymanski, Dhaliwal, & King, 1996; Yonelinas, 1997), and the process dissociation procedure (PDP: Jacoby, 1991). These three approaches will be described in the following sections, with particular focus on the PDP, due to the relevance of this approach to the work in this thesis.

Remember/Know (R/K) procedure

The R/K procedure, as used in recognition memory research, is a phenomenological approach which relies on subjective reports of states of awareness to supplement behavioural measures of recognition performance. This approach was developed out of Tulving's distinction between noetic and autonoetic consciousness (Tulving, 1983; Tulving, 1985b). Tulving argued that episodic remembering (or 'mental time travel') is specifically oriented towards the past and is accompanied by 'autonoetic' awareness, whereas the retrieval of declarative information is phenomenally distinct and is accompanied instead by 'noetic' awareness (Tulving, 1993; Tulving & Markowitsch, 1998). Gardiner and colleagues developed the R/K procedure in order to distinguish between the subjective experiences of remembering and knowing (Gardiner, 1988; Gardiner & Java, 1990; Gardiner & Java, 1993; Gardiner & Parkin, 1990). Experiments utilising this approach require participants to respond 'Remember' if they can consciously recollect any contextual aspect of prior presentation, and to respond 'Know' if they recognise the item on some other basis. Moreover, the Remember/Know distinction is generally assumed to overlap with the recollection/ familiarity distinction described by Mandler (1980), and it has been proposed that phenomenological accounts can be used to supplement objective accounts of recognition memory (Gardiner & Java, 1993).

Although Gardiner developed the Remember/Know paradigm from the model described by Tulving (1985b), the functional interpretation of Know responses is somewhat different in the dual-process application than that initially proposed by Tulving. Tulving (1985b) described the Remember/Know distinction as mapping onto the distinction between episodic and semantic retrieval, but in the most common application of this paradigm to dual-process models of recognition memory, Remember and Know responses are associated with recollection and familiarity processes, respectively. Although familiarity and semantic retrieval are both characterised as conscious retrieval in the absence of recollective experience, it can be argued that familiarity is also defined by a subjective awareness that the eliciting item has been previously and personally experienced, whereas this phenomenological experience is usually absent in semantic retrieval. Gardiner, Richardson-Klavehn & Ramponi (1998) studied transcripts of participants' rationales for making 'Know', 'Remember' or 'Guess' responses. 'Know' responses showed no evidence of conscious recollection of contextual details, neither was there evidence of memory for perceptual experiences. Most participants reported that they were aware of having personally encountered the item previously, but could not explicitly remember the episode. Therefore, it appears that Know responses show functional characteristics similar to those attributed to familiarity. Reasons for making a Remember response fell into one of five categories; i) intra-list associations (i.e., associations formed between two or more items within the list), ii) extra-list associations (i.e., associating an item with a simultaneous environmental event), iii) item-specific imagery, iv) the item's physical features, and v) self-reference.

Criticisms of the Remember/Know procedure

Phenomenological paradigms such as the Remember/Know procedure mandate a relationship of mutual exclusivity between recollection and familiarity, which is a consequence of the fact that the two responses cannot occur simultaneously. Criticisms regarding this mutual exclusivity assumption have been levelled at the phenomenological approach, as it has been argued that this assumption results in the contribution of familiarity to overall recognition memory being underestimated (Yonelinas & Jacoby, 1995). This is because any element of familiarity present in Remember responses is ignored as a result of conflating response type (i.e. Remember/Know) with the underlying processes. For this reason, it has been argued that Know responses should be corrected by dividing the proportion of Know responses by the opportunity the subject has to make a Know response (1 – R) before they can be considered to be an accurate estimate of familiarity (F) (Yonelinas & Jacoby, 1995). The formula for this correction is:

$$F = K / (1 - R)$$

Certain ambiguous and inconsistent behavioural and neuropsychological findings yielded by studies adopting the phenomenological approach have been resolved when Remember/Know data are reanalysed under a dual-process signal-detection model which incorporates an independence assumption (Yonelinas & Jacoby, 1995; Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998), although Yonelinas & Jacoby (1995) emphasise that Remember responses are not affected by this issue. This question is discussed in greater detail later.

A second criticism has been aimed specifically at one-stage Remember/Know paradigms (i.e. paradigms in which participants are instructed to respond New, Know or Remember). It was reported that a two-step Remember/ Know procedure (in which participants are asked to rate items as Remembered or Known only after accepting them as old) was preferable to the one-step procedure, as the latter led to a higher false alarm rate for Know responses than for Remember responses, indicating that participants were treating the two responses as confidence judgments (Knowlton, 1998; Hicks & Marsh, 1999). Therefore, differences in the implementation of these procedures between different laboratories may produce different patterns of results. It is important to note that Gardiner & Conway (1999) suggest that an addition of a third, 'Guess', response is also advisable. They argue that estimates of Know responses are often contaminated by guessing, and that these estimates under binary response R/K paradigms may not therefore provide a valid measure of noetic awareness (Gardiner & Conway, 1999). Unlike Know responses, it has been argued that Guess responses show no memory for studied items, even in forced-choice tests (Gardiner & Ramponi, 1998). From a signal detection perspective, however, this distinction makes little sense, as perceived 'guesses' are simply low confidence responses when the familiarity signal for an item falls close to criterion.

Receiver Operating Characteristics (ROCs)

The study of ROCs in the context of recognition memory has had a significant impact on the development and evaluation of different models of the processes underlying recognition memory. A receiver operating characteristic, or ROC, is the function that relates the proportion of correct recognitions (i.e. hits) to the proportion of incorrect recognitions (i.e. false alarms) in a binary discrimination task. ROCs are typically plotted as a function of response confidence (e.g. Yonelinas, 1994; Yonelinas, Dobbins, Szymanski, Dhaliwal, & King, 1996; Yonelinas, 1997). When plotted as z-scores (see Figure 1.5.1), ROCs give two measures of performance; the intercept of the transformed ROC provides a measure of discriminability (d′) or memory sensitivity (Yonelinas, 1997), whereas the slope provides a measure of the symmetry of the ROC. Two influential models of recognition memory, the unequal-variance signal-detection model and a dual-process threshold/detection model, accurately describe the receiver operating characteristic that is typically obtained in memory tasks, but only the latter model can provide estimates of recollection and familiarity (Wixted, 2007).

ROCs can also be plotted in probability space, (see Figure 1.5.2) where recognition responses accompanied with the highest level of confidence are represented to the far left of the ROC curve and subsequent points along the curve represent recognition responses accompanied by decreasing levels of confidence. Figure 1.5.2 demonstrates two types of recognition memory ROCs. The lower function is curvilinear and symmetrical against the diagonal. The curvilinear shape reflects the continuous Gaussian familiarity distribution and is symmetrical because the old and new item distributions have equal variance.

Such characteristics were typical of early recognition ROCs (Murdock & Dufty, 1972) and supported the view that recognition memory reflected only a single familiarity component that could be measured using a single parameter (e.g, d') denoting the distance between the means of the new and old familiarity distributions and which was independent of response bias. However, later studies have shown that recognition memory often produces asymmetrical ROCs, as shown by the upper function in Figure 1.5.2.

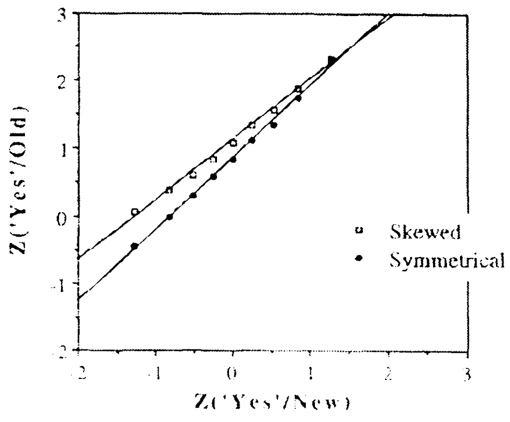


Figure 1.5.1.

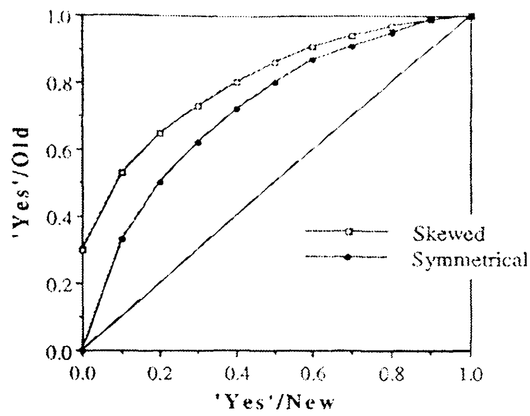


Figure 1.5.2.

Figure 1.5. Symmetrical and skewed receiver operating characteristic curves plotted for z-coordinates (Figure 1.5.1) and for probability coordinates (Figure 1.5.2). Adapted from Yonelinas and Jacoby (1995).

The asymmetry of the ROC curve is not, in itself, problematic for single-process models, as certain models can account for asymmetrical ROCs by assuming that old items are always associated with a greater amount of variance than new items (Squire, Wixted & Clark, 2007), these models predict that the degree of asymmetry will co-vary with the degree of accuracy. However, the degree of asymmetry in recognition ROC curves is not constant and is functionally independent of recognition accuracy (Glanzer, Kim, Hilford & Adams, 1999). This suggests that two distinct components are necessary to account for recognition ROC curves – one to explain increases in sensitivity (d') and another to explain the differential changes in variance in old and new item distributions. It is this aspect of the ROC function data that has provided the greatest challenge for single-process models of recognition memory. As the majority of dual-process accounts specify a threshold process for recollection which results in highly confident responding (Jacoby, Toth, & Yonelinas, 1993), they predict a skewed ROC with a slope of less than 1.0. Therefore, observed ROCs match those predicted by dual-process models more closely than those predicted by single-process models. This has been replicated and extended from equal-variance signal-detection models to unequal-variance signal detection models (Yonelinas, Dobbins, Szymanski, Dhaliwal, & King, 1996), although this extension has recently been questioned by Wixted (2007). ROCs predicted by dual-process models are very similar to those predicted by unequal-variance signal-detection models. Although the unequal-variance signal-detection model offers a viable account of curvilinear ROCs and linear *z*-ROCs (Wixted, 2007), the notion that decisions are based on a one-dimensional memory strength variable is not compatible with the dual-process theory of recognition memory.

This is because dual-process models incorporating recollection as a threshold process, predict ROCs that become more u-shaped than those predicted by unequal-variance signal detection models as the contribution of recollection increases (Yonelinas, Dobbins, Szymanski, Dhaliwal, & King, 1996). In support of this, Yonelinas et al. (1996) used a levels-of-process manipulation to maximise the contribution of recollection to recognition performance, and demonstrated that observed ROCs were linear for shallowly processed items but became more u-shaped for deeply processed items. Therefore, although both the dual-process and unequal-variance signal-detection models provided comparable accounts for shallowly studied words, only the dual-process model could account for the ROC observed for deeply processed items (Yonelinas, Dobbins, Szymanski, Dhaliwal, & King, 1996).

The Process Dissociation Procedure (PDP)

The PDP was originally developed as a means of addressing concerns regarding the issue of 'process purity' (Jacoby, 1991). Jacoby noted that performance on retrieval tasks almost always represents a blend of conscious and automatic processing, and that memory performance on 'indirect' tests (i.e. tests that do not require explicit retrieval, and which therefore putatively reflect only implicit memory) would be at least partially contaminated by explicit memory. Likewise, memory performance on 'direct' memory tasks (i.e. memory tasks requiring explicit retrieval) would be similarly contaminated by automatic influences. The PDP was introduced as a means of separating and estimating the contributions of conscious (recollection) and automatic (familiarity) influences towards performance on a retrieval task.

The PDP uses facilitation and interference paradigms in opposition in an attempt to separate estimates of recollection and familiarity. According to dual-process accounts, items in a recognition memory test requiring a simple judgment of prior presentation may be recognised either on the basis of recollection (which could be brought under intentional control) or on the automatic processes associated with familiarity (which could not). Such a paradigm is therefore facilitatory, as both recollection and familiarity contribute towards a common goal. A facilitatory paradigm is employed as the inclusion test condition which forms one part of the PDP. Jacoby (1991) also developed an interference paradigm which would place automatic and intentional uses of memory in opposition. In the most common version of this interference paradigm, study items are presented or processed in one of two different contexts. At test, participants are required to respond 'old' only if the item was presented in a specified context. These items are called targets. New items, and items previously presented in the other context (non-targets) are to be rejected (or 'excluded'). The interference paradigm is referred to as the exclusion task condition, which forms the other part of the PDP. The correct exclusion of non-targets is thought to require the recollection of their study context so that they can be discriminated from equally familiar targets associated with an alternative study context (Jacoby, 1991). A key response category in the exclusion task is a target response to a non-target, based upon the assumption that this must be a response based upon familiarity in the absence of recollection: if the item had been recollected, a correct non-target response would have been given. This observation is key to the development of the formulae shown below, but it is also important to note that the response requirements of the exclusion task are such that correct responses to targets are made on one key and correct responses to non-targets and new items on another, and this leads to some degree of uncertainty regarding the processes used in correctly rejecting new and non-target items - a key issue relevant to the work in this thesis.

According to dual-process accounts, differential responding to different classes of studied item can only be achieved by an intentional and controllable retrieval process; automatic influences of memory would not allow selective responding of this nature. Recollection, therefore, can be quantified as the difference between the probability of endorsing an item of a specified class when directed to select *for* items belonging to that class (facilitation/inclusion) and the probability of endorsing these same items when directed to select *against* items of that class (interference/exclusion). A series of simultaneous equations based on a probabilistic model can then be solved to yield estimates of the contributions of familiarity (F) and recollection (R) to recognition performance. Under exclusion conditions, a non-target will only intrude as an exclusion error (be incorrectly designated as a target), when recollection fails:

$$\textit{\textbf{Exclusion}} = \textit{\textbf{F}}\ (1 - \textit{\textbf{R}})$$

In contrast, the probability of responding with the same item under inclusion conditions equals the probability that the item is recollected, plus the probability that the item is familiar in the absence of recollection. This probability is expressed as follows:

$$\textit{\textbf{Inclusion}} = \textit{\textbf{R}} + \textit{\textbf{F}}\ (1 - \textit{\textbf{R}})$$

The probability of recollection equals the probability of responding with a non-target item under exclusion conditions subtracted from the probability of responding with the same item under inclusion conditions:

$$\textit{\textbf{R}} = \textit{\textbf{Inclusion}} - \textit{\textbf{Exclusion}}$$

Once an estimate of R has been obtained from performance data, F can then be solved for by using the following equation which is derived from the exclusion equation (Jacoby, Toth, & Yonelinas, 1993):

$$\textit{\textbf{F}} = \textit{\textbf{Exclusion}}\ /\ (1 - \textit{\textbf{R}})$$

The PDP has been applied to a variety of experimental manipulations, and has been used to demonstrate a wide variety of dissociations between recollection and familiarity. These findings are discussed later in this chapter. However, the PDP relies on a number of assumptions. A relationship of independence is assumed between familiarity and recollection, in that an item can be recognised on the basis of familiarity, on the basis of recollection, or on the basis of a combination of familiarity and recollection (Jones, 1987). The estimation procedure rests on the assumption that the criteria used for familiarity-based judgments are equivalent in the inclusion task and in the exclusion task, together with the assumption that the probability of recollection is equal in the two tasks. Finally, it is assumed that values of familiarity and values of recollection are totally uncorrelated.

Criticisms of the PDP

The PDP has been criticised on a number of counts, and has generated a significant amount of debate. While this review does not consider this debate in full, it is necessary to delineate a few key criticisms relevant to studies of recognition memory employing this paradigm. One of the principal criticisms is that the PDP conflates retrieval volition with states of awareness. Therefore the approach fails to account for phenomena such as involuntary conscious memory (Schacter, 1987; Richardson-Klavehn, Gardiner, & Java, 1994) in which recollection is experienced without conscious experience. The PDP also requires specific task-relevant contextual features to be retrieved in order for an item to be designated as recollected. If the specified contextual information is not retrieved the response is designated familiar, regardless of what other contextual aspects may have been recollected (recollection of contextual details other than those specified is termed 'non-criterial recollection').

In response to this criticism, the PDP was employed to directly address this phenomenon (Yonelinas & Jacoby, 1996). It was demonstrated that non-criterial recollection exhibited functional characteristics similar to those associated with familiarity (Yonelinas & Jacoby, 1996), and that the effects of non-criterial recollection were independent from those associated with criterial recollection. Yonelinas & Jacoby (1996) subsequently argued that recollection is situation specific, in that it is defined by task demands. This stance illustrates a key philosophical difference between the PDP and phenomenological accounts; whereas the former operationalises recollection as the retrieval of contextual information that can be employed in the conscious control of behaviour, phenomenological accounts operationalise recollection as the retrieval of any contextual aspect whether it be voluntary or involuntary, criterial or non-criterial.

The PDP was also criticised by Gruppuso et al. (1997), who demonstrated that increasing the difficulty of the criterial question by increasing list similarity decreased recollection estimates while increasing familiarity estimates. This is problematic for the PDP as it demonstrates that estimates of the contributions of recollection and familiarity to recognition memory judgments obtained with the PDP are dramatically affected by the discriminability of the two study lists. On the basis of these findings, it was argued that estimates of recollection and familiarity as measured by the PDP are determined by task demands, and that familiarity estimates can be contaminated by recollection if recollection cannot be used to exclude items. These data can also be cited to support the criticism that the PDP almost always underestimates the contribution of recollection as it only provides an index of the proportion of recollective experience that is subject to conscious control (although this criticism is not problematic if your definition of recollection is that of consciously controlled retrieval). Thus in conditions which promote high levels of non-criterial recollection, recollection estimates will drop and familiarity estimates will rise (Gruppuso, Lindsay, & Colleen, 1997). Similar criticisms were made by Dodson & Johnson (1996), who reported findings that undermined both the assumption that familiarity is automatic, and the assumption that estimates of recollection remain consistent between the inclusion and exclusion task. It was reported that manipulating the proportion of studied targets (i.e. to-be-included items) to studied non-targets (i.e. to-be-excluded items) influenced estimates of familiarity. Dividing attention removed this effect, indicating that familiarity is not an automatic process but that it is controlled and task-demanding (Dodson & Johnson, 1996). It was also reported that enhancing similarity between targets and non-targets increased misrecollection (or source confusion), which resulted in a different target recognition rate on the inclusion task from that on the exclusion task, thus violating the assumption that recollection is equivalent in inclusion and in exclusion tasks (Dodson & Johnson, 1996).

The assumption that recollection and familiarity share a relationship of independence has also come under criticism (Joordens & Merikle, 1993; Cowan & Stadler, 1996). Joordens and Merikle (1993) argued that a relationship of redundancy (Jones, 1987) provided an equally plausible model, based on the assumption that any conscious influence is always accompanied by a correlated unconscious influence (Joordens & Merikle, 1993). It has also been argued that recollection and familiarity share a relationship of exclusivity rather than a relationship of independence, as one cannot experience familiarity and recollection simultaneously (Gardiner & Parkin, 1990).

However, this argument applies to states of awareness, as delineated by the phenomenological approach, and does not address the processes of familiarity and recollection themselves.

Key empirical findings

Many behavioural studies relevant to the single versus dual-process issue have been conducted using the R/K, ROC and PDP methods. Key data points, and their relevance to questions concerning the characteristics of, and relationship between, recollection and familiarity, are described below, along with findings from neuropsychological and neuroimaging studies.

Behavioural evidence

Behavioural studies can provide evidence for models of recognition memory by demonstrating whether or not an experimental manipulation can have dissociative effects on the proposed components of recognition memory – familiarity and recollection. A number of independent variables have shown differential effects on familiarity and recollection within studies employing the remember/know paradigm and the PDP. For example, in comparison to familiarity, recollection is relatively more sensitive to depth of processing manipulations (e.g., Toth, Reingold & Jacoby, 1994). That is, recollection is enhanced when participants engage in the "deep", semantic analysis of study items rather than in the more superficial or "shallow" analysis of their perceptual attributes. Using the R/K paradigm, Gardiner (1988) reported a depth of processing effect was totally accounted for by "remember" responses, while " know" responses remained unaffected by this manipulation. In contrast, other studies, using the PDP, have also reported depth of processing influences on familiarity (Jacoby & Kelley, 1992; Toth, 1996). However these divergent findings were accounted for when the remember/know data, having been originally analysed under the exclusivity assumption, was reanalyzed under the independence assumption. The reanalysis showed a depth of processing effect in the same direction for both "remember" and "know" responses (Wagner, Gabrieli & Verfaellie, 1997). It has more recently been reported; however, that one component of familiarity seems to be sensitive to depth of processing manipulations while another component is not (Yonelinas, Kroll, Dobbins, Lazarra & Knight, 1998).

Dividing attention during study has been found to selectively affect "remember" responses (e.g., Gardiner & Parkin, 1990) as well as recollection in studies employing the PDP (e.g., Jacoby, 1991). Further evidence that attentional capacity selectively influences recollection was provided by another study employing the PDP, using a list length manipulation at study (Yonelinas & Jacoby, 1994). It was argued that, in expanding study list length, demands on attentional capacity increase – this manipulation selectively reduced estimates of recollection but not familiarity (Yonelinas & Jacoby, 1994). However, it has been argued that a single-process model can account for these data (Ratcliff, Van Zandt, & McKoon, 1995). This can be achieved by increasing familiarity values for items from longer lists as well as increasing variability in their familiarity values. For example, for new items presented at test, familiarity will be twice as large for lists that are twice as long. Therefore, the familiarity criterion separating old and new responses needs to be moved as the list length changes so that it may remain between old and new item distributions. Further support for dual process models, however, comes from studies of speeded recognition. These have indicated that estimates of recollection are reduced when participants are required to respond before a short, rather than a long, deadline, while estimates of familiarity are not influenced by this manipulation (Yonelinas & Jacoby, 1994). This suggests that familiarity is available earlier than recollection – in fact, it has been reported that accurate old/new judgments can be made approximately 100 ms prior to accurate source judgments (Hintzman, Caulton, & Levitin, 1998). The few variables held to selectively influence familiarity are those that increase the perceptual fluency with which items are processed. For example, briefly flashing an item immediately prior to presenting the same item at test increases the probability that the word will be recognised as old (Rajaram & Neely, 1992). This type of manipulation has been found to increase "know" responses while leaving "remember" responses unaffected (Rajaram, 1993). Also, matching the modality between study and test produces a higher proportion of "know" responses than when modality shifts between study and test, while "remember" responses remain unaffected by this manipulation (Gregg & Gardiner, 1994).

Neuropsychological evidence

It is well established that damage to the medial temporal lobes causes severe impairments in memory performance (e.g., Moscovitch & McAndrews, 2002; Yonelinas et al., 1998). Damage to the hippocampus and surrounding temporal lobes in amnesic patients has been shown to disrupt both recollection and familiarity, but generally has a larger disruptive effect on recollection. For example, amnesic patients generally exhibit substantial deficits on associative compared to item-recognition tests, indicating that recollection is disproportionately disrupted by medial temporal lobe damage. Specifically, in comparison to tests of item recognition, amnesic patients perform more poorly on tests that require them to remember when an item was presented (Aggleton, Vann, Oswald, & Good, 2000; Kopelman, 1989; Nunn, Graydon, Polkey, & Morris, 1999). Consistent with such examples, ROC studies in amnesic patients have indicated that only one process (i.e. familiarity) is needed to account for their recognition performance (Yonelinas et al., 1998), as would be expected if they exhibited a severe deficit in recollection. Furthermore, results from the remember/know (Blaxton & Theodore, 1997; Knowlton & Squire, 1995; Schacter, Verfaellie, & Anes, 1997; Schacter, Verfaellie, & Pradere, 1996), process-dissociation (Verfaellie & Treadwell, 1993) and ROC (Yonelinas, 1997) estimation methods indicate that, in studies which include patients with extensive temporal lobe damage, recollection is severely disrupted, whereas familiarity is disrupted to a lesser extent.

In a meta-analysis of 33 studies of amnesic patients and their performance on recognition memory, it was concluded that patients with relatively focal hippocampal damage displayed a greater impairment on recall than recognition (Aggleton & Shaw, 1996). Based on dual-process models, Aggleton & Shaw suggested that damage to the hippocampal system disrupts recollection, whilst leaving familiarity intact, thereby explaining their relatively preserved recognition performance (see also Aggleton et al., 2005).

In a study by Lazzara, Yonelinas & Ober (2001), in which they employed the R/K paradigm, patients with extended MTL damage showed a decrease in "R"as well as 'K' responses, whereas patients with focal hippocampal damage exhibited a decrease primarily in 'remember' responses. Their result is consistent with the view that the hippocampus is critical for recollection, whereas other areas in the MTL support familiarity. Moreover, other studies in which the R/K paradigm (Schacter, Verfaellie, & Anes, 1997), PDP (Verfaellie & Treadwell, 1993), or ROC approach (Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998) were employed demonstrated that isolated hippocampal lesions typically impair recollection, whereas extensive MTL damage has an effect on both processes. However, there are some inconsistencies across different studies. For example, in some R/K studies it has also been reported that amnesic patients show a large deficit in both recollection and familiarity (Knowlton & Squire, 1995), whereas others have argued that amnesia causes a deficit in recollection but an increase in familiarity, as 'know' responses increased (Schacter, Verfaellie, & Pradere, 1996). Yonelinas et al. (1998) have pointed out that the disparity between the different studies may be due to the fact that the false alarm rates differ enormously across studies, and that response bias should have been incorporated when interpreting the results (Verfaellie, Giovanello, & Keane, 2001).

Neuroimaging evidence

Functional neuroimaging techniques, such as functional magnetic resonance imaging (fMRI), have provided data to complement neuropsychological findings. In particular fMRI techniques offer a number of advantages over neuropsychological research in terms of the precise spatial localization of functional differentiation obtained within specific brain regions. This haemodynamic method detects changes in regional blood oxygenation, providing indirect measures of brain activity by imaging the oxygenation level of the blood flowing through the brain, as blood leaving relatively active neural populations is more richly oxygenated than blood leaving relatively inactive neural populations (Ogawa, Lee, Kay, & Tank, 1990).

The results of functional imaging studies are broadly consistent with the view that while familiarity relies on regions in or around the perirhinal cortex, recollection is supported by the hippocampus (Cansino, Maquet, Dolan, & Rugg, 2002; Davachi, Mitchell, & Wagner, 2003; Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000; Henson, Cansino, Herron, Robb, & Rugg, 2003; Henson, Rugg, Shallice, & Dolan, 2000; Henson, Rugg, Shallice, Josephs, & Dolan, 1999). In one important recent publication due to Yonelinas et al. (2005), participants were instructed to press one key if they recollected test items, and make old/new judgments as well as confidence judgments, on a four-point confidence scale, if they failed to recollect. Activation in the anterior medial frontal cortex, lateral parietal cortex, posterior cingulate, and hippocampus was related to recollection. Activation in the lateral prefrontal cortex, superior lateral parietal cortex, and precuneus was related to familiarity. The findings of Yonelinas et al. (2005) are broadly consistent with previous findings, but importantly, when controlling for confidence, there was only minimal overlap between the brain regions in which activity was correlated with recollection and with familiarity, thereby providing strong support for dual-process accounts of recognition memory.

In summary, the question of the validity and utility of the distinction between recollection and familiarity has generated substantial data and debate. The recent development of alternative dual-process models (Rotello, MacMillan & Reeder, 2004; Kelley & Wixted, 2001), as well as theoretical re-interpretations of data held to support dual-process accounts (Squire, Wixted & Clark, 2007; Wixted, 2007), has also breathed new life into this research area. An unchallenged assumption, however, is that the process of recollection entails recovery of contextual information, and it is broadly assumed that some degree of control can be exerted over recollection. The question of how and when control over recollection can be exerted is central to this thesis, and in the following sections, models in which retrieval control is incorporated are discussed. The ERP data described later will also, however, be linked back to considerations of the PDP, and the status of the process of familiarity, since the findings in the studies in this thesis provide data points relevant to these issues, although they are not the primary issues driving the experiments that were conducted.

Models of memory retrieval processing

Both cognitive theory and neuropsychological evidence suggest there are at least two classes of control operations that are involved in memory retrieval task performance (e.g., Burgess & Shallice, 1996; Schacter, Norman & Koustaal, 1998; Tulving, 1983). First, there is "retrieval cue specification" which is associaeted with the relationship between the retrieval cue and the known characteristics of the item to be retrieved. In other words, it is thought that efficient retrieval from episodic memory may depend on the ability to use semantic knowledge in order to systematically consider the most relevant characteristics of a current memory cue in relation to potential previous episodes (e.g. Schacter et al., 1998). The second proposed operation, is the process of evaluating the products of memory retrieval with respect to their relevance to the retrieval task.

In considering the above proposals, Dobbins, Foley, Schacter & Wagner (2002) examined neural activity across semantic encoding, source recognition and items recognition tasks. They suggested that, if controlled semantic analysis/selection of semantic features are required to specify effective retrieval cues for source recognition and to analyze task-relevant semantic features during encoding anterior left inferior prefrontal cortex, an area related to semantic retrieval and selection (Buckner et al., 1995; Wagner, Koutstaal, & Schacter, 1999; Wagner, Paré-Blagoev, Clark, & Poldrack, 2001), should be activated in both tasks. In contrast, item recognition should not engage this brain region as controlled semantic analysis would not be required for this task (Fletcher & Henson, 2001). Furthermore, Dobbins et al. (2002) suggested that the monitoring requirements of source memory should recruit unique control processes given that neither item recognition nor semantic encoding should require the monitoring or evaluation of the outcome of episodic retrieval. In line with these proposals, Dobbins et al., (2002) reported that source memory tasks, relative to item recognition, differentially require distinct cue specification and monitoring operations that are supported by anatomically separable left prefrontal regions. More specifically, their pattern of findings suggested that anterior left inferior prefrontal cortex is involved in the controlled retrieval of semantic information that is necessary during semantic encoding and is a critical component of cue specification during a source retrieval attempt. However, frontopolar and posterior dorsolateral prefrontal cortex regions were exclusively engaged during the source task, suggesting a role in control processes that guide the monitoring or evaluation of the contents of episodic retrieval. Furthermore, consistent with the idea that the engagement of such processes in the controlled aspects of source memory is necessary regardless of task outcome, the degree of prefrontal activity was insensitive to retrieval success (Dobbins, Foley, Schacter, & Wagner, 2002).

The above findings indicate that episodic memory is supported by a number of prefrontal brain regions associated with cognitive control processes that guide and monitor episodic retrieval attempts. That is, these prefrontal regions are necessary for exerting control over retrieval. The question of how this can be done, and under what circumstances it is in fact accomplished, is central to this thesis. While the data presented later do not speak to the roles in retrieval control that are played by specific pre-frontal regions, they do speak to questions about how and when retrieval control is implemented. In the following sections, models of retrieval that specify some of the processes that are involved in the control of retrieval are outlined. Common to all of them is the assumption that the human memory system can only operate as effectively as it does because of various classes of control operation that are engaged when retrieval is required.

The General Abstract Processing System (GAPS)

Tulving (1983) first proposed this framework for episodic memory retrieval, the foundation of which lies in the thirteen elements that he holds to constitute the episodic memory system. These include encoding operations as well as the relationship between encoding and retrieval. In depth details of the remainder of the GAPs framework are not relevant and will not be discussed further here. There are, however, some critical concepts that must be noted. One contained in the GAPS, and which is central to all models of memory retrieval, is the concept of a memory trace or engram (Schacter, 1987; Semon, 1921). The engram results from memory encoding, and it is the interaction between a trace or engram and a retrieval cue that is a key process in episodic retrieval. The trace/cue interaction has been termed ecphory (Semon, 1914), and *ecphoric information* is one term that has been used to describe the outcome of ecphory.

For present purposes, perhaps the most important concept that was introduced by Tulving (1983) is *retrieval mode*, even though this is not included in the GAPS framework. According to Tulving, for episodic retrieval to occur it is necessary to enter a cognitive set that ensures stimuli are processed as episodic retrieval cues (Wheeler, Stuss & Tulving, 1997). Retrieval mode is a tonic state that is maintained while episodic retrieval is required, which remains constant across different episodic retrieval tasks (Rugg & Wilding, 2000), and biases individuals to process stimulus events as retrieval cues rather than as simple environmental inputs (for a recent review, see Wheeler, Stuss & Tulving, 1997).

It has also been claimed that entry into retrieval mode is necessary in order for episodic retrieval to occur, but this claim seems somewhat incompatible with the widely accepted view that spontaneous or unintentional recollection can occur (Graf, Mandler & Haden, 1982; Jacoby & Dallas, 1981). While it is in principle possible to argue that retrieval mode can in some circumstances be adopted automatically, this claim is not supported by the findings of empirical studies of retrieval mode (see below). A more parsimonious perspective is that adopting retrieval mode may have positive benefits for episodic retrieval, but that there are conditions under which retrieval from episodic memory can occur in the absence of mode, for example when a particularly vivid memory is activated by an appropriate retrieval cue.

Strong empirical support for the construct of retrieval mode comes almost wholly from studies in which brain activity was recorded while participants completed memory retrieval tasks. On the basis of findings in a series of positron emission tomography (PET) studies, Tulving and colleagues (1994) proposed that retrieval mode was supported by activity in right-prefrontal cortex. This claim was based on findings that activity in this region was greater during tasks that required episodic retrieval than during tasks that did not, and that the activity in this region did not differentiate between different classes of test items. Lepage, Ghaffar, Nyberg & Tulving (2000), conducted a multi-study analysis of PET data gathered from experiments in which participants completed either an episodic (old/new recognition memory) or a semantic retrieval task (Kapur et al., 1995; Nyberg et al., 1995). Across these tasks the right prefrontal cortex was identified as the region that supported retrieval mode, as this cortical region showed as much differential activation during recognition testing of old items as it did during testing of new items. A brain region can, therefore, be regarded as a neuroanatomical correlate of retrieval mode if it (*i*) becomes differentially active during attempted retrieval of past events and (*ii*) does so independently of the level of ecphory (recovery of stored information).

These findings were obtained in PET studies of episodic retrieval and due to the nature of the imaging technique it is not possible to separate activity that is initiated by the presentation of individual items from activity that is initiated at the start of a task and which is maintained for the duration of a task (Donaldson, Allan & Wilding, 2002; Rugg, 1998). As the presence of brain activity that differentiates episodic from non-episodic tasks, but which does not differentiate between stimulus-types, can be interpreted as providing support for the concept of retrieval mode, the findings in these PET studies provide conceptual support for retrieval mode only if the pattern of activity that is responsible for the results is maintained throughout the episodic task.

Arguably stronger evidence in support of the concept of retrieval mode comes from studies where event-related potentials (ERPs) were recorded during tasks designed to index retrieval mode (Duzel et al., 1999; Duzel et al., 2001; Morcom & Rugg, 2001). In the studies of Duzel and colleagues (1999; 2001), participants studied a series of words. At test, they were presented with blocks of four-item lists. They were cued to engage in either an episodic retrieval (old/new recognition) or a semantic retrieval task (animacy judgments) at the start of each block. Compared to cues signalling the requirement to complete the semantic task, the cues signalling the episodic retrieval task evoked ERPs which were more positive-going. The relative positivity onset prior to the first test word in each block and was maintained for the duration of the block. The fact that the effect was maximal over right anterior sites is consistent with the findings from PET studies (Lepage et al., 2000) and supports the claim that retrieval mode is supported by this region of the brain.

Morcom & Rugg (2001) employed the same retrieval task as Duzel et al. (1999), but participants in their studies were cued on each trial to complete either an episodic or a semantic retrieval task. Consistent with the finding of Duzel et al. (1999), Morcom & Rugg (2001) observed that the activity evoked by the episodic retrieval cues was relatively more positive-going at right fronto-central scalp sites than the activity evoked by the semantic retrieval cues (Morcom & Rugg, 2001).

In keeping with the conclusion of Duzel et al. (2001), Morcom & Rugg (2001) proposed that the differences between the cue-related activity indicate the adoption and/or the maintenance of a retrieval mode. This claim is also supported by the findings of Herron & Wilding (2004), who demonstrated that preparatory activity at right frontal electrodes was more positive-going in two different episodic retrieval tasks than in a semantic retrieval task (Herron & Wilding, 2004).

While the effects reported by Duzel et al. and by Morcom & Rugg are broadly consistent with a mode interpretation, it is not the only plausible account of the data. The concept of retrieval orientation recently proposed by Rugg & Wilding (2000), is an alternative possibility. Orientation differs from mode in that retrieval orientations should vary according to the content of what episodic information is to be retrieved from memory. Therefore, while retrieval mode should be invariant across different episodic retrieval tasks, retrieval orientation should not. In the experiments of Duzel et al., (1999, 2001) and Morcom & Rugg (2001), the same episodic and semantic retrieval tasks were employed. Therefore, it is possible that these studies may have revealed indices of retrieval orientation specific to these task-pairings, rather than indices of retrieval mode. For further relevant comments on retrieval orientation see the following section on the Rugg & Wilding (2000) proposal (page 67).

Burgess and Shallice (1996) model of memory control

On the basis of a detailed analysis of memory protocol studies and considerations of how memories are distorted in individuals who confabulate, Burgess & Shallice (1996) put forward a model of memory control. According to this model, confabulations occur due to the failure of memory control processes, which are governed by the frontal cortex (Burgess & Shallice, 1996). The model constitutes a stage where retrieval cues are specified (descriptor processes) and stages following retrieval where the information retrieved via those cues is monitored and verified (editor processes) and integrated with other cognitive demands (mediator processes: for a related view, see Koriat & Goldsmith, 1996). These processes are assumed to be under a degree of strategic control during autobiographical retrieval and to operate iteratively. Therefore, if the monitoring processes reveal that the information retrieved is inappropriate or not sufficiently relevant, further retrieval cues are specified and the processes are reiterated.

Burgess & Shallice's (1996) conception of these control processes is based on the notion of a supervisory system proposed by Norman & Shallice (1980; 1986). They also argued that descriptor processes and editing processes are specific to memory retrieval and controlled by the frontal cortex – claims that are supported by work with neuropsychological patients (for review, see Stuss, Eskes & Foster, 1994) as well as numerous recent findings in PET and functional magnetic resonance imaging (fMRI) studies (Tulving et al., 1994). The precise functional roles that are played by sub-regions of the frontal cortex are, however, a matter of considerable debate (for recent reviews, see Fletcher & Henson, 2001; Wood & Grafman, 2003).

The Source Monitoring Framework (SMF)

In the SMF (Johnson, Hashtroudi, & Lindsay, 1993) memory is not viewed as a literal reproduction of the past. Rather, memory is the result of various perceptual and reflective processes that form memory records. According to Johnson et al. (1993), memory records have different characteristics that include details of perceptual, contextual, semantic and affective information, as well as cognitive operations that were engaged at the time of encoding.

The amounts of these different characteristics are assumed to vary with the origin of the memory records, as memories acquired from different origins have different patterns of the distributions of these characteristics. For example, an activated memory record for a perceived event is likely to have more perceptual details than an imagined event. Johnson and colleagues propose that source judgments can be made by assessing the distribution of different memory characteristics for memories of different origins. So when distinguishing between stimuli that might have been perceived or imagined (Johnson, Raye, Foley, & Foley, 1981) one strategy would be to use the amount of perceptual detail that is recovered, as this should be greater for real than imagined events and therefore a good indicator of the source of a memory. The SMF thus involves attribution and decision processes that evaluate characteristics of a memory record, and the central concepts in the SMF are supported by the findings in numerous experiments. For example, in the studies of Dodson & Johnson (1993) participants were able to retrieve the details of an episode better when the test questions presented all possible sources to consider than when a yes-no binary question specific to one particular source was asked. It was argued that the simultaneous presentation of all sources oriented participants to consider all dimensions of the memory record's characteristics at the same time and encouraged them to put more weight on characteristics that are diagnostic for the demands of the task. The claim that source discriminations are often made on the basis of an assessment of the presence or absence of particular characteristics is also supported by the verbal reports of participants in source monitoring studies (Johnson, Foley, Suengas, & Raye, 1988).

Constructive Memory Framework (CMF)

On the basis of the SMF, Schacter and colleagues (1998) proposed the CMF in which retrieval processing involves focusing, pattern completion and criterion setting. According to Schacter et al. (1998), the critical process, and the principal addition to SMF, is focusing, a process which involves refining a description of the characteristics of episodes that are to be retrieved. A good retrieval focus can lead not only to recollection of information relevant to target information but also the details of the target information (Schacter, Norman, & Koutstaal, 1998). The description of the information to be retrieved is then matched with the stored memory representations (McClelland, McNaughton, & O'Reilly, 1995). When this pattern completion process produces a match, this will lead to a decision stage, where recovered information is evaluated according to task-dependent criteria, in much the same way as in the SMF.

While doing so in different ways, and to different extents, the frameworks outlined above (see also Koriat & Goldsmith, 1996) emphasise the importance for retrieval of processes that operate after ecphory or pattern matching, as well as processes (e.g. focusing) that operate prior to the interaction between a retrieval cue and a memory record or trace. It is now widely accepted that the strategic control of retrieval involves processing at both of these loci, and this assumption is also made by Rugg & Wilding (2000), who provided a description of processes that operate before and after ecphory, as well as a discussion of how these processes could be isolated in appropriately designed brain imaging experiments.

Rugg & Wilding (2000)

Rugg & Wilding (2000) distinguished four classes of retrieval process. Of these four, the three that may form part of a retrieval attempt are retrieval mode, retrieval orientation and retrieval effort. The fourth class of process Rugg & Wilding use is termed 'retrieval success' and includes ecphoric or pattern matching processes, as well as processes that operate downstream of this stage . The focus in this thesis is on when control over retrieval can be exerted, and, as described in later chapters, the principal way in which this is done is by making inferences on the basis of the conditions under which an ERP index of successful retrieval changes in magnitude. One way of conceiving how these changes come about is that they result from changes in the processes that form part of a retrieval attempt. Mode has already been discussed, therefore only orientation and effort are discussed below.

As previously mentioned, retrieval orientation is a cognitive set that is maintained tonically and that determines the specific form of retrieval operations that will be engaged when a retrieval cue is encountered. Thus, orientation but not mode should vary according to the specific episodic demands of a retrieval task. Rugg & Wilding (2000) proposed that neural correlates of orientation can be identified by comparing the activity elicited by identical retrieval cues denoting different episodic retrieval tasks, and the consequences of adopting orientations can be investigated by comparing the activity elicited by new (unstudied) test items.

In an experiment that was designed to investigate the relationship between retrieval mode and retrieval orientation (Herron & Wilding, 2004), ERPs evoked by three retrieval cues were recorded, one signalling semantic retrieval, the others two different kinds of episodic retrieval. The ERPs evoked by the different episodic retrieval cues elicited common right frontal positivities relative to those elicited by the semantic cue. This shared modulation resembled similar effects reported in previous studies (Morcom & Rugg, 2001), and was concluded to be a likely correlate of processes related closely to retrieval mode. Critically, ERPs elicited by the two episodic cues differed, and the ways in which they diverged from those elicited by the semantic cue were not equivalent. Herron & Wilding (2004) drew two conclusions from these results. First, the requirement to retrieve different kinds of episodic information results in the adoption of task-specific retrieval orientations. Second, retrieval mode and retrieval orientation are neurally dissociable classes of retrieval process.

Retrieval effort can be defined as the differential engagement of processing resources during a retrieval attempt (Rugg & Wilding, 2000). Commonly operationalised in terms of the relative level of memory difficulty, it can be measured by the accuracy of memory performance and/or the time taken by participants to respond during a retrieval task. Thus, manipulating task difficulty by, for example, varying the length of the study-test list or interval while keeping study task and retrieval cues constant, should reveal neural correlates of effort. With the more difficult retrieval task assumed to require greater retrieval effort and show poorer response accuracy and longer reaction times. According to Rugg & Wilding (2000), both orientation and effort are processes which may be engaged during the use of a cue in a retrieval attempt, and may be engaged regardless of whether the attempt is successful or not.

Concluding remarks

Memory is not a unitary system, as demonstrated by previous empirical work. There is now a sizeable number of studies which provide support for the view that recognition memory can be supported by two separate processes, and that the two processes are qualitatively different, although the debate about these processes, and how they contribute under different circumstances on different tasks, remains very much alive. A critical observation for the work in this thesis is the fact that specific events can be recovered from a system containing very many events and often many similar events. This suggests that selective remembering is likely to involve control operations that operate prior to retrieval as well as after retrieval. There are various theoretical proposals concerning retrieval processing, and the processes involved, as well as how they co-operate. The principal ones have been reviewed above. Central to all of them is the assumption that processes such as recollection can be controlled, and that this probably occurs because of processes that occur prior to ecphory, as well as after it.

The work in this thesis is concerned with strategic retrieval processing in episodic memory, with one important focus being on the way in which strategic retrieval processing promotes selective recovery of information from memory. The following chapters will, more specifically, consider how, through use of the recognition memory exclusion task, event-related potentials (ERPs) may further elucidate cognitive processes underlying strategic recollection. Before reviewing findings from studies that have employed ERPs to investigate these memory processes (Chapter 3), issues relating to ERP methodology will first be discussed.

Chapter Two

Event-related potentials

It is thought that all psychological function depends on basic biophysical processes, and that a large proportion of these processes consist of the transmembrane electrochemical activity of neurons (Churchland, 1986). Therefore, the recording and measurement of electrophysiological brain activity during specific psychological tasks can inform and constrain theories of psychological function.

The fundamental unit of the brain is a neuron. A neuron communicates with other neurons via electrical impulses, also called potentials, and chemical secretions called neurotransmitters. Electrical input to one neuron comes from many others, each having a specific amount of influence, or weight, on the neuron. When neuronal networks are activated, they produce a noticeable change in voltage potential, which can be captured by an electroencephalograph (EEG). Spontaneous EEG activity was first discovered in animal studies during the late nineteenth century by Caton (1875).

Electrogenesis

An understanding of the principles of electrogenesis and of the propagation of field potentials is of crucial importance in the interpretation of EEG. Electrogenesis occurs at the level of individual neurons due to the bi-directional flow of positive and negative ions resulting from changes in the permeability of the cellular membrane. These individual electrical events are thought to consist largely of changes in the polarisation of cell bodies and dendrites of pyramidal cells as opposed to axonal action potentials (Allison, Wood & McCarthy, 1986).

When the membranes of large groups of neurons are polarised simultaneously, the resultant potentials undergo spatial summation resulting in a local field potential. The spatial arrangement of the neurons constituting the generator determine whether the field is 'open' or 'closed' (Coles & Rugg, 1995), see Figure 2.1. An open field consists of neurons of the same orientation arranged in parallel, and is essentially a dipole as it contains both positive and negative charges between which current can flow.

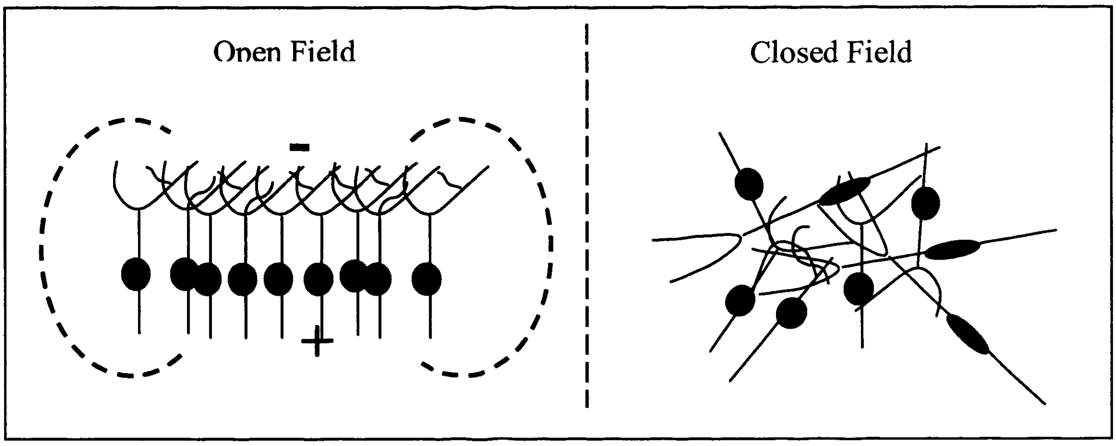


Figure 2.1. Open and closed field configurations. Adapted from Alison et al. (1986).

A local field potential will only propagate throughout the brain, skull and scalp (which are conductive media) if it is generated by an open field, and if the neurons making up the field are synchronously active. A closed field is a group of neurons which are configured in such a way that the individual potentials cancel each other (Wood, 1987), see Figure 2.1. For example, a closed field may consist of neurons of opposite orientation, or of neurons arranged radially so that current can only flow inwards (Kutas & Dale, 1997). The potential produced by a 'closed' field does not spread beyond its generators and therefore cannot be detected at the scalp. These limitations mean that only a proportion of brain activity can be detected at the scalp. The principal brain structure that satisfies all of these constraints is the neocortex, 70% of which consists of pyramidal cells organised by groups in columns and oriented perpendicular to the surface of the cortex (Nunez, 1981).

Consequently the EEG is the summation of the electrical activity of large populations of cells conducted through the brain and its coverings to the scalp (Allison et al., 1986; Nunez, 1981). It consists of a voltage by time function. The amplitude of the normal human EEG varies between approximately –100 and +100 microvolts, and the frequency ranges from DC up to 100Hz (Coles & Rugg, 1995). The amplitude of the EEG signal recorded at the scalp strongly depends on how synchronous the activity of the underlying neurons is, and how distant the generators are from the recording electrodes.

EEG Acquisition

An event-related potential (ERP) is scalp-recorded electrical activity time-locked to a specific physical or mental event (Picton, Lins & Scherg, 1995). In cognitive psychology experiments this event is typically the experimental stimulus. The ERP is most commonly extracted from the EEG by means of averaging the signal across multiple trials of the same stimulus type. As the activity recorded is time-locked to the presentation of each experimental stimulus, ERPs therefore provide a trial-based measure of neural activity. This allows averaged ERPs to be formed for experimental condition post-hoc depending on outcome. For example, ERPs elicited by the presentation of a studied item during a recognition memory test can be categorised according to whether the item was recognised correctly or not.

ERPs are sensitive to sensory, perceptual, motor and cognitive processes (Kutas & Dale, 1997). They have excellent temporal resolution, in the order of milliseconds. ERPs can therefore track cognitive processes in real time, and provide information about the dynamics of neural activity, as well as interactions between the activity of multiple neural populations (Rugg, 2001). The fact that ERPs are sensitive indicators of changes in neural activity, regardless of whether these changes influence awareness or observable behaviour, means that they can be used to examine cognitive processes when direct behavioural measures cannot be obtained. For example, ERPs have been used to examine the processes underlying implicit memory (Paller, Kutas & McIsaac, 1995), and to study the neural correlates of attended versus unattended stimuli (Hillyard, Hink, Schwent, & Picton, 1973).

The small changes in voltage time-locked to or elicited by events of interest in ERPs are difficult to detect. Therefore, the equipment, procedures and parameters employed in the recording of ERP data significantly influence both the nature and the quality of the data collected. Electrode type and the quality of the interface between the skin and the electrode are both important in assuring high quality data, whereas recording parameters such as the reference site and the sampling rate employed can influence the topographic shape, polarity, and temporal resolution of the resulting ERPs. The recording system is typically designed to minimise signal distortion and to remove artefactual noise in the signal picked up from the experiment environment and the participant.

The basic unit of data elicited in ERP recording is a measure of the potential difference between two scalp locations. An ERP waveform is a sequence of such data points, sampled at discrete intervals. The sampling rate of this analogue-digital conversion determines the temporal resolution of the resulting waveform. The rate must be such that it captures all frequencies of interest within it (Cooper, Osselton, & Shaw, 1980; Picton et al, 2000). Typically, ERPs are concurrently recorded from midline and lateral scalp sites. Locations are defined with respect to designated landmarks and measurement criteria, and one of these, the International 10-20 system (Jasper, 1958), is shown in Figure 2.2.

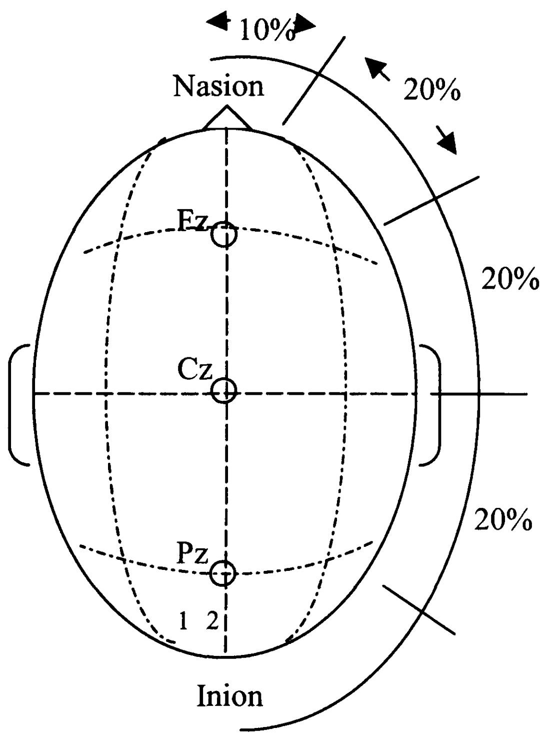


Figure 2.2. An illustration of the calculation and layout of the 10/20 system (Jasper, 1958).

Other montages are increasingly being used, such as the Queen Square system of electrode placement which has been proposed as a standard in recording the pattern of evoked potentials in clinical testing (Blumhardt, Barrett, Halliday & Kriss, 1977). Irrespective of the montage system employed, recordings at each site are commonly made with respect to a common reference point, although other arrangements are possible (Cooper, Osselton & Shaw, 1980).

Electrodes form the connection between electrical activity at the scalp and the input circuit of the amplifier. It is crucial that the signal is not distorted significantly at this interface if the recording is to be accurate. The quality of recording is significantly influenced by the type of metal with which the electrodes are made. Non-polarizable Silver/Silver Chloride (Ag/AgCl) electrodes are most commonly used, as these are able to accurately record very slow changes in potential with minimal distortion (Picton et al, 2000). A further possible source of distortion is the quality of the connection between the electrode and the scalp. The electrical impedance at this interface should be less than the input impedance of the amplifier by a factor of at least 100, or the recording is likely to suffer from artefactual effects of electromagnetic fields (Picton et al, 2000).

As a potential is the difference between two points, all ERP recordings must be made with respect to a reference electrode (Coles & Rugg, 1995). The location of the reference employed is of crucial importance when interpreting the scalp distribution and/or polarity of an ERP, as measurements of potentials are relative rather than absolute. The absolute values in referenced recordings will differ according to the location of the reference employed.

Analogue/Digital (A/D) converters sample the ongoing EEG, converting these signals from analogue into digital form to facilitate data analysis (Picton et al, 2000). Filtering enables the recording system to detect target electrical brain activity while rejecting frequencies that are unlikely to reflect the activity of interest. Low and high cut-off frequencies specify the bandpass of the amplifier, and frequencies that fall outside of this bandpass are rejected by the amplifiers. Typical recording parameters are between 0.01 and 100 Hz (Coles & Rugg, 1995).

Processing

The EEG waveform can be assumed to be composed of two parts (John, Ruchkin, & Vidal, 1978). The critical part is the neural activity (the signal) evoked by the particular stimulus in a given task. The second part of the EEG sample is noise. This latter component consists of neural contributions to the waveform that are unrelated to the presented stimulus, as well as non-neural contributions such as muscle activity and eye movements. Signal extraction procedures must be employed in order to separate the signal from the noise. Electromagnetic noise from the environment is removed by the use of differential amplifiers which allow electrical noise common to a ground electrode and the electrodes of interest (known as 'common mode signals') to be cancelled (Picton et al., 2000).

The most widely employed signal extraction procedure is signal averaging. The assumption entailed when applying this procedure to ERPs is that the 'noise' in a given sample of EEG is random. Therefore, averaging across trials will reduce the impact of the noise in the averaged ERP, whilst leaving electrophysiological activity which is constant across trials unaffected. The greater the number of trials contributing to the average, the higher the signal/noise ratio.

However, averaged ERPs should be interpreted with caution as signal averaging can lead to distortions of the original signal present in the single-trial data. It is possible for an averaged ERP waveform to bear little relation to the ERPs observed in individual trials, as trial-to-trial variability in either the latency or amplitude of the ERPs can 'smear' the averaged ERP (Picton et al, 2000).

All EEG data must be closely examined to ensure that the ERPs only contain true brain activity. This is necessary because a number of artefacts can still be present in the data after recording and averaging. The waveforms are therefore usually analysed off-line in order to determine that all artefacts have been removed or corrected prior to analysis. These artefacts can take the form of baseline drifts, saturation and eye movement artefacts.

One means of increasing the signal/noise ratio is to reject certain classes of trials prior to averaging. A common source of EEG contamination is due to eye blinks and eye movements, both of which cause changes in potential over anterior scalp locations (Lins, Picton, Berg, & Scherg, 1993). Concurrent EOG (electro-oculargram) recording permits monitoring of eye blink artifacts. Blink-related artefacts can be eliminated in one of two ways; blinks can both be discouraged and excluded, or the contribution of the blink artefact to all other recording channels can be estimated for each individual participant and corrected.

Limitations

As the scalp recorded event-related potential (ERP) is a sum of brain electrical activities from different brain generators, it is difficult to separate the contributions from discrete brain networks when analyses are limited to fairly gross measurements such as peak latency, area or amplitude. Analytic techniques including Principal Component Analysis (PCA) have been used in reducing ERP waveforms to their component parts (Wood & McCarthy, 1984). A once-popular method employed to extract different components from the ERP waveform PCA measures patterns of covariance between temporal changes in voltage, topographic changes in voltage and changes in voltage associated with experimental manipulations, and yields a set of components which are weighted for each time-point in the waveform. These weights indicate to what degree the various components are present in the waveform (Picton, Lins, & Scherg, 1995). However, the use of PCA can be misleading when different experimental conditions elicit the same component at different latencies, as it can identify spurious components (Coles & Rugg, 1995). It has also been demonstrated that PCA can 'misallocate' variance between supposedly orthogonal components (Wood & McCarthy, 1984).

ERPs suffer from poor spatial resolution. Because the brain acts as a volume conductor, there is no way of knowing the exact location of the neural generator/s that give rise to a particular pattern of activity detected at the scalp without using other constraining sources of information. The difficulty in determining the neural generators of an ERP scalp field is known as 'the inverse problem'. Any attempt to solve the inverse problem is obstructed by the fact that there is no unique solution in terms of generators for any given pattern of scalp activity (Wood, 1982): it is an error to assume that the scalp location of an ERP deflection necessarily reflects the fact that the neural source lies in the tissue directly below the deflection. Analytical procedures have been developed that allow one to infer candidate ERP sources from scalp fields. One such method is the Brain Electrical Source Analysis procedure (BESA; Scherg, 1990) which models the head as a number of shells, each of which constitutes the skull, scalp and brain tissue, and each of which has a different conductivity value. BESA solutions specify sources in terms of their quantity, anatomical location, orientation, time-course and relative strengths (Coles & Rugg, 1995). More recent developments in the field of source localisation have applied assumptions drawn from neuroanatomical knowledge to apply specific constraints to source localisation (e.g. dipoles must be located in grey matter, dipoles must be oriented perpendicular to the cortical sheet, dipoles must possess locally coherent activity), and take advantage of information gained from haemodynamic imaging studies employing analogous tasks to produce a single solution or 'best fit' for any scalp field (Phillips, 2001). However, the relationship between electrophysiological and haemodynamic signals is not yet fully understood. Consequently, caution is necessary when using haemodynamic measures to constrain the source localisation of ERP data.

ERPs and Psychology

The exclusive use of behavioural measures for memory research can provide only limited insights into the cognitive processes supporting memory performance. This is because behavioural measures do not provide direct access to the neural events thought to instantiate cognitive processing and can only index the output of these processes. The employment of electrophysiological techniques, however, provides more direct information with regard to the associated neural activity by measuring electrical brain activity elicited during the performance of specific cognitive tasks.

As with other neuroimaging techniques, ERPs can be employed in one of three principal ways (Rugg, 1995). First, they can be used in experimental manipulations to isolate a known cognitive process and identify its neural correlate. Second, ERPs can be used to investigate the pattern of neural activity associated with specific experimental manipulations, and use this information to makes inferences about the cognitive processes engaged. A third approach is to investigate the circumstances under which a known cognitive process is engaged by using pre-existing knowledge about its neural correlates and assessing how these are influenced by various experimental manipulations. The second and third approaches are of the most interest to psychologists, as these employ neuroimaging techniques primarily to inform theories of cognitive function.

ERP components

ERP waveforms consist of a series of peaks and troughs which are generally described in terms of their latencies, polarities, scalp distributions and amplitudes, measured in relation either to a pre-stimulus baseline (the mean voltage level of the waveform in the period preceding stimulus presentation), or to another feature of the waveform. Traditionally, each deflection was defined as a single 'component', and was labelled according to its latency and polarity. A positive component at 100 msec is called 'P100' and a negative deflection at 200 msec is a 'N200'.

There is no unique definition of an ERP component, as the descriptive framework employed depends on whether the researcher is adopting a 'physiological' or a 'functional' approach. The former emphasises anatomical localisation and defines components as the activity of a single neural generator, whereas the latter emphasises the functional significance of ERP deflections and defines components in terms of the processing operations with which they are associated (these two approaches are discussed in greater detail shortly). These two approaches lie at opposite ends of a continuum, and in reality researchers take an interpretative approach that lies somewhere between these two extremes. However, it is generally agreed that a single ERP component should represent the activity of a pool of neurons correlated with a specific processing operation.

The evoked potentials that are determined by physical aspects of the stimulus have been labeled 'exogenous', and those related to the cognitive components are "endogenous". The former are sensitive to the physical characteristics of the stimulus, whereas the latter reflect the operation of higher order cognitive processes. This distinction is not categorical, and components can show sensitivity both to the physical characteristics of the stimulus and to task demands. Many evoked potentials are named after their latency when first seen, and these names have stuck despite the act that they are no longer strictly accurate, e.g. a 'P300' can occur at any point between 300-800 msec and consequently the 'N400' may occur prior to it. The earliest ERP components are far field potentials and they reflect activity in the receptors and peripheral relay stations. Following these are the early cortical evoked responses, which appear to be generated in the primary visual areas of the brain. Examples include the N100 and the P100 (both occurring 100msec after presentation of a visual stimulus) which reflect the physiological action of the visual system.

Endogenous event related potentials are of considerable scientific interest because of their relationship to cognitive function. It is the study of the ERP components that are related to higher cortical functions that has captured the interest of researchers interested in perceptual, cognitive, and motor behaviour. Two of the key ERP components are discussed below, because they are of direct relevance to the work in this thesis.

P300

Sutton, Braren, Zubin & John (1965) first described the P300 component and its association with cognitive function. The P300 is elicited by a variety of stimuli in many experimental conditions. It has been linked with many processes and is classically associated with the oddball paradigm. In this paradigm, two classes of stimuli are presented, one of which occurs less frequently than the other. When the task is to detect the infrequent stimuli, the P300 is of greater amplitude for this stimulus type (Yamaguchi & Knight, 1995; Polich, 1990; Duncan- Johnson & Donchin, 1977). The latency of P300 increases with the time required to distinguish between rare and frequent stimuli. The amplitude increases with rarity of the stimulus (Donchin, 1981; Donchin, Ritter, & McCallum, 1978).

As well as the attention dependent P300 described above, a passive or 'novelty' P300 occurs to infrequent non stimuli that are not task relevant (Courchesne, Kilman, Galambos & Lincoln, 1984; Knight, 1984). This novelty P300, also called P3a, has a shorter latency and different scalp distribution than the classic P300, sometimes called P3b. P3a is more anteriorly distributed than P3b, and in the context of the work described in this thesis P3b (hereafter P300) is the more relevant of the two components.

P300 amplitude changes have been described in various conditions, including frontal lobe lesions (Wirsen, Sternberg, Rosen & Ingvar 1992), hyperactive children treated with methylphenidate (Sangal & Sangal, 2004), infantile autism (Kemner, van der Gaag, Verbaten & van Engeland, 1999), and schizophrenia (Wood, Potts, Hall, Ulanday & Netsiri, 2006). Overall the P300 is related to task relevance and categorization time. It is sensitive to feedback and to the informational value of the stimulus. The P300 has also been linked to learning. In general, the amplitude and latency of the P300 are used as indices of information processing (Johnson –Jr, Kreiter, Russo, & Zhu, 1998). P300 latency has also been shown to covary with speed of information processing as indexed by reaction times; the faster the speed of processing, the earlier P300 latency (Ford, Roth, Mohs, Hopkins III, & Kopell, 1979; Kutas, McCarthy, & Donchin, 1987; Picton & Stuss, 1980). This has made it a key component in the study of cognitive function using ERPs. The reason why this component is reviewed here is because the time course, scalp distribution and sensivity of this component to experiment variables means that changes in P300 need to be considered as possible reasons for some of the ERP modulations that are described in later chapters.

N400

A second ERP component, related to semantic memory, is the negative-going N400. It occurs between 200 and 500 ms after presentation of a potentially meaningful information-bearing stimulus and varies systematically according to the pre-existing context that is established by semantic and long-term memory influences. The N400 component was first reported by Kutas & Hillyard (1980) who recorded ERPs in a sentence-reading task. In this paradigm words are presented serially and participants are questioned about the content of the sentence at the end of the experiment. 25% of the sentences ended with a semantically incongruous word. The ERPs to words that completed the sentence but which rendered the sentence meaningless were associated with a negative-going shift – the N400, which was attenuated when the last word fitted the context of the sentence. Furthermore the amplitude of the shift was proportional to the degree of incongruity.

The N400 is largest over central and parietal scalp locations, and there is some evidence that in the classical sentence processing task it is larger over the right hemisphere than over the left (Kutas & Hillyard, 1980). Subsequent work has linked the amplitude of the N400 to the degree of semantic relatedness between words and their preceding context (Kutas & Hillyard, 1984).

However, modulations of the N400 are not restricted to the terminal word sentence paradigm. The N400 is also attenuated by the repetition of individual words over relatively short delays (Bentin, McCarthy, & Wood, 1985; Rugg, 1985; Rugg & Nagy, 1989). In addition, this component is sensitive to non-semantic relationships between stimuli (Barrett & Rugg, 1990; Rugg & Barrett, 1987). A large N400 component is also evoked by semantic anomalies presented in the auditory modality (Coles, Gratton, & Fabiani, 1990).

In summary, N400 amplitude is reduced as a function of associative, semantic, and repetition priming within or across sensory modalities (Kutas & Federmeier, 2000; although see Rhodes & Donaldson, 2008). The relevance of this modulation for the empirical work in this thesis is the fact that the N400 is sensitive to repetition of stimuli, and occurs in a time window and over scalp regions where memory-related effects of interest occur.

Concluding remarks

Two final notes of caution are required when interpreting ERP data. Firstly, it is important to remember that it can never be proven that two or more processes do not elicit qualitatively distinct patterns of electrophysiological activity through the use of ERPs, or to conclusively prove that an experimental condition is not associated with a specified ERP effect, as a null effect may occur either because the effect is taking place in a closed field and is therefore undetectable by scalp electrodes, or because the level of activity associated with the condition is too weak to be detected at the scalp. Therefore it is impossible to conclude that an experimental manipulation has no effect on brain activity simply because no difference is observed in the ERPs. Secondly, as with all neuroimaging techniques, ERPs are purely correlational. One cannot therefore establish a causal relationship between cognitive function and electrophysiological activity solely through the use of scalp-recorded ERPs. ERPs must be employed simultaneously with invasive techniques (e.g. pharmacological manipulations) in order to demonstrate a causal relationship between function and neural activity.

Chapter Three

ERPs and recognition memory

Cognitive operations associated with successful episodic retrieval are reflected by a class of ERP modulations called 'old/new effects'. The effects can be revealed by contrasting ERPs evoked in conditions where retrieval is successful against those evoked in baseline conditions where retrieval does not or cannot occur. For example, by comparing the differences between the waveforms evoked by correctly recognised old words (hits) and correctly rejected new words (correct rejections) in recognition memory tasks. A robust finding is that ERPs differentiate items correctly recognised as old from correctly rejected new items (Sanquist, Rohrbaugh, Syndulko & Lindsley, 1980; Neville, Kutas, Chesney & Schmidt, 1986; Friedman, 1990; Rugg, Brovedani & Doyle, 1992; Wilding & Sharpe, 2004). There are a number of ERP old/new effects, two of which are directly relevant to the work in this thesis and which will be reviewed in the following section.

Left-parietal ERP old/new effect

The left-parietal ERP old/new effect (also referred to as the 'late positive component' – LPC, (Paller & Kutas, 1992)) typically occurs between 500 and 800 ms post-stimulus and is largest at left parietal/posterior sites. However, the scalp distribution of this effect differs depending on the type of task, study-test delay and nature of the materials employed as stimuli. For example, whereas the parietal effect is usually bilateral in tests of continuous recognition (e.g. Rugg, Brovedani, & Doyle, 1992), it is often left-lateralised in study-test designs employing verbal stimuli (e.g. Wilding

& Rugg, 1996). For this effect, correct responses to old items are relatively more positive-going than correct responses to new items, as well as incorrect responses to old and new items (Sanquist et al, 1980; Smith & Guster, 1993; Wilding, Doyle, & Rugg, 1995; Wilding & Rugg, 1996, 1997).

It was at one time hypothesised that the left-parietal ERP old/new effect reflected familiarity-based recognition memory (Rugg & Doyle, 1992). Rugg & Doyle suggested that the effect reflects familiarity-based recognition as the left-parietal ERP old/new effect was larger for low than high frequency words (Rugg & Doyle, 1992, also see Cycowicz, Friedman, & Snodgrass, 2001). Their proposal was based on the assumption that familiarity was engaged to a greater degree for low than for high frequency words (Jacoby & Dallas, 1981). However, in other studies it has been demonstrated that although there is an increase in recollection and familiarity for low as well as for high frequency words, the frequency effect has a greater impact on recollection than familiarity (Gardiner & Java, 1990; Gardiner, Richardson-Klavehn, & Ramponi, 1997; Hirshman, Fisher, Henthorn, Arndt, & Passannante, 2002; Rugg, Cox, Doyle, & Wells, 1995).

In keeping with this observation it quickly became apparent that the left-parietal ERP old/new effect was in fact a correlate of recollection-based recognition, as further studies demonstrated that the amplitude of this effect was larger for Remember than Know judgments (Smith, 1993; Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997), deep compared to shallow encoding (Rugg et al., 1998) and recognition accompanied by the retrieval of contextual information (Wilding & Rugg, 1996; Donaldson & Rugg, 1998; Curran, 2000; Curran, Schacter, Johnson, & Spinks, 2001). Reports that the left-parietal ERP old/new effect is not elicited in patient groups thought to have a selective impairment in recollection support the view that this effect is a correlate of recollection-based recognition (Tendolkar et al., 1999; Duzel, Vargha-Khadem, Heinze, & Mishkin, 2001). Other work confirmed that the left-parietal ERP old/new effect was a mnemonic effect rather than an effect sensitive to factors such as probability and targetness (Friedman, 1990; Smith & Guster, 1993; Herron, Quayle & Rugg, 2004). The left-parietal ERP old/new effect, therefore, is currently considered to be a correlate of recollection-based recognition memory.

An interesting development in recent years comprises the patterns of left-parietal ERP old/new effects on exclusion tasks. Of central importance is the finding that a left-parietal ERP old/new effect was not elicited by correctly excluded non-target items amongst participants who showed good discrimination between target and non-target items, but a left-parietal ERP old/new effect was elicited by non-target items amongst old participants who showed poor discrimination even when these items were correctly excluded (Dywan, Segalowitz, & Webster, 1998). This finding is particularly surprising given the assumption that the majority of correctly excluded old items are excluded on the basis of recollection (Jacoby, 1991), and either implies that this assumption is incorrect or implies that the left-parietal ERP old/new effect is sensitive to additional factors contingent on recollection, or not a correlate of recollection at all.

Modulations of the left-parietal ERP old/new effect in exclusion tasks

For present purposes, it is important to highlight recent findings in which left-parietal ERP old/new effects were not elicited by items that, at least from one theoretical perspective, should have been recollected. These data were obtained in ERP studies employing the exclusion task.

As noted previously, the exclusion task is one part of the process-dissociation procedure (PDP), a method developed by Jacoby and colleagues (Jacoby, 1991; Jacoby, Toth & Yonelinas, 1993) in order to assess the respective contributions of recollection and familiarity to performance on recognition memory tasks. In a typical experiment employing the exclusion task, study items are presented in two different contexts, defined by different presentation lists, different presentation modalities or encoding tasks. At test, participants are presented with the studied items from these two contexts along with unstudied items. Participants are required to give different responses to different classes of studied items. They are to make 'old' responses only for items presented in a specified study context (targets). The items previously presented in the alternative context are classified as non-targets, and participants are to respond 'new' to non-targets as well as to genuinely new items.

The exclusion task is designed in such a way that successful completion of the task depends upon recollection, since familiarity alone will not, in most circumstances, permit discrimination of targets from non-targets. Jacoby (1991) argued that in the exclusion task participants rely upon recollection of targets as well as recollection of non-targets in order to make task judgments. This assumption is central to the way in which the PDP is employed in order to make estimates of recollection and familiarity (see Chapter 1, pages 45-50). If this assumption is correct, then both targets and non-targets attracting correct judgments should be associated with left-parietal ERP old/new effects.

The findings from the ERP studies that have employed the exclusion task consistently reveal the existence of left-parietal ERP old/new effects for target items (Dywan, Segalowitz, & Webster, 1998; Herron & Rugg, 2003b; Wilding & Rugg, 1997). In the first published ERP exclusion task study, participants were required to respond to one class of old items (either originally spoken in a male or female voice; designated the target) with one response button and to the other category of old items (designated the non-target) and new items with the other response button. There were left-parietal ERP old/new effects for both targets and non-targets, with the effect being reliably larger for targets (Wilding & Rugg, 1997). The nature of the task response requirements could have been responsible for the reduction in the magnitude of the left-parietal ERP old/new effect for non-targets, as both recollected and forgotten non-targets attract the same response. In elaboration on this point Wilding and Rugg concluded that the difference in amplitudes reflected a "diluting effect": a reduction (relative to targets) in the proportion of trials on which non-targets attracting a correct judgment were associated with recollection. This account was supported by the greater accuracy for non-target responses (74% correct) than target responses (58% correct), coupled with an equivalent probability of recollection across the two tasks, due to the identical encoding tasks, thereby suggesting that a larger proportion of correct non-target judgments were not accompanied by recollection. This was the explanation offered for the reduced size of the left-parietal

ERP old/new effect for non-targets relative to that accompanying targets. In subsequent work, however, it has been shown that this explanation is insufficient.

In two exclusion task experiments reported by Herron & Rugg (2003b), participants completed one identical and one different encoding task. The common task that was required for half of the study words in each experiment was to incorporate each word into a sentence and to say it aloud. For the second task in Experiment 1, participants were asked to rate words for pleasantness, while in Experiment 2 the second task was simply to read aloud each word that was presented. Non-targets were defined as words from the common task in both experiments, and the accuracy of target judgments was superior in Experiment 1. Non-target accuracy was equivalent in the two experiments.

Target as well as non-target items elicited left-parietal ERP old/new effects in Experiment 2, while in Experiment 1 the effect was observed only for target items. These findings suggest that target items in both experiments were classified on the basis of recollection. By contrast, the classification of non-targets items differed between the two experiments as the left-parietal ERP old/new effect was observed for non-targets only in Experiment 2. This pattern of findings suggests that participants relied on recollection to classify non-target items in Experiment 2 only. The authors interpreted these findings as reflecting the adoption of different retrieval strategies. They suggested that when memory for targets was good (Experiment 1), non-targets were classified on the basis of the failure to recollect information about targets. They suggested that this strategy was not optimal when memory for targets was poor, and as a result, recollection of non-targets was prioritised in Experiment 2 to a greater degree than in Experiment 1. Complementary findings and similar conclusions have been reported by Herron & Rugg (2003a). However, the study design used by Herron & Rugg means that the differences in levels of target accuracy were confounded with target-encoding task. Therefore it is possible that the results can be explained in terms of the target encoding condition employed as well as a difference in target accuracy. Another possible explanation for the findings is that in Experiment 1 non-target items were simply forgotten. That is, the deeply studied targets in Experiment 1 may have produced a greater degree of retroactive interference such that information about non-targets was less available in Experiment 1 than in Experiment 2. Therefore in Experiment 1 a large proportion of non-target items may have been excluded because they were misclassified as new words.

In two recent studies, (Dzulkifli & Wilding, 2005; Dzulkifli, Herron & Wilding, 2006), the Herron & Rugg strategic retrieval proposal was rigourously tested in tasks where there was no target/non-target confound and where there were direct estimates of the accuracy of non-target judgments available. Dzulkifli & Wilding (2005) reported differences between classes of ERPs evoked by items that were acquired during two different retrieval tasks. Participants studied words initially, all of which were concrete nouns. For half of the words, the task was to decide how difficult the object denoted by each word would be to draw. For the remainder, the task was to generate uses for the object denoted by each word. Old and new (unstudied) words were presented at test, and participants completed exclusion tasks. The study did not elicit reliable left-parietal ERP old/new effects for non-targets, which suggests that participants prioritised recollection of information about targets over information about non-targets.

Dzulkifli, Herron, & Wilding (2006) also acquired ERPs during separate test phases of a verbal recognition memory exclusion task. The study design was equivalent to that of Dzulkifli & Wilding (2005) with the exception that the study and test lists were longer and there were longer intervals between study and test. These variations led to a reduction in the level of memory accuracy in comparison with the earlier study.

The left-parietal ERP old/new effect was evident for targets and for non-targets in all test phases, consistent with the view that participants recollected information about both of these classes of test word. These findings contrast with those of the Dzulkifli & Wilding (2005) study in which the same tasks were used, and in which a left-parietal ERP old/new effect was found for targets only, but for this earlier study the accuracy of task judgments was markedly higher. In summary, the two Dzulkifli et al studies showed that where accuracy for targets and non-targets is high a left-parietal ERP old/new effect is observed for targets only. However, when accuracy for task judgments is lower both classes of items elicit left-parietal ERP old/new effects.

The combination of all of the above findings provides support for the claim that selective control of recollection is indexed by the patterns of ERP left-parietal old/new effects for targets and for non-targets. Further investigation into the strategic control of information recollection has been carried out using different presentation lists, different presentation modalities and encoding tasks. The findings in these studies define some of the boundary conditions under which selective recovery of task-relevant information may or may not occur.

Wilding, Fraser, & Herron (2005) acquired ERPs during two experiments in order to determine boundary conditions for when recollection of colour information can be controlled strategically. In initial encoding phases, participants saw an equal number of words presented in red or green. In subsequent retrieval phases, all words were shown in white. Participants were asked to endorse old words that had been shown at encoding in one colour (targets), and to reject new test words as well as old words shown in the alternate colour (non-targets). Study and test lists were longer in Experiment 1, and as a result, the accuracy of memory judgments was superior in Experiment 2. The left-parietal ERP old/new effect was reliable for targets in both experiments and reliable for non-targets in Experiment 1 only. These findings also support those of Herron & Rugg (2003b) in that when performance accuracy was high the left-parietal ERP old/new effect was evident for targets only. These findings are therefore consistent with the view that participants were able to restrict recollection to targets in Experiment 2, while recollecting information about targets as well as non-targets in Experiment 1. The fact that a selective strategy of restricting recollection of task related information to targets was implemented in Experiment 2 indicates that participants were able to exert considerable control over the conditions under which recollection of task-relevant information occurred even when the information associated with targets and with non-targets corresponds closely.

Another important study that has contributed to understanding of the boundary conditions under which selective attenuation of the left-parietal ERP old/new effect occurs is due to Herron & Rugg (2003a). In their experiment, an equal number of pictures and words were presented in the encoding phase. At test, all stimuli were words, which were either old or new. The old words were either re-presentations of words, or of words corresponding to the objects denoted by the pictures. In separate retrieval phases, targets were designated as old words that had been encountered either as words or as pictures. There were left-parietal ERP old/new effects for targets when the sought after study items were either pictures or words. However, non-target items elicited a left-parietal ERP old/new effect only when pictures were the designated targets. Herron & Rugg proposed that because both targets *and* non-targets elicited successful retrieval in the picture condition, more information is needed to be retrieved to allow picture targets to be discriminated from non-targets than was the case for word targets.

The absence of such effects for non-targets when words were designated as targets suggests that recollection of non-target items did not occur in this condition. Herron & Rugg suggested that the absence of a left-parietal old/new effect for non-targets came about because of the high level of cue-target compatibility, which allowed participants to search memory with a high degree of specificity. However, the presence of a non-target left-parietal old/new effect in the picture target condition was due to the fact that under this task condition, it was not possible to recollect information specific to studied pictures. According to this account, the cue-target incompatibility in the picture target condition impeded participants from searching memory with a high degree of specificity, thereby explaining the left-parietal old/new effect for non-targets (words). In summary, the findings of Herron & Rugg (2003a) can be explained in terms of the different circumstances under which selective recollection can be accomplished. The important point from the Herron and Rugg (2003a) findings for present purposes is that the ERP data are consistent with the view that recollection can be restricted to certain kinds of memory representations under some circumstances. These findings have been replicated by Johnson & Rugg (2006) and Hornberger, Morcom & Rugg (2004).

There are, however, some data points that are not accommodated straightforwardly within the framework described above. One set of findings comes from a study that was based closely on the initial Herron & Rugg (2003b) experiments. Herron & Rugg (2003b) reported that non-targets elicited a left-parietal ERP old/new effect when target accuracy was low, but not when it was high. Their explanation for this was that target information was the focus for recollection when the likelihood of target recollection was high, as this gave rise to accurate task performance.

As levels of target accuracy were confounded with target-encoding task, however, an alternative hypothesis arises; it is possible that target-specific retrieval strategies are also influenced by the nature of the encoding operations performed at study and not just by target accuracy. Herron & Wilding (2005) tested this hypothesis by varying target accuracy, but without confounding accuracy with encoding task. Instead, all targets were encoded using the same pleasantness-rating task used by Herron and Rugg (2003a; deep condition), but target accuracy was lowered in one condition by inserting a 40-min interval after the target study phase. In both conditions, the non-target encoding task was the same (animacy judgments).

The study elicited reliable left-parietal ERP old/new effects for targets in both the easy and difficult conditions, with the magnitude of the old/new effect being larger in the easy condition. Herron & Wilding interpreted this as showing that participants adopted a strategy of priotistising the recollection of target information at the expense of non-target information even when target accuracy was low (Herron & Wilding, 2005). This suggests that contrary to Herron & Rugg's (2003b) hypothesis, the level of target accuracy is not the sole determinant of the conditions under which strategic retrieval will occur. However, Herron &Wilding employed a within participants manipulation of difficulty, whereas the other studies have used between participant comparisons. This is an important distinction to make as the differences in effects recorded could be due to this manipulation. It may be that changing strategies during a single experimental session is not something that can be accomplished.

A series of findings which are also not accommodated in the Herron & Rugg (2003b) account are due to Dywan and colleagues (Dywan, Segalowitz & Webster, 1998; Dywan, Segalowitz, Webster, Hendry, & Harding, 2001; Dywan, Segalowitz, & Arsenault 2002). They employed a variant of the exclusion task in which items from two separate contexts comprise items encountered in a prior study phase, and new test items that are repeated after a designated lag at test. In the test phase of these experiments, previously studied words (targets) were presented along with new words, some of which repeated after a lag of only a few trials (non-targets). Across all of the studies target accuracy was comparable to that of previous studies, however, a left-parietal ERP old/new effect was observed for targets, whereas no effect was detected for excluded non-targets. These findings are inconsistent with those of Herron & Rugg (2003b) and the two Dzulkifli et al studies.

The key motivations for the experiments reported in this thesis relate to this paradigm, first described by Jennings & Jacoby (1997), and how use of it in the following experiments permits an investigation into the extent to which the existing standard exclusion task findings of strategic control of recollection generalise to a procedure with a somewhat different design. It is important to generalise these findings in order to ascertain whether they are a consequence of peculiarities associated with one particular incarnation of the exclusion task. Moreover, one of the implications of the theoretical accounts given above is that under some circumstances people can exert considerable control over whether or not information is recollected, and this in turn suggests that ERPs acquired in episodic retrieval tasks may be a useful functional tool for determining the conditions under which this can be achieved, as well as, ultimately, the mechanisms that are responsible for the strategic control of recollection (for discussion, see Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a; Hornberger, Morcom, & Rugg, 2004). The broad utility of ERPs in this regard depends in part upon the extent to which comparable patterns of selective attenuation of left-parietal ERP old/new effects can be obtained across tasks with somewhat different demands at the time of retrieval.

Mid-frontal ERP old/new effect

The mid-frontal ERP old/new effect - also referred to as 'FN400' (Curran, 1999) - is the less well defined of the two old/new effects described here, and as such there is more debate about its likely functional significance. The effect is observed between 300 and 500 ms post-stimulus, is largest at anterior-superior electrode sites, and comprises a relatively greater positivity for hits than for correct rejections. Rugg and colleagues (1998) were among the first to suggest that the mid-frontal ERP old/new effect is a correlate of familiarity (Rugg et al., 1998, although see Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997).

Rugg et al. (1998) employed one shallow (orthographic) and one deep (semantic) encoding task at study, whilst at test participants were asked to make old/new recognition memory judgments. ERPs associated with hits were relatively more positive-going than those associated with correct rejections at anterior-superior sites. In addition, this anteriorly distributed effect was of equivalent size in both the shallow and deep conditions. However, the magnitude of the left-parietal ERP old/new effect was influenced by the depth of processing manipulation: the effect was larger for ERPs associated with hits in the deep than in the shallow encoding task. Rugg et al. suggested that the anterior modulation is an index of familiarity, a claim based upon; 1) the fact that the modulation preceded the putative index of recollection, 2) the ERP old/new effects associated with the deep and shallow conditions were of equivalent size, and 3) the effect was not present for misses.

The results of Rugg et al. provide strong evidence for a dual-process account, because two functionally distinct ERP old/new effects linked to explicit memory were identified. However, their data provides equivocal evidence for the link between the mid-frontal ERP old/new effect and familiarity. This is because a number of studies have demonstrated that both recollection and familiarity are affected by depth of processing at encoding, though recollection is typically influenced more than familiarity (Gardiner, Java, & Richardson-Klavehn, 1996; Khoe, Kroll, Yonelinas, Dobbins, & Knight, 2000; Toth, 1996; Wagner, Gabrieli, & Verfaellie, 1997; Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998).

Subsequent studies have, however, provided some data supporting the link between the mid-frontal ERP old/new effect and the process of familiarity. For example, in an experiment where the recognition memory ERP old/new effects associated with words and pseudowords (pronounceable non-words) were compared, Curran (1999) demonstrated that left-parietal ERP old/new differences were larger for words than pseudowords, whereas they did not differ significantly at mid-frontal electrode sites. Based on this finding, Curran proposed that the anteriorly distributed effect indexes familiarity, arguing that familiarity is the basis upon which recognition memory judgments for pseudowords are typically made (Curran, Schacter, Norman, & Galluccio, 1997; Gardiner & Java, 1990).

In a further study by Curran (2000), words were presented in either singular or plural forms (e.g. *frog*, *lakes*) at study. During the subsequent test phase, an old/new recognition memory task was completed in which the test words were either the same as at study (old: *frog*, *lakes*), had reverse plurality (lures: *frogs*, *lake*), or were new (*capitol*). The assumption was that old responses to words in the reversed plurality category would be based on familiarity rather than recollection, whereas correct responses to old words would be based upon recollection as well as familiarity, in line with previous behavioural findings (Hintzman & Curran, 1995; Hintzman, Curran, & Oppy, 1992). As predicted, the left-parietal ERP old/new effect behaved as it would for recollection: ERPs evoked by correctly identified old items were relatively more positive-going than those evoked by similar lures and correct rejections. Critically, in the 300-500 ms time window, ERPs evoked by correctly identified old items and similar lures were relatively more positive-going than those evoked by correct rejections.

Similar findings were obtained by Curran & Cleary (2003) in a study where the stimuli were pictures. At study greyscale line drawings of different objects, animals, scenes, and people were presented. Participants were instructed to memorise the orientation of these pictures. At test, participants were instructed to make an old response to pictures that had been studied in the same orientation, and a new response to similar items (reversed orientation) and new pictures. For the analysis, participants were divided into two separate groups, post-study, depending on their level of accuracy - 'good performers' and 'poor performers'. Both 'good' and 'poor' performers showed a mid-frontal ERP old/new effect that was related to familiarity-based recognition: lures and hits were of equal magnitude, whereas correct rejections were relatively more negative-going. In addition, for the 'good' performer group a left-parietal ERP old/new effect was obtained, where hits were relatively more positive-going than lures and correct rejections. No reliable left-parietal ERP old/new effect was obtained for the 'poor' performer group (Nessler, Mecklinger & Penney, 2001). The findings in this and the previous study support a familiarity account of the mid-frontal ERP old/new effect in so far as the levels of familiarity should be similar for copy cues and for slightly changed (plurality or orientation) stimuli.

In a previous study, however, Curran et al. (2001) did not obtain evidence consistent with a familiarity account. Words were heard during encoding, and at test participants were required to make old/new recognition judgments to visually presented words. In this experiment, the 'similar' lures were semantically similar to the items presented at study, whereas the new items (dissimilar lures) did not have an obvious semantic association with the studied words. There was no reliable ERP old/new effect at mid-frontal electrode sites for old words or for semantically similar lures. Curran et al. suggested that the absence of the mid-frontal ERP old/new effect may be due to the switching of modality across study and test, under the assumption that this manipulation reduces the availability of familiarity for test judgments.

Reliable mid-frontal ERP old/new effects have also been obtained in studies in which study and test items were presented in different modalities (Curran & Dien, 2003; Joyce, Paller, Schwartz, & Kutas, 1999; Nessler et al., 2001) however also see (Wilding, Doyle, & Rugg, 1995). Similar to Curran et al. (2001), Nessler et al. (2001) presented items auditorally at study, whereas during the recognition memory test the items were presented visually. Nessler et al. demonstrated that the mid-frontal ERP old/new effect was reliable and of the same magnitude for hits and lures (semantically similar items). Curran & Dien (2003) obtained similar results with the same modality manipulation across study and test.

Nessler & Mecklinger (2003) examined the ERP old/new effects for old items, similar lures (semantically similar), and new items after short (40 s) and long (80 s) delays. They found that old/new recognition accuracy did not show any reliable differences across the two delay conditions. The behavioural data is consistent with the electrophysiological data, in that the mid-frontal ERP old/new effect for old items did not differ across the two delay conditions. However, the likelihood of an incorrect judgment for lures increased as the delay time between study and test increased, and the correlate of familiarity was evident for the lure/new contrast in the short delay condition only. It was argued that the null-result in the long delay condition may have come about due to weak memory traces (Nessler & Mecklinger, 2003).

Other researchers have shown that the mid-frontal ERP old/new is also affected by test items being perceptually similar (Curran, Tanaka, & Weiskopf, 2002). This study employed computer-generated two-dimensional polygons, referred to as *blobs*. Twelve different blob families (categories) were generated. The study phase entailed the training of participants so that they could discriminate between blobs that were in the same family (in blobs) versus blobs that belonged to a different family (out blobs). In the subsequent test phase, Curran et al. found that mid-frontal ERP old/new effects were obtained for blobs. Given that it is difficult to assign semantic labels to these stimuli, Curran et al. argued that this finding provides support for the link between the mid-frontal ERP old/new effect and perceptual correspondences that may contribute to familiarity.

There is also neuropsychological data that is relevant to the question of the functional significance of the mid-frontal ERP old/new effect. Tendolkar et al. (1999) demonstrated that patients with Alzheimer's Disease (AD) only showed a mid-frontal ERP old/new effect, whereas the matched controls showed both a mid-frontal and left-parietal ERP old/new effect. The patients' recognition rates were above chance; however, they failed to recollect the correct source for test items. This finding is consistent with the view that the principal deficit in AD is with recollection (Fox, Warrington, Seiffer, Agnew, & Rossor, 1998), and that the mid-frontal ERP old/new effect in the AD patients indexes their residual recognition judgments made on the basis of familiarity (see also Mecklinger, 2000).

In a relatively recent study (Curran, 2004), attention was manipulated during study, and confidence was manipulated at test. The mid-frontal ERP old/new effect was equivalent under full versus divided attention conditions, which runs counter to the claim that attention manipulations influence familiarity as well as recollection (for review, see Yonelinas, 2002). This finding is comparable to the result reported by Rugg et al. (1998) in the deep/shallow encoding manipulation reviewed previously. For the confidence manipulation, there were not enough trials to analyze the differences between the mid-frontal ERP old/new effects for high and low confidence hits. However, ERPs associated with low confidence correct rejections were somewhat more positive-going than those associated with high confidence correct rejections ($p = .06$). This aspect of the data provides some degree of support for the link between the mid-frontal ERP old/new effect and the process of familiarity, as new items which have a strong level of relative famiiairty will attract a lower confidence correct rejection response than new items with a weaker level of familiarity.

In a challenge to the familiarity view of the mid-frontal ERP old/new effect, it has been suggested (Voss & Paller, 2006; Yovel & Paller, 2004) that the effect is not correlated with episodic memory but that it is an index of conceptual priming. One study in which the data has been interpreted to support this claim is that reported by Olichney et al. (2000), who required participants to decide whether visually presented single word stimuli were semantically congruent or incongruent with a spoken category name that preceded each stimulus. ERPs were acquired time-locked to the visual stimuli, and all stimuli were repeated three times during the task. Reliable positive-going repetition effects were obtained for incongruent endings only in the 300-500 ms time window, and these data have been interpreted as being consistent with the view that in this time window ERPs index conceptual priming rather than familiarity (Olichney et al, 2000). By this view, the familiarity interpretation of the mid-frontal ERP old/new effect is an incorrect inference and the effect in verbal recognition memory tasks occurs simply because of the conceptual priming associated with presentations and re-presentations of the same stimuli. Data in support of this position comes from the absence of the mid-frontal ERP old/new effect for faces, which presumably cannot benefit from conceptual priming (Yovel & Paller, 2004). However, in some cases, mid-frontal ERP old/new effects for faces have been obtained, (Johansson, Mecklinger, & Treese, 2004; Nessler, Mecklinger, & Penney, 2005), and as reviewed above, the 'blob' data is difficult to incorporate into a conceptual priming framework (Curran et al., 2002). The extent, moreover, to which the data due Olichney et al. (2000) is relevant to the processes engaged during recognition memory tasks is questionable, given that only category judgments were required at the time of ERP acquisition, and that each item was preceded by a category cue which became increasingly informative as to the identity of the subsequent item with each repetition.

If mid-frontal ERP old/new effects were evident when familiarity is equated but conceptual priming varied there would be direct support for the conceptual priming account. However, this pattern of data has not been demonstrated, in fact, the reverse has been shown; that is the presence of mid-frontal ERP old/new effects when conceptual priming is likely to be constant. In a series of studies incorporating perceptual manipulations of stimuli across study and test phases of retrieval tasks (Ecker, Zimmer, & Groh-Bordin, 2007; in press; Groh-Bordin, Zimmer, & Ecker, 2006; Groh-Bordin, Zimmer & Mecklinger, 2005; Schloerscheidt & Rugg, 2004), the mid-frontal ERP old/new effects for items attracting correct judgments were larger when studied items were re-presented in the same format at test, than when the studied items were re-pesented in a different format. In so far as the meaning of the stimuli is not altered by changes in perceptual format, these findings contradict a conceptual priming account of the mid-frontal ERP old/new effect.

It has been reported that the mid-frontal ERP old/new effect may not be an obligatory correlate of familiarity-based recognition memory (Tsivilis, Otten, & Rugg, 2001). This study explores the effects of context on ERP correlates of recognition memory. Participants at study were presented with complex stimuli which consisted of an item superimposed onto a background scene. Five classes of stimuli were presented at test; the same item-background pairing as at study ('SAME'), a different pairing of a studied item and a studied background ('REARRANGED'), a new item on a studied background ('NEW-OLD), a studied item on a new background ('OLD-NEW), and a new item on a new background ('NEW-NEW'). Participants were required to make old/new judgments for the item component of stimuli presented at test. Interestingly, although correctly recognised SAME and REARRANGED stimuli elicited greater positivity than novel stimuli over frontal sites between 300-500 ms, correctly recognised OLD-NEW stimuli did not. The finding that there were no sginficant behavioural or ERP differences between REARRANGED and OLD-NEW stimuli was cited to suggest that processing reflected by the mid-frontal ERP old/new effect may not be directly related to a familiarity-driven recognition response (Tsivilis, Otten, & Rugg, 2001). It was hypothesised that the mid-frontal ERP old/new effect may reflect processing 'downstream' from that responsible for familiarity-based recognition, and may be sensitive to novel components of a stimulus (Tsivilis, Otten, & Rugg, 2001).This provides some insight into the functional significance of the effect, but, as Tsivilis et al. note, the possibility still remains that in tasks with verbal material and single presentations of study and test items the effect acts as an index of familiarity.

In summary, some researchers have suggested that the mid-frontal ERP old/new effect is linked to familiarity (Curran, 1999, 2000; Curran & Cleary, 2003; Curran & Friedman, 2004; Curran et al., 2002; Duzel, Vargha-Khadem, Heinze, & Mishkin, 2001; Mecklinger, 2000; Nessler & Mecklinger, 2003), and while there are data points that are inconsistent with this account (Curran, 2004; Rugg et al, 1998), these typically comprise null results. There are, furthermore, data points that contradict directly a conceptual priming account of the mid-frontal effect (Ecker, Zimmer, & Groh-Bordin, 2007; in press; Groh-Bordin, Zimmer, & Ecker, 2006; Groh-Bordin, Zimmer & Mecklinger, 2005; Schloerscheidt & Rugg, 2004), and overall the weight of evidence supports a familiarity account of this old/new effect.

Conclusions

ERP studies have provided empirical evidence for a number of dissociable effects associated with episodic memory. The left-parietal ERP old/new effect, which is the effect with the longest history (Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980), is proposed to be a correlate of recollection. As reviewed above, a number of studies have provided support for the link between the mid-frontal ERP old/new effect and the process of familiarity. However, because of contradictory data points, the link between the mid-frontal ERP old/new effect and familiarity remains a matter of debate (Curran, 2004; Olichney et al., 2000; Tsivilis et al., 2001; Voss & Paller, 2006; Yovel & Paller, 2004). The absence or attenuation of parietal ERP old/new effects for some classes of old item relative to others within exclusion memory tasks has been interpreted as evidence for selective attention to task-relevant material only (Dywan et al., 2002; Dywan et al., 1998; Dywan et al., 2001), or as evidence that participants can control, at least under some circumstances, what information will be recollected during a task in order to complete the task efficiently (Dzulkifli, Herron, & Wilding, 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a; Hornberger, Morcom, & Rugg, 2004).

At issue in the experiments described in the subsequent chapters is the extent to which previous findings of left-parietal ERP old/new effects for targets and non-targets in exclusion tasks could be generalised to a variant of the exclusion task with different retrieval demands. Are the differing experimental findings described in the preceding section a consequence of peculiarities associated with the particular incarnation of the exclusion task employed? Furthermore, can the explanation offered initially by Herron & Rugg (2003b) for the attenuation of left-parietal ERP old/new effects in exclusion tasks under some circumstances but not under others be generalised to additional exclusion task type paradigms? Moreover, the experiments will also begin to define some of the boundary conditions under which selective recollection of task-relevant material can or cannot occur.

Chapter Four

General Methods

Introduction

This chapter outlines the methods common to all the EEG experiments reported in this thesis. Procedures specific to each experiment are described in the relevant methods sections. The studies reported employed the same criteria for participant inclusion in the first instance, and similar materials. The ERP recording parameters, as well as data processing and analysis, were identical in experiments 2, 3, 4, 5 and 6. In Experiment 1, the recording parameters and some elements of initial data processing were different, because the EEG was acquired on a different acquisition system.

Participants

They were all aged between 18 and 30 years of age, right handed, as defined by self report, and were native English speakers who reported normal, or corrected to normal, vision. Participants were screened for neurotropic medication, and any clinical diagnosis of dyslexia. They were all students from Cardiff University and gave informed consent prior to commencing the experiments. They were paid £7.50/hour for their participation.

Materials

Stimulus lists consisted of words, ranging from four to nine letters in length. They were all low- frequency words (range 1-7 per million), and were drawn from the MRC psycholinguistic data base (http://www.psy.uwa.edu.au/MRCDataBase/uwa_mrc.htm).

The words were presented visually, in upper case white letters on a black background in central vision on a computer monitor. The images subtended a maximum of 5° of visual angle horizontally and 0.6° vertically.

All experiments included study and test lists. ERPs were acquired during the test phases only. Details regarding the construction of the study and test lists in order to control for item and order effects will be provided in the method sections in each of the experimental chapters. The experiments contained either two (Experiment 5) or four (Experiments 1, 2, 3, 4 and 6) study-test cycles. For all experiments, study and test list combinations were constructed so that across participants all words were encountered as each class of item. These comprised new (unstudied) words, studied words, and some new words that were repeated. Within each study cycle, the order of presentation of study items for each participant in each experiment was determined randomly by the stimulus presentation software. The order of presentation of test items was such that the repeated new words were re-presented after randomised intervening lags of between 7-9 items. Across test lists within each experiment, words appeared both at study and at test (old items), or were presented only at test. In the latter case, they were presented, on different lists, either once (new items) or twice (repeated new items).

Experiment procedures

Participants were fitted with an electrode cap before commencing each experiment (see below). The procedure for all participants started with preparation of the skin with a cotton bud. This procedure helps to minimise the contribution of artefacts to the recorded EEG, by reducing the electrical impedance levels at the scalp. For each participant, the inter-electrode impedance level at all sites was below 5 KΩ at the outset of each experiment session. The participants were then seated in a sound-attenuated recording booth. They were situated approximately one metre in front of a computer monitor. Prior to each experiment, the participants were given a written instruction sheet to read, and the task requirements were also explained verbally. Participants were asked to relax, keep still, and maintain fixation on the centre of the screen and blink as they would normally throughout the experiment. In all experiments there was a short practice session before the experiment began. In each experiment there was also a short break after each study-test cycle.

Electrophysiological recording procedures

For experiment 1 EEG was recorded from 34 silver/silver chloride electrodes, 32 of which were housed in an elastic cap. For experiments 2 - 6, EEG was recorded from 27 silver/silver chloride electrodes, 25 of which were housed in an elastic cap. The sites were located at midline as well as left and right hemisphere locations (Jasper, 1958). The electrode locations are shown in Figure 4.1. For both recording procedures the remaining two electrodes were placed on the right and left mastoids.

For experiments 2 - 6, EEG channels were referenced during acquisition to Fz, and were subsequently re-referenced off-line to the algebraic average of the two mastoids. Data were sampled continuously at a rate of five ms per point for experiments 2, 3, 5 and 6, and 4 ms per point for Experiment 4. The durations of the epoched data were 1280 ms and 924 ms respectively, all including a 100 ms pre-stimulus baseline period relative to which all mean amplitude measures were taken. EEG and EOG were recorded with a bandwidth of 0.03-40 Hz (-3dB) in all except Experiment 1, where

EEG and EOG was acquired referenced to linked electrodes located midway between POz and PO3/PO4, respectively. EEG and EOG were recorded with a bandwidth range of DC-419Hz; initial sampling rate 2048 Hz. Data was high-pass filtered off-line (0.03Hz) and down-sampled to 200 Hz (5 ms/point). The duration of the recording epoch was 1280 ms, including a 100 ms pre-stimulus baseline period.

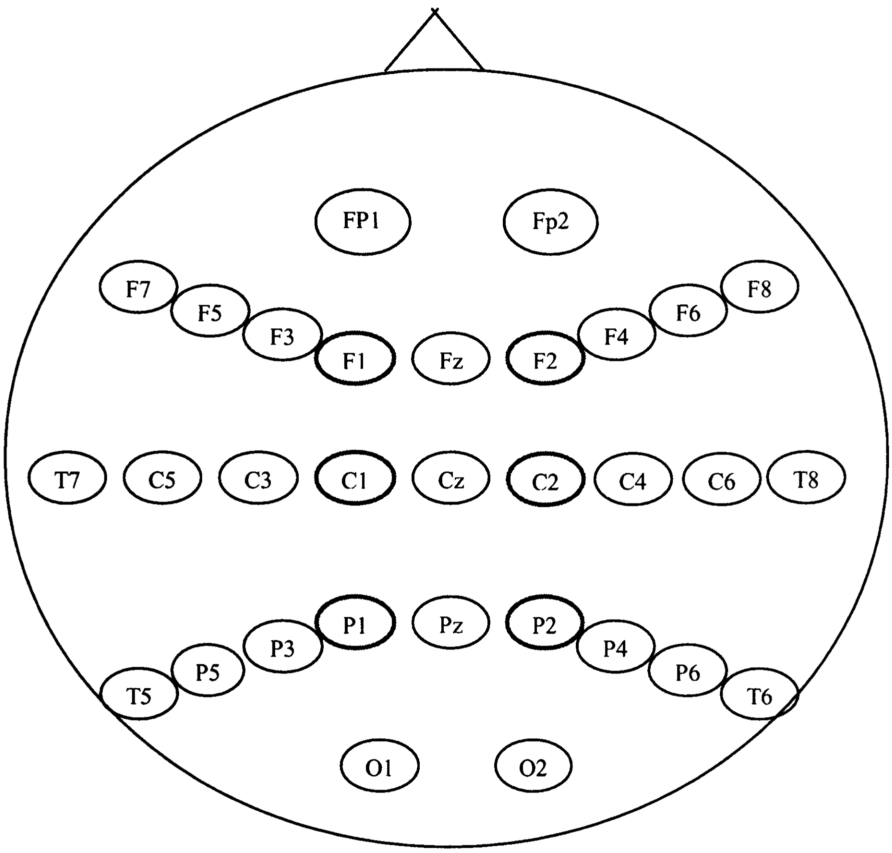


Figure 4.1. Selected sites from the international 10/20 system (Jasper, 1958). The sites employed in experiments 2, 3, 4, 5, and 6 reported in this thesis are shown in black. The sites used for Experiment 1 are those used for the remaining experiments with the addition of the 6 sites shown in red.

Data processing

Processing and analysis were completed off-line after the end of each experiment session. Trials containing large EOG artefact, and/or movement artefact, were identified using set criteria and verified by visual inspection prior to rejection or inclusion. Trials containing A/D saturation, and/or baseline drift (difference between first and last data point) exceeding $\pm 80\mu V$ were also rejected. Other EOG blink artefacts were corrected using a linear regression estimate (Semlitsch, Anderer, Schuster, & Presslich, 1986).

In all experiments, the averaged ERPs were subjected to a seven-point binomially weighted smoothing filter prior to analysis, and waveforms were formed for each of the critical response categories for each participant. Participants were excluded from subsequent statistical analyses, both for ERP and for behavioural data analysis, if they did not contribute a minimum of 16 artefact-free ERP trials to each of the critical response categories.

Data analyses

Behavioural data

The accuracy and RT data were analysed by employing t-tests (corrected for multiple comparisons where appropriate) and repeated measures ANOVAs. The Geisser-Greenhouse correction procedure was implemented where necessary in all ANOVAs, for accuracy, RT and ERP data (Greenhouse & Geisser, 1959).

Two measures of discrimination (Pr: Snodgrass & Corwin, 1988) were calculated for all experiments. The first was computed to determine whether participants were able to distinguish between old words and new words (p(hit) - (FA)). The second was computed to determine whether participants were able to distinguish between old words and repeated new words (p(hit) - p(rFA)). Measures of response bias (Br:

Snodrgass & Corwin, 1988) were also calculated for all experiments, where Br = p(FA)/(1 – Pr).

ERP data

Analyses of ERP old/new effects

Two sets of analyses were completed for all the experiments reported in this thesis. Both set of analyses were performed over three time windows (300-500, 500-800 and 800-1100 ms). The first set of analyses (hereafter 'global analyses'), included mean amplitude data from 18 electrode sites, split equally over the two hemispheres, with an equal number of sites at anterior, central, and posterior scalp locations (see Figure 4.1). The analyses included the factors of condition (the conditions included will vary across experiments and will be identified for each experiment), anterior/posterior (AP) dimension (three levels: anterior: F3/F4/F5/F6/F7/F8, central: C3/C4/C5/C6/T7/T8, and posterior: P3/P4/P5/P6/P7/P8), hemisphere (two levels: left/right), and site (three levels: inferior: F7/F8/T7/T8/P7/P8, mid-lateral: F5/F6/C5/C6/P5/P6, and superior: F3/F4/C3/C4/P3/P4).

The second set of analyses (hereafter 'midline analyses') included mean amplitude data from Fz, Pz and Cz. This set of analyses included the factors of condition, and site (three levels: anterior: Fz, central: Cz, posterior: Pz). The outcomes of the analyses at the midline will only be reported if there is an interaction involving condition as well as electrode site. These analyses were completed in order to provide a more sensitive assessment of changes of interest on the anterior/posterior dimension than would be obtained via the global analyses.

The main interest in the experiments reported in this thesis is on ERP differences according to condition. Therefore, only effects involving this factor will be reported. Reliable two- and three-way interactions involving the critical factor will be followed up with appropriate directed analyses, as described in the relevant empirical chapters.

Directed analyses of mid-frontal ERP old/new effects

One set of directed analyses was carried out for the mid-frontal ERP old/new effect for all experiments. The analyses were carried out in the 300-500 ms time window for all experiments. This time window was selected as it has been shown that for anterior sites in this post-stimulus epoch, ERPs are sensitive to item familiarity (Curran, Tepe, & Piatt, 2006; Rugg et al., 1998). The analyses included data from F3, Fz, and F4 only, and included the factors of condition (as specified in each experiment chapter) and site (three levels: F3/Fz/F4).

Directed analyses of left-parietal ERP old/new effects

The directed analyses for the left-parietal ERP old/new effect included factors of condition, hemisphere, and site (four levels: P3, P4, P5, P6), and were completed over the 500-800 ms time window. This time window was selected as it captures when and where the left-parietal ERP old/new effect is primarily evident (Friedman & Johnson, 2000; Rugg, Herron, & Morcom, 2002).

Presentation of Tables, Figures and Scalp Topographies

The tables for the critical behavioural data are show in the main body of text, with some additional material in the appendices where necessary. The tables for the accuracy data present the mean proportions of correct and incorrect responses, separated according to condition. RT tables in the main body of the text display the mean RTs for correct and incorrect responses in all conditions.

All experimental chapters include tables showing the outcomes of the global and mid-line analyses on the ERP data. These are located at the end of each chapter. Only the highest order interactions in each contrast of interest are described in the main body of the text. The ERP figures and topographic maps are presented at the end of each chapter, with additional material in the appendices as necessary. All maps shown are computed from difference scores, obtained by subtracting the mean amplitudes associated with one critical condition from another.

Chapter Five

Experiments 1 and 2

Introduction

Inferences about the control of retrieval have been made on the basis of findings in ERP studies in which participants completed recognition memory exclusion tasks (Jacoby, 1991, 1998). In these tasks, participants are typically required to distinguish between new items (those presented at test for the first time) and two classes of old items, each having different study histories – for example, an equal number may have been spoken in a male/female voice in a prior encoding phase (Jacoby & Kelley, 1992; Wilding & Rugg, 1997). At the time of retrieval, participants are asked to respond on one key to items with one type of study history (often designated as 'targets') and on another key to new items as well as to items with different study histories ('non-targets').

The reason why the ERP findings in exclusion tasks have been interpreted in terms of retrieval control is due to the pattern of ERP old/new effects that have been obtained. The exclusion task is designed in such a way that successful completion of the task depends upon recollection, since familiarity alone will not, in most circumstances, permit discrimination of targets from non-targets (the possible use of familiarity as the sole basis for judgments in exclusion tasks will be addressed further within the general discussion at the end of the thesis). Jacoby (1991) has argued that, in the exclusion task, participants rely upon recollection of targets as well as recollection of non-targets in order to make task judgments. This assumption is required if one wishes to estimate the contributions that recollection and familiarity make to recognition memory performance using the computational approach provided by Jacoby and colleagues (the Process Dissociation Procedure (PDP): Jacoby, 1991; Jacoby, 1998). If this assumption is correct, then both targets and non-targets attracting correct judgments should be associated with left-parietal ERP old/new effects, because this aspect of the electrical record has been linked to the process of recollection (Friedman & Johnson, 2000; Rugg & Allan, 2000; Wilding & Sharpe, 2003).

The left-parietal effect takes the form of greater positivity for correctly identified old items relative to correctly identified new items. This positivity has a left temporo-parietal scalp maximum and onsets around 500 ms post-stimulus. A variety of evidence links this effect to recollection. For example, the effect is greater when elicited by recognized items attracting correct rather than incorrect source judgments (Wilding & Rugg, 1996; Wilding, 2000); and for items attracting 'remember' as opposed to 'know' judgments (Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997; Smith, 1993; Trott et al., 1999; but see Spencer, Vila Abad, & Donchin, 2000). In addition, the effect is absent or attenuated markedly in neurological patients in whom recollection is selectively impaired (Duzel, Vargha-Khadem, Heinze, & Mishkin, 2001).

The critical ERP data in exclusion tasks that is of particular relevance here concerns the left-parietal ERP old/new effects elicited by correct judgments to targets and to non-targets. In a number of recent studies, the magnitude of the left-parietal ERP old/new effects has been markedly larger for targets than for non-targets (e.g.

Czernochowski, Mecklinger, Johansson, & Brinkmann, 2005; Dzulkifli, Herron, & Wilding, 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a, 2003b; Hornberger, Morcom, & Rugg, 2004).

This pattern of data was first reported by Herron & Rugg (2003a; for a pre-cursor, see Wilding & Rugg, 1997), who conducted two exclusion task experiments. For these two experiments, participants completed one identical and one different encoding task. The common task that was required for half of the study words in each experiment was to incorporate each word into a sentence and to say it aloud. For the second task in Experiment 1, participants were asked to rate words for pleasantness, while in Experiment 2 the second task was simply to read aloud each word that was presented. Non-targets were defined as words from the common task in both experiments, and the accuracy of target judgments was superior in Experiment 1. Non-target accuracy was equivalent in the two experiments.

Target as well as non-target items elicited left-parietal ERP old/new effects in Experiment 2, replicating the findings of Wilding & Rugg (1997), while in Experiment 1, the effect was observed only for target items. These findings suggest that target items in both experiments were classified on the basis of recollection. By contrast, the basis for classification of non-target items presumably differed between the two experiments, as the left-parietal ERP old/new effect was observed for non-targets in Experiment 2 only. This pattern of findings suggests that participants relied on recollection to classify non-target items in Experiment 2 only. The authors interpreted these findings as reflecting the adoption of different retrieval strategies. They suggested that when memory for targets was good (Experiment 1), non-targets were classified on the basis of the failure to recollect information about targets. They suggested that this strategy was not optimal when memory for targets was poor, and as a result, recollection of non-targets was prioritised in Experiment 2 to a greater degree than in Experiment 1. Complementary findings and similar conclusions have been reported by Herron & Rugg (2003b).

Herron & Rugg (2003a) employed a between-participants design in which target memorability was manipulated via encoding task. In Experiment 1 targets were encoded using a "deep" task (pleasantness rating); in Experiment 2 targets were encoded using a "shallow" task (read aloud). All non-targets were encoded in the same task (sentence generation). Non-targets elicited a left-parietal ERP old/new effect when target accuracy was low (in Experiment 2) but not when it was high (Experiment 1). The study design means that the differences in levels of target accuracy were confounded with target-encoding task. Therefore it is possible that the results can be explained in terms of the target encoding condition employed as well as a difference in target accuracy. Another possible explanation for the findings is that in Experiment 1 non-target items were simply forgotten. That is, the deeply studied targets in Experiment 1 may have produced a greater degree of retroactive interference such that information about non-targets was less available in Experiment 1 than in Experiment 2. Therefore in Experiment 1 a large proportion of non-target items may have been excluded because they were misclassified as new words. Herron & Rugg (2003a) addressed this concern in a behavioural study on six additional participants, where Experiment 1 was replicated with the target and non-target classifications reversed. Accuracy for targets was 86%, with a new-item false alarm rate of 3%. Herron & Rugg concluded that it was therefore highly unlikely that memory for non-targets in Experiment 1 was so poor that they were in general mistaken for new items.

In two recent studies, (Dzulkifli & Wilding, 2005 and Dzulkifli, Herron, & Wilding, 2006), the Herron & Rugg strategic retrieval proposal was rigorously tested in tasks where there was no target/non-target confound and where there were direct estimates of the accuracy of non-target judgments available. Dzulkifli & Wilding (2005) reported old/new effects in a study where participants studied words initially, all of which were concrete nouns. For half of the words, the task was to decide how difficult the object denoted by each word would be to draw. For the remainder, the task was to generate uses for the object denoted by each word. Old and new (unstudied) words were presented at test, and participants completed exclusion tasks. There were reliable left-parietal ERP old/new effects for targets only, which suggests that participants prioritised recollection of information about targets over information about non-targets. In a second study, Dzulkifli, Herron, & Wilding (2006) utilised the study design employed by Dzulkifli & Wilding (2005), with the exception that the study and test lists were longer and there were longer intervals between study and test. These variations led to a reduction in the level of memory accuracy in comparison with the earlier study.

The left-parietal ERP old/new effect was evident for targets as well as for non-targets in all test phases, consistent with the view that participants recollected information about both of these classes of test word. These findings contrast with those of the Dzulkifli & Wilding (2005) study in which the same tasks were used, and in which a left-parietal ERP old/new effect was found for targets only. For the earlier study, however, the accuracy of task judgments was markedly higher. In summary, the two Dzulkifli et al. studies show that, where accuracy for targets and non-targets is high, a left-parietal ERP old/new effect is observed for targets only. However, when accuracy for task judgments is lower, both classes of items elicit left-parietal ERP old/new effects.

The combination of all of the above findings provides support for the claim that selective control of recollection is indexed by the patterns of ERP left-parietal old/new effects for targets and for non-targets. One important question is what factors can influence the selective control of recollection in the exclusion task. The Dzulkifli et al. (2005, 2006) and Herron & Rugg (2003a) studies suggest that levels of target accuracy are one key factor, with high levels of target accuracy encouraging participants to adopt a target-specific retrieval strategy, resulting in an attenuated non-target left-parietal ERP old/new effect, due to the prioritisation of recollection of target information over non-target information .

The preceding descriptions demonstrate that under some circumstances people can exert considerable control over whether or not information is recollected, and this in turn suggests that ERPs acquired in episodic retrieval tasks may be a useful functional tool for determining the conditions under which this can be achieved, as well as, ultimately, the mechanisms that are responsible for the strategic control of recollection (for discussion, see Dzulkifli & Wilding, 2005; Herron & Rugg, 2003; Hornberger, et al., 2004). The broad utility of ERPs in this regard depends in part, however, upon the extent to which comparable patterns of selective attenuation of left-parietal ERP old/new effects can be obtained across tasks with somewhat different retrieval demands to those described above. This observation is the motivation for the two studies described in this chapter.

The version of the exclusion procedure employed here was introduced initially by Jennings & Jacoby (1997). In this variant, all study items are subjected to the same encoding operations. In the subsequent retrieval task, a proportion of new (unstudied) test items are repeated after an intervening lag (hereafter repeated test items). Either studied items or repeated test items can be designated as targets in this design, and the use of the studied items as targets is employed in the pair of experiments reported here.

For both of the following studies, the repeated test items were the non-targets. The only difference between the two studies was the encoding task used in the study phase; in Experiment 1 the task was to say aloud a word which rhymed with the presented study word whilst for Experiment 2 it was to read each study word aloud. In this design, the repeated test items are, by virtue of the short lag between first and second presentation, likely to be associated with strong memory representations. Under these circumstances, therefore, participants might not be able to prioritise recollection of studied items over repeated test items, despite high levels of studied item accuracy.

Data inconsistent with this possibility, however, come from a series of experiments by Dywan and colleagues (Dywan, Segalowitz, & Webster, 1998; Dywan, Segalowitz et al., 2001 and Dywan, Segalowitz, & Arsenault 2002) in which they utilised the same variant of the exclusion task described above. Across all of the experiments in which the participants were young adults, a left-parietal ERP old/new effect was observed for targets, whereas no reliable effect was detected for excluded non-targets. What is surprising about these data is that the extensive attenuation of the non-target left-parietal ERP old/new effect occurred even though mean target accuracy across studies (.58) was markedly lower than the level required in other studies in order to demonstrate a similar pattern of attenuation of non-target left-parietal effects (Herron & Rugg, 2003b, Dzulkifli et al. 2005, 2006) . These data suggest that the likelihood of recollecting information about targets is not the only factor influencing the strategy adopted by participants in exclusion tasks, in keeping with the findings of Herron & Wilding (2005). At issue in the following two experiments are the generality of the findings obtained in the experiments described above.

Method

Due to the similarities between the designs of the two experiments, they are described jointly, with differences between the two noted where appropriate.

Participants

21 participants completed Experiment 1; the average age was 22 years (range 18 to 30). The data from five participants was discarded prior to analysis. For two of these the reason for rejection was that they did not contribute sufficient trials of incorrect responses to target items (target miss)(for criteria see General Methods, Chapter 4). The remaining participants were excluded due to excessive EOG artefact (see General Methods for criteria). Of the remaining 16 participants, 15 were female. 19 participants completed Experiment 2; the average age was 20 years (range 18 to 24)

and the data from three participants (three female) was discarded due to excessive EOG artefact (see General Methods for criteria) and consequently low numbers of trials in critical conditions. Of the remaining 16 participants, 15 were female. All participants were right-handed native English speakers. No participants were taking neuroleptic medication at the time of testing or reported a history of mental illness. All were paid at a rate of £7.50/hour and gave informed consent prior to commencing the experiments. No participant completed both experiments.

Stimuli and design

Across both experiments, words were taken from the MRC psycholinguistic database (frequency range = 1-7 occurrences per million, length = 4-9 letters: Coltheart, 1981). These were presented in white letters on a black background on a computer monitor placed 1 m from participants. The stimuli subtended maximum visual angles of 5^{o} (horizontal) and 0.6^{o} (vertical).

In both experiments, 280 critical words were split into 8 equal groups of 35 words. Words appeared in only one group. One complete word task list comprised two study lists and two test lists. There were 70 words (2 groups) on each study list. There were 175 words on each test list. These comprised the 70 words presented at study along with 35 unstudied words, and a further 35 unstudied words which then repeated once after 7-9 intervening items. The numbers of words re-presented after lags 7, 8, and 9 were approximately equal. For each test list there were also 6 fillers placed towards the end of the lists. These did not appear on any study list and were included in order to ensure that the final repeating word fell within the 7-9 item repeat interval. No words appeared in both test lists. Rotating the groups of words across study and test lists so that all words were presented at study and test, once or twice at test only, and in either the first or second study-test cycle, resulted in the creation of 8 complete task lists. The order of presentation of words in the study lists was determined randomly for each participant. The order of presentation of test items was determined pseudo-randomly. In total, each participant saw 502 presentations of words (140 study words, 350 test words + 12 fillers)

Procedure

Prior to commencing either experiment, participants were informed that they would be presented with a series of words on the computer screen. In each study phase, participants completed one encoding task for all words. For Experiment 1 they were asked to say aloud a word which rhymed with the presented study word. Participants were informed that for polysyllabic words (e.g. marmalade) where a rhyme did not come immediately to mind it was acceptable to produce a word that rhymed only with the last syllable of the target word. For Experiment 2 they were asked to read each word aloud. For all participants an asterisk before study words initiated each study trial and remained on the screen for 1000 ms. The screen was then blanked (100 ms) before the study word was presented for 300 ms. Participants were asked to give their response after the study word appeared. In Experiment 1 the next trial started after the participant pressed a key on the response box. In Experiment 2 the next trial started 2500 ms after the study word was presented.

Each test trial started with a fixation asterisk (500 ms duration), which was removed from the screen 100 ms prior to presentation of a test word (300 ms duration). The screen was then blanked until the participant responded, and the next trial started

1000 ms after the response. For each test phase, participants responded with one hand to words that were seen at study ('old words'), and with the other to unstudied test words ('new words') and to unstudied test words which repeated during the test phase ('repeated test words'). Responses were made on a key-pad with the left and right thumbs. The hands required for the binary test judgment were also balanced across participants and all participants were encouraged to respond quickly and accurately. Responses slower than 4000 ms and faster than 300 ms were regarded as errors and were discarded from behavioural and ERP analyses. An average of < 1% of trials per participant in both experiments (range 0.2 – 1.6%) were excluded due to this criterion.

EEG acquisition

These procedures were different in the two experiments. For Experiment 1 there were 32 recording locations from the International 10-20 system (Jasper, 1958) comprising midline (Fz, Cz, Pz, Oz), left and right hemisphere sites (FP1/FP2, F7/F8, F5/F6, F3/F4, F1/F2, T7/T8, C5/C6 C3/C4, C1/C2, P7/P8, P5/P6, P3/P4, P1/P2, O1/O2). Additional electrodes were located on the mastoid processes. EEG was acquired referenced to linked electrodes located midway between POz and PO3/PO4 respectively. EEG data was high-pass filtered off-line (0.03Hz) and down-sampled to 200 Hz. The EEG acquisition parameters were: range 0.03 – 40 Hz; sampling rate 2048 Hz.

For Experiment 2, EEG was recorded from 25 silver/silver chloride electrodes at midline sites (Fz, Cz, Pz) and left/right hemisphere locations (FP1/FP2, F7/F8, F5/F6, F3/F4, T3/T4, C5/C6, C3/C4, T5/T6, P5/P6, P3/P4, O1/O2: Jasper, 1958).

Additional electrodes were placed on the mastoid processes. EEG data acquisition parameters were: range 0.03 – 40 Hz; sampling rate 200 Hz.

For both experiments, data from Fz were recovered, the data were re-referenced offline to the algebraic mean of the signal at the two mastoids, and EOG was recorded from above and below the right eye (VEOG) as well as on the outer canthi (HEOG). Trials containing large EOG artefact were rejected, as were trials containing A/D saturation or baseline drift exceeding ±80μV. Other blink artefacts were corrected using a linear regression estimate (Semlitsch, Anderer, Schuster, & Presslich, 1986). A 7 point binomially weighted smoothing filter was applied prior to analysis.

Results

Behavioural data

Table 5.1 shows response accuracies and reaction times (RTs) for correct and incorrect responses to old, new and repeated test items in experiments 1 and 2. Two measures of discrimination (Pr: Snodgrass & Corwin, 1988) were calculated. The first was computed to determine whether participants were able to distinguish between old and new words. The second was computed to determine whether participants were able to distinguish between old words and repeated test words. In Experiment 1, Pr was reliably greater than 0 in both cases (Pr values = 0.61 and 0.57: $t(15) = 14.63$, $p<.001$ and $t(15)=11.61$, $p<.001$), and these two Pr scores did not differ reliably from each other. In Experiment 2, both Pr values were also reliably greater than 0 (Pr values = 0.62 and 0.53: $t(15)= 20.54$, $p<.001$ and $t(15) = 10.44$,

$p<.001$). Discrimination between old and repeated test words was inferior to that between old and new words ($t(15) = 3.54$, $p<.01$).

Measures of response bias (Br) were also calculated, where $Br = p(FA)/(1 - Pr)$. For the discrimination involving new words in Experiment 1, the mean value across participants was 0.14, while Br for the discrimination involving repeated test words was 0.22. Br scores did not differ reliably from each other. The values in each case indicate a mild to moderate conservative bias (Snodgrass & Corwin, 1988). In Experiment 2, Br for the discrimination involving new words was 0.20, whilst Br for the discrimination involving repeated test words was 0.33. Br scores differed reliably ($t(15) = -4.85$, $p<.001$), indicating a relatively more conservative bias for the discrimination involving new words.

For Experiment 1, a one-way ANOVA on the RTs for correct responses revealed significant differences between item class ($F(1.9, 29.2) = 13.74$, $p <.001$). Follow up paired comparisons showed that there were significant differences only between reaction times for old and repeated test items ($t(15)=3.43$, $p< .005$) and between new items and repeated test items ($t(15)= 5.36$, $p< .001$). These significant differences arose due to faster RTs to correct responses for repeated test items than to correct responses to new and old items. A one-way ANOVA on the RTs for correct responses in Experiment 2 revealed no reliable differences.

Table 5.1. Probabilities of correct (p(correct)) and incorrect (p(incorrect)) responses and reaction times in milliseconds (RT) to old, new and repeated test words in experiments 1 & 2.

		Word class		
		Old	New	Repeated Test
Exp. 1	p(correct)	0.67 (0.18)	0.94 (0.03)	0.90 (0.08)
	RT	1137 (691)	1038 (626)	903 (448)
	p(incorrect)	0.33 (0.18)	0.06 (0.03)	0.10 (0.08)
	RT	1286 (598)	1390 (471)	1268 (422)
Exp. 2	p(correct)	0.69 (0.13)	0.93 (0.06)	0.83 (0.13)
	RT	908 (395)	876 (353)	875 (348)
	p(incorrect)	0.31 (0.13)	0.07 (0.06)	0.17 (0.13)
	RT	1089 (628)	1130 (375)	954 (340)

ERP data

ERPs could in principle be obtained for 6 response categories in both experiments: correctly and incorrectly identified old, new and repeated test words. Too few participants made sufficient false alarms to new and repeated test words (2 participants for both conditions in each experiment) to permit analysis of the ERP data for these response categories. Therefore baseline corrected averaged ERPs (100 ms pre-stimulus baseline) were formed for correctly identified old words (hits), new words (correct rejections) and repeated test words (repeated hits), and incorrectly identified old words (misses), and were analysed for the 16 participants in each experiment who contributed sufficient artefact-free trials to these critical response categories. Mean trial numbers for these response categories were 72, 109, 47 and 35, in Experiment 1 and 82, 49, 116 and 36 in Experiment 2.

For both experiments, the ERP data were analysed over three time windows: 300-500, 500-800 and 800-1100 ms. For the three time windows, two sets of analyses were completed. In the first set (hereafter the Midline analyses) the analyses were restricted to 3 midline locations (Fz, Cz, and Pz). In the other set of analyses (hereafter the Global analyses), data from lateral electrode locations was employed. The data comprised ERPs acquired from 18 electrode locations, an equal number at left and right hemisphere sites at anterior (F3/F4, F5/F6 and F7/F8), central (C3/C4, C5/C6 and T7/T8) and posterior (P3/P4, P5/P6 and T5/T6) scalp locations. These analyses included the factors of category, location in the anterior/posterior plane (AP: 3 levels), location in the left-right plane (HM: left hemisphere, right-hemisphere) and site. Initial analyses were conducted involving the data from correct responses to old, new and repeated test words. Significant effects involving category were followed up by all possible paired contrasts between the three response categories. For the analyses of data including lateral scalp locations, interactions with the AP and/or HM dimension were followed up by analyses at each level of the relevant factor.

Two additional directed analyses were conducted. The first was carried out to assess changes in the mid-frontal ERP old/new effect with condition, and was carried out in the 300-500 ms time window for both experiments. This time window was selected as it has been argued that, at anterior sites near the midline in this post-stimulus epoch, ERPs are sensitive to item familiarity (Curran, Tepe, & Piatt, 2006; Rugg et al., 1998). The analyses included data from F3, Fz, and F4 only, and included the factors of category and site (three levels: F3/Fz/F4). The second directed analysis addressed directly changes in left-parietal ERP old/new effects and included factors of category, hemisphere, and site (four levels: P3, P4, P5, P6), and was completed over the 500-800 ms time window. This time window was selected as it captures when the left-parietal ERP old/new effect is primarily evident (Friedman & Johnson, 2000; Rugg, Herron, & Morcom, 2002). The results for Experiment 1 are reported first, followed by those for Experiment 2, and only in the sets of directed analyses are the ERPs elicited by incorrect responses to targets (misses) included alongside those associated with correct responses to targets, non-targets and new test items.

Experiment 1

Hits, correct rejections and repeated hits

Figure 5.1 is relevant to the following statistical analyses and shows the ERPs elicited by hits, correct rejections and repeated hits at electrode sites F3/F4, C3/C4, P3/P4, Fz, Cz and Pz. The figure shows that, from approximately 300 ms onwards, the ERPs elicited by hits and repeated hits are more positive-going than those elicited by correct rejections. This greater relative positivity for both classes of old item peaks at approximately 600 ms and is more pronounced at central and posterior midline sites. There is little difference of note between the ERP old/new effects associated with targets and with non-targets.

300-500 ms:

Midline analyses:

The initial analysis revealed a main effect of category ($F(2.0, 29.9) = 38.59$, $p<.001$) as well as an interaction between category and site ($F(2.6, 39.2) = 3.06$, $p<.05$). The follow-up analyses comprised all possible paired contrasts of the three categories, and these revealed that the ERPs evoked by hits were reliably more positive-going than those elicited by correct rejections ($F(1,15) = 50.66$, $p<.001$). A category by site interaction for the contrast between hits and repeated hits ($F(1.8, 27.6) = 4.33$, $p<.05$) reflected the fact that, while hits are more positive-going than repeated hits at Fz, at Pz the reverse is true. The final contrast revealed only that the ERPs evoked by repeated hits were reliably more positive-going than those elicited by correct rejections ($F(1,15) = 62.03$, $p<.001$).

Global analyses:

The second set of analyses for this time window revealed a main effect of category ($F(1.9, 28.5) = 35.50$, $p<.001$), as well as interactions between category and site ($F(2.3, 34.3) = 13.46$, $p<.001$), and category, AP and site ($F(6.4, 96.1) = 2.85$, $p<.05$). The follow-up analyses comprised all possible paired contrasts of the three categories. Table 5.2 shows the outcomes of the paired contrasts in the global analyses for all three time windows, only those terms for which outcomes were reliable in at least one paired contrast are shown.. For the 300-500 ms time window, the contrast between hits and correct rejections revealed an interaction between category and site, reflecting the fact that the old/new effect is largest at sites closest to the midline.

For the contrast between repeated hits and correct rejections there was a three-way interaction between category, AP and site, and further analysis at each of the AP levels revealed a greater relative positivity for repeated hits at central and posterior sites closest to the midline (central category by site interaction: $F(3.4, 51.1) = 7.38$, $p<.001$, parietal category by site interaction: $F(2.4, 36.7) = 8.14$, $p<.001$). For the hits versus repeated hits contrast there was an interaction between category, AP and site. Further analysis at each of the AP levels revealed no significant effects. It is most likely that the interaction came about because of a relative greater positivity for repeated hits at posterior midline scalp locations that was not evident at frontal and central locations (see Figure 5.1).

500-800 ms:

Midline analyses:

The initial analysis revealed a main effect of category ($F(1.4, 20.9) = 35.27$, $p < .001$). The follow up analyses comprised all possible paired contrasts of the three categories, and these revealed that, while not differing from each other, the ERPs evoked by hits and repeated hits were both reliably more positive-going than those elicited by correct rejections ($F(1,15) = 87.14$, $p < .001$ and $F(1,15) = 70.80$, $p < .001$ respectively).

Global analyses:

The second set of analyses for this time window revealed a main effect of category ($F(1.6, 24.0) = 36.15$, $p < .001$), as well as an interaction between category and site ($F(2.2, 32.6) = 18.78$, $p < .001$). The follow-up analyses comprising all possible paired contrasts of the three categories are shown in the middle portion of Table 5.2.

There was a three-way interaction between category, AP and site for the contrast between hits and correct rejections. Further analysis at each of the AP levels revealed that at each AP level the old/new effects are largest close to the midline (frontal category by site interaction $F(2.6, 37.5) = 7.50$, $p < .001$, central category by site interaction: $F(3.0, 45.0) = 11.77$, $p < .001$, parietal category by site interaction: $F(2.7, 39.8) = 5.26$, $p < .005$). The most likely reason for the three-way interaction is that the old/new effects are larger and more widespread at posterior sites. The contrast between repeated hits and correct rejections produced an interaction between category and site, reflecting the fact that the greater positivity associated with repeated hits is largest at the sites closest to the midline.

Table 5.2. The outcomes of the paired contrasts between the mean amplitudes associated with hits, correct rejections and repeated hits for the global analyses over the 300-500, 500-800 and 800-100 ms time windows in Experiment 1. CR = correct rejection, RHit = repeated hit, CC = category, HM = hemisphere, AP = anterior/posterior plane, SI = site, df = degrees of freedom. *** = p < .001, ** = p < .01, * = p < .05, • = p < .1, ns = non-significant. Epsilon values are shown in brackets.

	df	Hit vs CR	CR vs RHit	Hit vs RHit
300-500 ms				
CC	1,15	37.21***	63.20***	ns
CC x SI	2,30	$34.89_{(.44)}$***	$19.23_{(.50)}$***	ns
CC x AP x SI	4,60	ns	$3.25_{(.67)}$*	$3.36_{(.67)}$*
500-800 ms				
CC	1,15	84.46***	60.70***	ns
CC x SI	2,30	$55.81_{(.50)}$***	$26.58_{(.55)}$***	ns
CC x AP x SI	4,60	$2.54_{(.67)}$*	ns	ns
800-1100 ms				
CC	1,15	22.23***	12.02**	ns
CC x SI	2,30	ns	$8.16_{(.61)}$**	ns
CC x AP x SI	4,60	$2.70_{(.63)}$*	ns	ns

800-1100 ms:

Midline analyses:

The initial analysis revealed a main effect of category ($F(1.5, 22.5) = 6.37$, $p<.05$) as well as an interaction between category and site ($F(2.8, 41.8) = 3.57$, $p<.05$). The follow-up analyses comprised all possible paired contrasts of the three categories, and these revealed a category by site interaction for the contrast between hits and correct rejections ($F(1.2, 17.6) = 4.58$, $p<0.05$), reflecting the fact that the relatively greater positivity for hits than for correct rejections was smallest at Pz. There was also a category by site interaction for the contrast between repeated hits and correct rejections ($F(1.6, 24.2) = 6.02$, $p<.05$), but in this case the interaction term reflected the fact that while repeated hits are more positive-going than correct rejections at Fz, at Pz the reverse is true.

Global analyses:

The second set of analyses for this time window revealed a main effect of category ($F(1.6, 24.5) = 9.01$, $p<.01$), as well as an interaction between category and site ($F(2.2, 32.7) = 3.82$, $p<.05$). The results of the follow-up analyses comprising all possible paired contrasts of the three categories are shown in the lower portion of Table 5.2.

The contrast between hits and correct rejections revealed a three-way interaction between category, AP and site. Further analysis at each of the AP levels revealed no significant interactions between category and site. It is most likely that the interaction came about because the old/new effects are largest at central sites close to the midline. For the contrast between correct rejections and repeated hits there was an interaction between category and site, which was due to the increased magnitude of the relatively greater positivity for repeated hits at sites closest to the midline.

Mid-frontal ERP old/new effects:

To further investigate how the mid-frontal ERP old/new effect changed with category, additional directed analyses were conducted. This involved the mean amplitudes for hits, misses, repeated hits and correct rejections at F3, Fz and F4 in the 300-500 ms time window. Figure 5.2 is relevant to the following statistical analyses and shows the ERPs elicited by the four classes of items at electrode sites F3, Fz, and F4. The figure shows that from approximately 300 ms hits and repeated hits are more positive-going than misses and correct rejections, with misses being more positive-going than correct rejections. From approximately 500 ms the differences between misses and correct rejections diminish at Fz and F4.

The directed analysis revealed a main effect of category ($F(2.0, 29.9) = 16.67$, $p<.001$). Paired contrasts demonstrated that hits ($F(1,15) = 34.82$, $p<.001$ and $F(1,15) = 11.41$, $p<.005$) as well as repeated hits ($F(1,15) = 31.50$, $p<.001$ and $F(1,15) = 6.41$, $p<.05$) were both more positive-going than correct rejections and misses at these mid-frontal electrode sites. Misses were also reliably more positive-going than correct rejections ($F(1,15) = 5.15$, $p<.05$). There were no significant differences between the two classes of hits. This pattern of data at the mid-frontal electrode sites is further illustrated in Figure 5.8, where the mean amplitudes for the old/new effects for hits, misses and repeated hits averaged across sites F3, Fz and F4 are shown for both experiments.

Left-parietal ERP old/new effects:

This analysis involved the mean amplitudes for hits, misses, repeated hits and correct rejections at P3, P5, P4 and P6 in the 500-800 ms time window. Figure 5.3 is relevant to the following statistical analyses and shows the ERPs elicited by the four classes of items at the electrode sites included in the analyses. The figure shows that in the critical 500-800 ms time window hits and repeated hits are equally more positive-going than misses and correct rejections, with minimal differences between misses and correct rejections.

The analyses revealed a main effect of category ($F(2.0, 30.0) = 22.82$, $p < .001$). This was followed up by all possible paired contrasts, and the outcomes of these showed that ERPs evoked by hits ($F(1,15) = 87.62$, $p<.001$) and by repeated hits ($F(1, 15) = 42.29$ $p<.001$) were reliably more positive-going than those evoked by correct rejections. Figure 5.4 shows topographic maps of the differences in neural activity at the scalp between hits and repeated hits respectively compared to correct rejections for both experiments and illustrates this greater positivity for old words relative to new. The contrast between the ERPs evoked by hits and repeated hits revealed no significant effects. The contrast between hits and misses revealed that hits were more positive-going than misses ($F(1,15) = 25.48$, $p<.001$) and that this greater relative positivity was maximal at P3 (category by site interaction: $F(1.9, 29.0) = 3.84$, $p<.05$). Likewise repeated hits were also more positive-going than misses ($F(1,15) = 29.15$, $p<.001$), however a condition by site interaction reflected the fact that this greater relative positivity was maximal at P4 ($F(1.9, 29.0) = 4.20$, $p<.05$). There were no significant effects involving category revealed in the contrast between misses and correct rejections.

Experiment 2

Hits, correct rejections and repeated hits analyses

Figure 5.5 is relevant to the following statistical analysis and shows the ERPs elicited by hits, correct rejections and repeated hits at electrode sites F3/F4, C3/C4, P3/P4, Fz, Cz and Pz. The figure shows that, from approximately 300 ms onwards, the ERPs elicited by hits and repeated hits are more positive-going than those elicited by correct rejections. At right anterior sites later in the epoch hits remain consistently more positive-going than those elicited by correct rejections. However, from approximately 700 ms onwards at right anterior sites, the ERPs elicited by repeated hits are no longer more positive-going than those elicited by correct rejections.

300-500 ms:

Midline analyses:

The initial analysis restricted to midline locations revealed a main effect of category ($F(2.0, 29.4) = 26.24$, $p < .001$), as well as an interaction between category and site ($F(2.8, 42.2) = 4.76$, $p<.01$). The follow-up analyses revealed that the ERPs evoked by hits were reliably more positive-going than those elicited by correct rejections ($F(1,15) = 29.37$, $p<.001$). There was a category by site interaction for the contrast between hits and repeated hits ($F(1.6, 23.3) = 9.14$, $p<.005$), reflecting the fact that while hits are more positive-going than repeated hits at Fz, at Pz there are minimal differences between these classes of ERPs. The final contrast between repeated hits and correct rejections revealed a main effect of category ($F(1,15) = 54.14$, $p<.01$). This was moderated by an interaction between category and site ($F(1.6, 24.0) = 3.85$, $p<.05$) which reflected the fact that the greater positivity for repeated hits is smallest at Fz.

Global analyses:

The second set of analyses for this time window revealed a main effect of category ($F(2.0, 29.9)= 22.18$, $p<.001$), as well as interactions between category and site ($F(2.1, 30.8) = 16.77$, $p<.001$), and category, AP and site ($F(4.0, 60.5) = 2.62$, $p<.05$). The follow-up contrasts (upper portion of Table 5.3) revealed that between hits and correct rejections there was a four-way interaction between category, AP, HM and site. Further analysis at each of the three levels of the AP factor showed only one significant interaction involving category, which was between category, HM and site at central electrode locations ($F(1.9, 28.8) = 9.26$, $p<.001$). This was because the relatively greater positivity for hits over correct rejections was largest at C3. For the repeated hits versus correct rejection contrast there was a three-way interaction between category, AP and site. Further analysis at each of the three levels of the AP factor showed a relatively greater positivity for repeated hits at all three AP levels (frontal: $F(1,15) = 20.00$, $p<.001$, central: $F(1,15) = 34.74$, $p<.001$ and parietal $F(1,15) = 44.79$, $p<.001$). There was a significant interaction between category and site only at parietal electrode locations ($F(1.8,26.7) = 5.58$, $p<.05$) which was because the relatively greater positivity for repeated hits was largest at P3/P4. For the remaining paired contrast between repeated hits and hits, there were no reliable effects involving category.

500-800 ms:

Midline analyses:

The initial analysis revealed a main effect of category ($F(1.6, 24.5) = 25.24$, $p<.001$), and an interaction between category and site ($F(2.7, 40.6) = 3.94$, $p<.05$). The follow-up analyses again comprised all possible paired contrasts of the three categories, and these revealed that the ERPs evoked by hits and repeated hits were both reliably more positive-going than those elicited by correct rejections ($F(1,15) = 33.28$, $p<.001$ and $F(1,15) = 47.07$, $p<.001$ respectively). The contrast between correct rejections and repeated hits was moderated by an interaction between category and site ($F(1.5,22.1) = 6.07$, $p<.05$) reflecting the fact that the relatively greater positivity for repeated hits at Pz was larger than the comparable positivity at Fz.

Global analyses:

The second set of analyses for this time window revealed a main effect of category ($F(1.7, 24.8) = 21.06$, $p<.001$), as well as interactions between category and AP ($F(2.4, 35.6) = 6.28$, $p<.005$), category and site ($F(2.0, 29.8) = 24.13$, $p<.001$) and a three way interaction between category, AP and site ($F(4.4, 65.9) = 3.92$, $p<.005$). The follow-up analyses (see Table 5.3) show that, for the contrast between hits and correct rejections, there was a three-way interaction between category, AP and site.

Table 5.3. The outcomes of the paired contrasts between the mean amplitudes associated with hits, correct rejections and repeated hits for the <u>global</u> analyses over the 300-500, 500-800 and 800-100 ms time windows in Experiment 2. Nomenclature as for Table 5.2 (page 137).

	df	Hit vs CR	CR vs RHit	Hit vs RHit
300-500 ms				
CC	1,15	20.87***	41.94***	ns
CC x SI	2,30	$19.75_{(.56)}$***	$35.94_{(.61)}$***	ns
CC x AP x SI	2,30	ns	$3.65_{(.58)}$*	ns
CC x AP x SI x HM	3,40	$3.24_{(.62)}$*	ns	ns
500-800 ms				
CC	1,15	27.11***	43.65***	ns
CC x SI	1,15	$35.26_{(.58)}$*	$19.25_{(.64)}$***	$12.31_{(.63)}$***
CC x AP	1,20	$7.55_{(.63)}$ **	$13.5_{(.67)}$ ***	ns
CC x AP x SI	3,40	$6.60_{(.73)}$ ***	$4.80_{(.58)}$ *	ns
800-1100 ms				
CC	1,15	6.46*	ns	ns
CC x SI	1,15	ns	ns	$4.68_{(.61)}$*
CC x AP	1,20	ns	$5.49_{(.62)}$*	$5.34_{(.67)}$*
CC x AP x SI	3,40	ns	ns	ns

Further analysis at each of the three levels of the AP factor showed significant interactions between category and site at midline ($F(2.0, 30.1) = 6.14, p<.01$) and parietal ($F(1.6, 24.5) = 6.36, p<.01$) electrode sites only, these reflected the relatively greater positivity for hits being largest at inferior sites.

The contrast between repeated hits and correct rejections also revealed a three-way interaction between category, AP and site. Further analysis at each of the three levels of the AP factor showed significant interactions between category and site at midline ($F(2.5, 38.2) = 3.22, p<.05$) and parietal ($F(2.1, 30.8) = 6.97, p<.005$) electrode sites, and these arose because the relatively greater positivity for repeated test items was largest at central and parietal midline sites. The final contrast between hits and repeated hits revealed a significant interaction between category and site which came about because the greater positivity for hits is largest at sites closest to the midline.

800-1100 ms:

Midline analyses:

The initial analysis revealed an interaction between category and site ($F(3.1, 47.1) = 3.63, p<.05$). The follow-up analyses comprised all possible paired contrasts of the three categories, and these revealed only a category by site interaction for the contrast between hits and correct rejections ($F(1.3, 19.3) =8.12, p<0.01$), reflecting the fact that the relatively greater positivity for hits than for correct rejections was smallest at Pz.

Global analyses:

The second set of analyses for this time window revealed a main effect of category ($F(1.4, 21.5) = 4.12$, $p<.05$) as well as interactions between category and AP ($F(2.2, 32.5) = 4.12$, $p<.05$) and category and site ($F(2.2, 32.4) = 3.64$, $p<.05$). The follow-up contrasts (lower portion of Table 5.3) revealed that between hits and correct rejections there was only a main effect of category which was due to the greater positivity for hits. There were category by AP and category by site interactions for the contrast between hits and repeated hits. Further analyses at each of the AP factor levels showed a significant effect of category at frontal electrode sites only ($F(1,15) = 4.99$, $p<.05$), reflecting the greater relative positivity for hits at anterior sites. The final contrast between correct rejections and repeated hits revealed only an interaction between category and AP. Further analysis at each of the three levels of the AP factor showed a main effect of category at parietal sites only ($F(1,15) = 11.75$, $p<.005$), which was due to the relative greater positivity for repeated hits.

Mid-frontal ERP old/new effects:

Figure 5.6 is relevant to the following statistical analyses and shows the ERPs elicited by all four classes of item at electrode sites F3, Fz, F4. The figure shows that, in the critical 300-500 ms time window, the ERPs elicited by hits, repeated hits and misses are all more positive-going than those elicited by correct rejections. Later in the epoch the differences between misses and correct rejections become far less prominent.

The initial analysis revealed a main effect of category only ($F(1.9, 29.2) = 18.56$, $p < .001$). Paired contrasts within the experiment demonstrated that hits and misses ($F(1,15) = 28.24$, $p<.001$ and $F(1,15) = 10.50$, $p<.01$) as well as repeated hits ($F(1,15) = 23.07$, $p<.001$) are all more positive-going than correct rejections at these mid-frontal electrode sites. The contrast between hits and correct rejections also revealed an interaction with site ($F(2,30) = 5.95$, $p<.01$) which reflects the fact that the mid-frontal ERP old/new effect for studied words is largest at Fz. This can clearly be seen in Figure 5.4, which shows a topographic map illustrating the scalp distribution of the difference between activity evoked by hits and that evoked by correct rejections over the 300-500 ms time window. There were no reliable differences between the ERPs elicited by hits, repeated hits and misses.

Left-parietal ERP old/new effects:

Figure 5.7 is relevant to the following statistical analyses and shows the ERPs elicited by the four classes of items at electrode sites P3/4 and P5/6. The figure shows that from approximately 300 ms to 950 ms post-stimulus, hits and repeated hits are equally more positive-going than misses and correct rejections, with minimal differences between misses and correct rejections.

The initial analysis revealed a main effect of category ($F(1.4, 21.2) = 25.40$, $p<.001$) and an interaction between category and site ($F(1.7, 25.3) = 6.04$, $p<.01$). The outcomes of the paired follow-ups showed that ERPs evoked by both classes of old words were reliably more positive-going than those evoked by new words (hit: $F(1,15) = 31.07$, $p<.001$ and repeated hit: $F(1,15) = 86.10$, $p<.001$). There was also an interaction between category and site for the contrast between hits and correct rejections ($F(1,15) = 20.20$, $p<.001$), which reflected the fact that the relatively greater positivity for old words is largest at sites bordering the midline (P3/P4). The greater positivity for old words relative to new is further illustrated in Figure 5.4, which shows a topographic map of the differences in neural activity recorded at the scalp between hits and correct rejections, and demonstrates a degree of left hemisphere lateralisation that was not liable in the statistical analyses. For the repeated test words the differences in neural activity compared to that associated with new items shows a classic P3 distribution (see Figure 5.4). Both classes of old word were also reliably more positive-going than misses (hit: $F(1,15) = 52.31$, $p<.001$ and repeated hit: $F(1,15) = 71.65$, $p<.001$). The contrasts between the ERPs evoked by misses and by correct rejections over this time window at these posterior electrode locations revealed no reliable effects involving category.

Discussion

Previous ERP findings (see chapter Introduction) are consistent with the view that it is possible under some circumstances for people to exert considerable control over the recollection of information. This suggests that, within episodic retrieval tasks, the use of ERPs may be an effective functional tool for establishing the conditions under which such regulation can be attained, as well as, ultimately, the mechanisms that are responsible for the strategic control of recollection (for discussion, see Dzulkifli & Wilding, 2005; Herron & Rugg, 2003b; Hornberger et al., 2004). The benefits of using ERPs in this manner depend somewhat, however, upon the degree to which equivalent patterns of selective attenuation of left-parietal ERP old/new effects can be obtained across tasks other than standard exclusion tasks, and in particular, those which have different retrieval demands.

The motivation for the two studies described in this chapter was to; (i) assess the extent to which previous findings of left-parietal ERP old/new effects for targets and non-targets in exclusion tasks could be generalised to a variant of the exclusion task, (ii) assess the impact of changing encoding task on the patterns of left-parietal ERP old/new effects observed, and (iii) provide a starting point for investigating the apparent inconsistencies between the findings of these studies and those of Dywan et al. (1998, 2001, 2002). The critical behavioural and ERP findings relevant to these issues will be discussed in the following sections. This will be followed by a brief discussion of further ERP findings relevant to the functional interpretation of the mid-frontal ERP old/new effect.

Left-parietal ERP old/new effects

The directed analyses of the left-parietal ERP old/new effects showed reliable old/new effects for studied as well as repeated test items in both experiments. There were no reliable differences between misses and correct rejections at posterior sites in the 500-800 ms epoch in either experiment. If the magnitude of left-parietal ERP old/new effects is an index of the extent to which recollection was engaged, then the pattern of effects is consistent with the view that participants did not prioritise recollection of studied words over repeated test words in either experiment.

In both experiments, participants were able to discriminate between the three critical classes of test word. Mean levels of accuracy for targets were 0.67 in Experiment 1 and 0.69 in Experiment 2. In previous exclusion task studies where new items were not repeated, some degree of attenuation of non-target old/new effects has been reported with levels of target accuracy comparable to those reported here (cf. Dzulkifli et al., 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a; Herron & Rugg, 2003b; Wilding et al., 2005). It may be the case that the reason for the findings here is due to the difficulty in controlling recollection of the repeated test items, with the findings in earlier studies reflecting relatively lower degrees of difficulty for the non-target categories employed in those experiments. This issue is returned to in Chapter 7. The previous findings, however, that are of greatest relevance here are those reported by Dywan and colleagues who employed the paradigm used in experiments 1 and 2 (Dywan et al., 2002; Dywan et al., 1998; Dywan et al., 2001).

In each of these three publications, at least one group of participants was given the same task instructions as those provided to participants in Experiment 2 described earlier. In contrast to the findings in experiments 1 and 2, however, parietally distributed ERP old/new effects were markedly and reliably larger for correct responses to studied words than for correct responses to repeated test words (referred to as 'lag' words by Dywan et al.). In fact, in all three publications, there is little evidence for a relatively greater positivity for correct responses to repeated test words in comparison to correct rejections at parietal locations in the 500-800 ms time window.

Previous findings have shown that higher levels of target accuracy are more likely to result in an attenuation of the non-target left-parietal ERP old/new effect (Dzulkifli et al., 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a, 2003b; Wilding et al., 2005). It is therefore very surprising that with a higher level of target accuracy than that in the Dywan et al studies there is no observable attenuation of the left-parietal ERP old/new effect for repeated test items in either experiment.

It is also unlikely that the disparity in findings is due to the encoding task, as Dywan et al. required participants simply to read words aloud, the same encoding task that was employed in Experiment 2. In the studies due to Dywan et al., the lag between first and second presentations of repeated test words was fixed at 6 items, whereas in experiments 1 and 2 the lag varied between 7 and 9 items. One possibility, therefore, is that the greater predictability of the occurrence of repeated test words contributed to the disparate findings. While this possibility cannot be ruled out entirely, it seems somewhat unlikely when considering the relatively complex demands of the retrieval task, and the fact that in none of the studies were participants informed of the repetition lag.

A possible account of the disparities across studies stems from the fact that, in both experiments described here, the ratio of studied words to repeated test words was 2:1, contrasting with the 1:1 ratio in the studies of Dywan et al. The P300 (P3b) potential is sensitive to the relative probabilities of classes of stimuli, as well as their task-relevance (Donchin & Coles, 1988). The P300 is typically larger for task-relevant as well as for lower probability classes of stimuli, and this component is commonly largest at centro-parietal scalp sites, with little if any hemisphere lateralisation (Horst, Johnson, & Donchin, 1980; Squires, Squires, & Hillyard, 1975). In light of these observations, the probability disparity across studies offers to explain the differences between the ERP findings. By this account, the greater relative positivity for repeated test words relative to new words in experiments 1 and 2 but not in the work of Dywan et al. is simply a consequence of a larger P300 elicited by this class of stimuli in Experiments 1 and 2 (see data for Pz shown in Figures 5.1 and 5.7).

The probability disparity will be addressed in Experiment 3. Prior to this, however, one further aspect of the parietal ERP data warrants comment, as do other aspects of the findings in these experiments. For the parietal effect, there was no statistical evidence for left-lateralisation for the parietal ERP old/new effects in either experiment. Inspection of Figure 5.4 suggests that there is a degree of lateralisation of the ERP old/new effect for studied items in Experiment 2, but the relevant statistical analyses did not reveal interactions involving condition and hemisphere (see Table 5.3). The absence of an asymmetry in the differences between the ERPs evoked by old and new words is arguably more surprising for studied words than for repeated test words. This is because in continuous recognition memory tasks, where participants encounter a single list of items and some repeat after a variable number of intervening items, parietally distributed ERP old/new effects tend to show little if any hemisphere asymmetry (e.g. Rugg, Mark, Gilchrist, & Roberts, 1997; Rugg & Nagy, 1989; Swick & Knight, 1997). To the extent that the repeated test words in this task are comparable to repeated words in a standard continuous recognition memory task, the absence of asymmetric effects in these experiments is consistent with the prior literature, even if it does not help with an explanation as to why the degree of lateralisation of parietal ERP old/new effects varies across continuous and study-test recognition memory tasks.

From this perspective, the surprising aspects of the data in these experiments are the parietal ERP old/new effects for studied words. There is no immediate explanation for this null finding in the current data, although the absence of strongly lateralised parietally distributed old/new effects has been reported in other studies (see, for example Senkfor & Van Petten, 1998; Van Petten, Senkfor, & Newberg, 2000; Wilding et al., 2005; Yovel & Paller, 2004).

Mid-frontal ERP old/new effect

Previous research has suggested that frontally distributed ERP old/new differences (appearing between 300 and 500 ms) index familiarity (Curran, 1999, 2000; Curran & Cleary, 2003; Curran, Tanaka, & Weiskopf, 2002; Guillem, Bicu, & Debruille, 2001; Mecklinger, 2000; Nessler, Mecklinger, & Penney, 2001; Rugg et al., 1998).

How do the findings in Experiments 1 and 2 contribute to this issue? One important observation is that, within both experiments, moderate to high levels of familiarity for studied words may not be a good basis for task judgments. The reason for this claim is the assumption that repeated test words will be highly familiar because of the short lag between first and second presentation. As a result, familiar but not recollected studied words might attract incorrect responses despite relatively high levels of familiarity as they might be misclassified as repeated test items. It follows from this argument that if the mid-frontal ERP old/new effect indexes familiarity then the effect should be evident for misses in both of these experiments.

The directed analysis of the mid-frontal ERP old/new effect confirmed that within both experiments there were reliable old/new effects for both classes of old items. Furthermore, in Experiment 1, hits and repeated hits were reliably more positive-going than misses, which in turn showed a greater relative positivity in comparison to correct rejections. In Experiment 2, there were no differences between the two classes of old item and misses, all of which were again reliably more positive-going than correct rejections. In both experiments there were no reliable differences between hits and repeated hits at mid-frontal electrode locations.

Since reliable mid-frontal ERP old/new effects were obtained for misses in both experiments, as Figures 5.2 and 5.6 show, the data are consistent with the account that the mid-frontal ERP old/new effect indexes familiarity. These findings converge with previous studies in establishing a link between the mid-frontal ERP old/new effect and familiarity, and they do so in tasks where for the first time there is no response confound: correct responses to new words and incorrect responses to studied words were made on the same key (Bridson, Fraser, Herron & Wilding, 2006).

Concluding remarks

Reliable mid-frontal ERP old/new effects were obtained for misses and all classes of old item in both experiments, consistent with the account that the mid-frontal ERP old/new effect indexes familiarity. There were reliable parietal ERP old/new effects for both studied and repeated test items in both experiments. This is surprising, given previous findings (Dywan et al., 1998; Dywan et al., 2001; Dywan et al., 2002), and is the starting point for further investigations into the boundary conditions under which differential attenuation of the parietal ERP old/new effect for the repeated test items occurs within this variant of the exclusion task.

The probability disparity across studies offers one explanation of the differences between the parietal ERP findings of these experiments and those of Dywan et al. (1998, 2001, 2001). By this account, the greater relative positivity for repeated test words relative to new words in experiments 1 and 2 but not in the work of Dywan et al. is simply a consequence of a larger P300 elicited by this class of stimuli in experiments 1 and 2 (see data for Pz shown in Figures 5.1 and 5.7). The lower probability of occurrence in these experiments, moreover, might also have encouraged participants to adopt a different strategy for completing the task, focusing to a greater extent on the repeated test words in both experiments than in the studies of Dywan et al. To the extent that this strategy resulted in an increase in the task-relevance of the repeated test words, again the prediction would be that this class of stimuli should elicit a sizable P300. This leads to considerations as to whether the disparities between studied and repeated test word ERP old/new effects can be explained by the occurrence of P300 modulations. Experiment 3 was designed in order to address this issue by manipulating the probability of occurrence of studied and repeated test words to replicate the 1:1 ratio employed in the Dywan et al. studies.

The following chapter also contains a report of a second experiment, which replicates Experiment 3 except for the fact that target/non-target designation was reversed at test, such that repeated test items were designated as targets. The reason for this manipulation was the fact that no direct indicator of the memorability of repeated test items can be obtained when they are designated as non-targets, since correct responses to new items and non-targets are made on the same key in the exclusion task, as outlined in the Introduction (see page 46). The absence of such information makes it difficult to interpret unequivocally any changes in the non-target ERP old/new effects as being due to the strategic control of recollection, since participants may have correctly classified a proportion of non-targets because these items were simply forgotten and misclassified as new words. Consequently, for the interpretation of findings in terms of the control of recollective processes it is important that memory for non-targets is assessed directly.

Figure 5.1. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at sites F3/F4, C3/C4, P3/P4, Fz, Cz and Pz in Experiment 1.

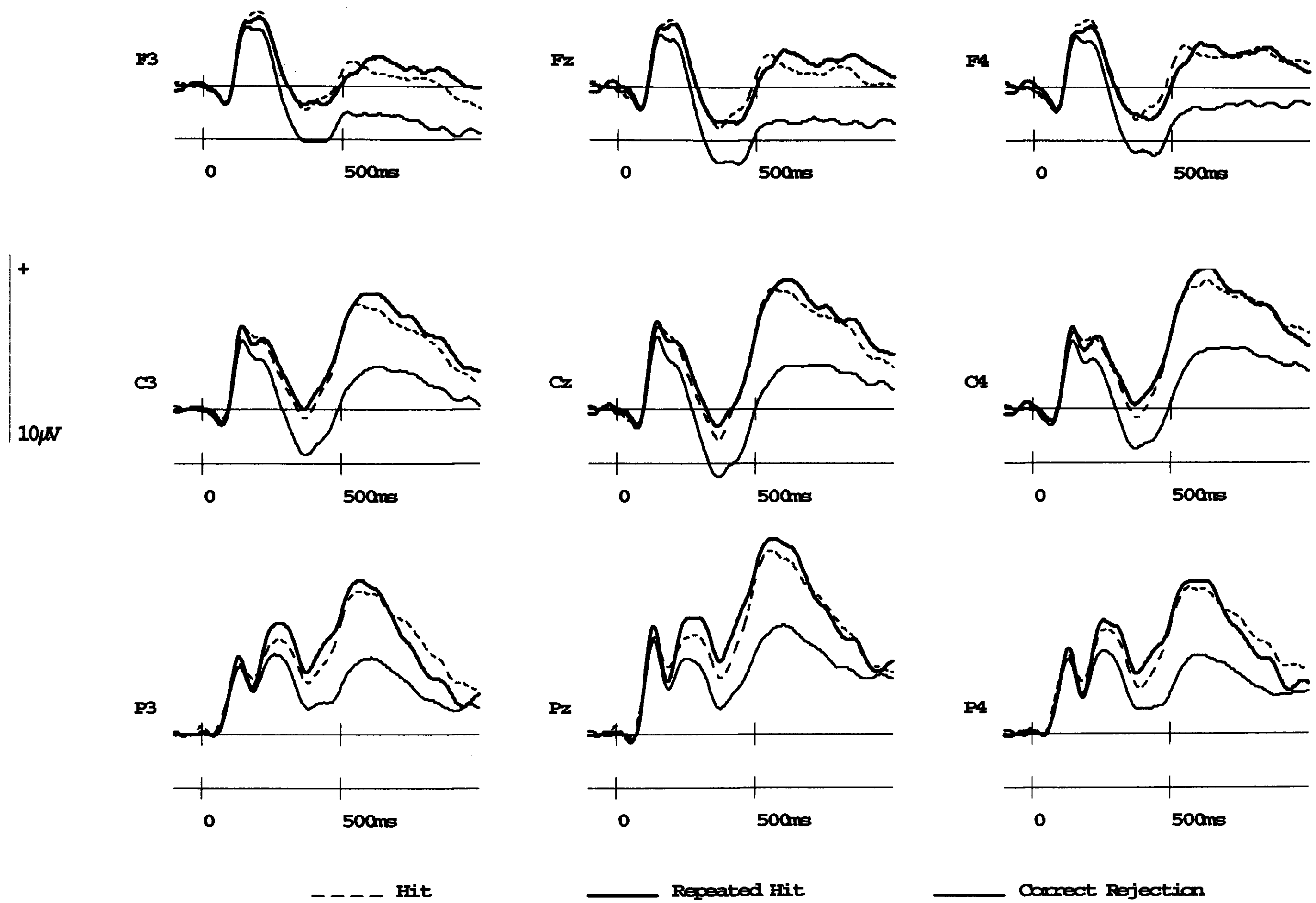


Figure 5.2. Grand averaged ERPs elicited by hits, misses, correct rejections and repeated hits at sites F3, Fz, F4, in Experiment 1.

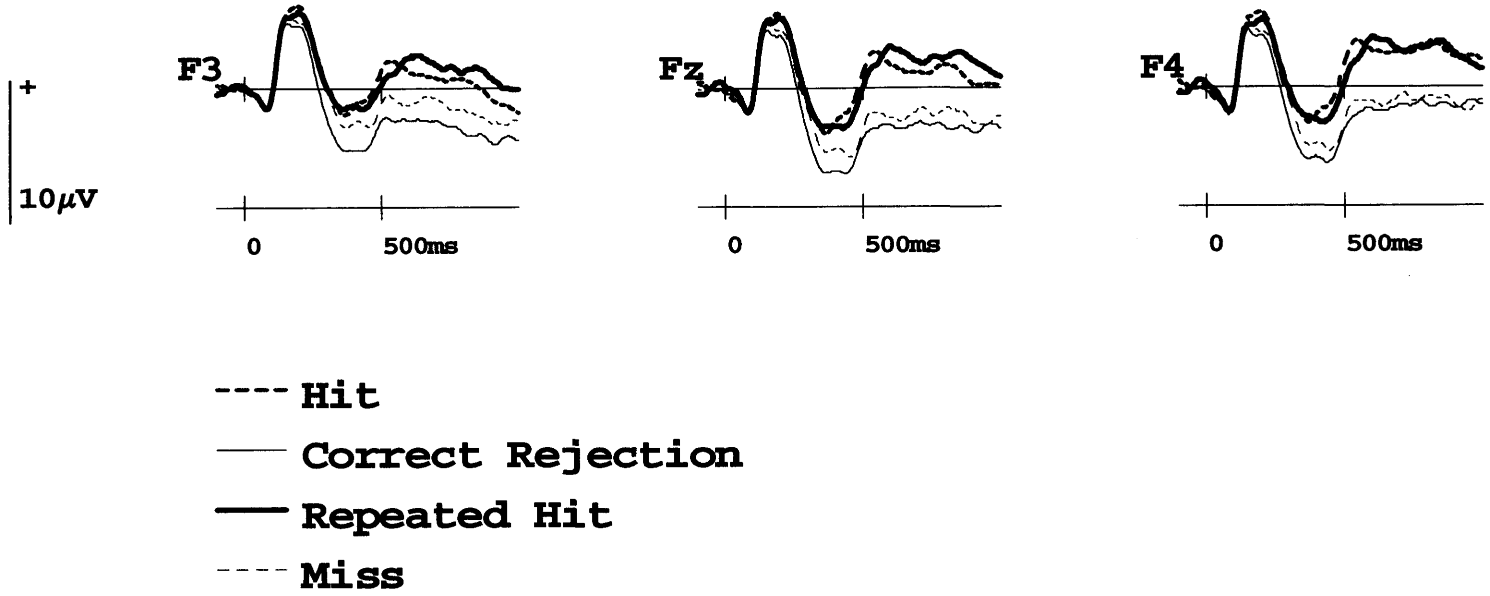


Figure 5.3. Grand averaged ERPs elicited by hits, misses, correct rejections and repeated hits at sites P3/4, P5/6, in Experiment 1.

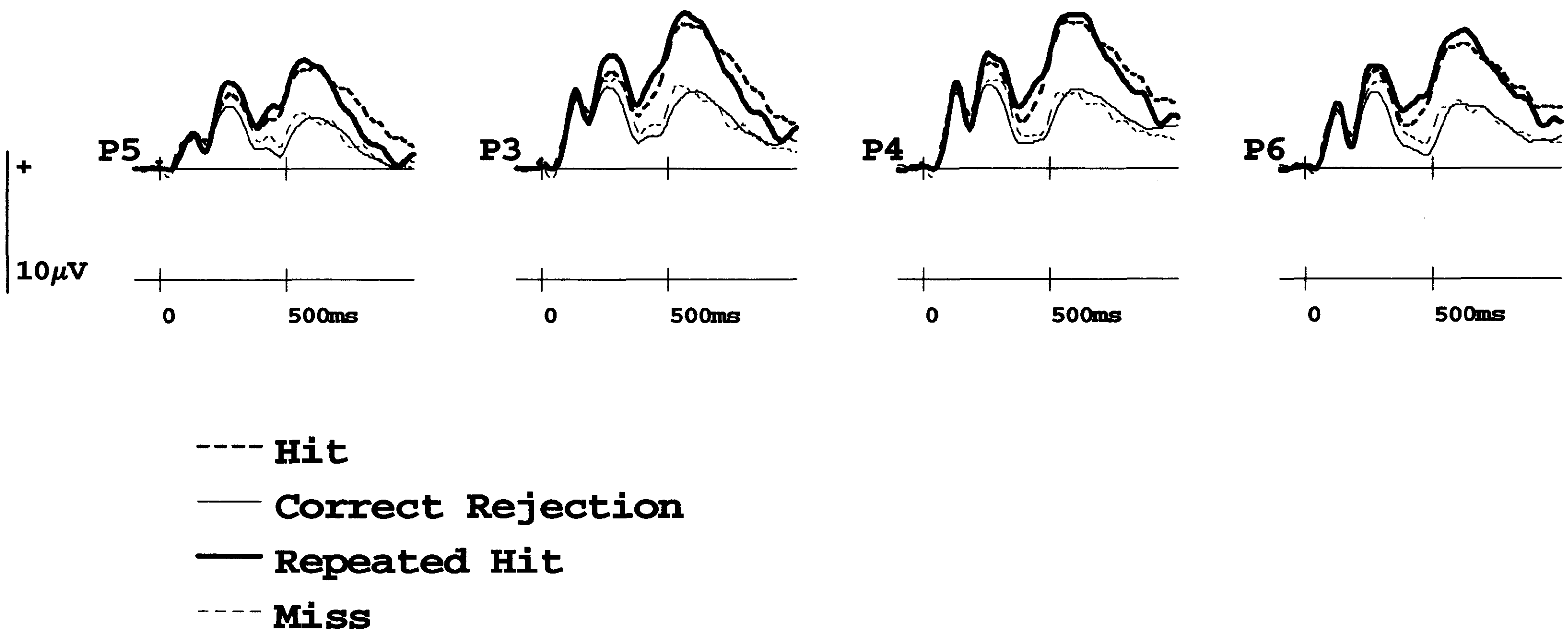


Figure 5.4. Scalp distributions of the ERP old/new effects for hits, misses and repeated hits in experiments 1 and 2. The data are shown for three post-stimulus epochs: 300-500, 500-800 and 800-1100 ms. The maps were computed from scores obtained by subtracting mean amplitudes from the ERPs evoked by correct rejections from hits, repeated hits and misses. The paired values below each map denote the maxima and minima of the amplitude differences between response categories, which can be interpreted relative to the colour bar at the foot of the figure.

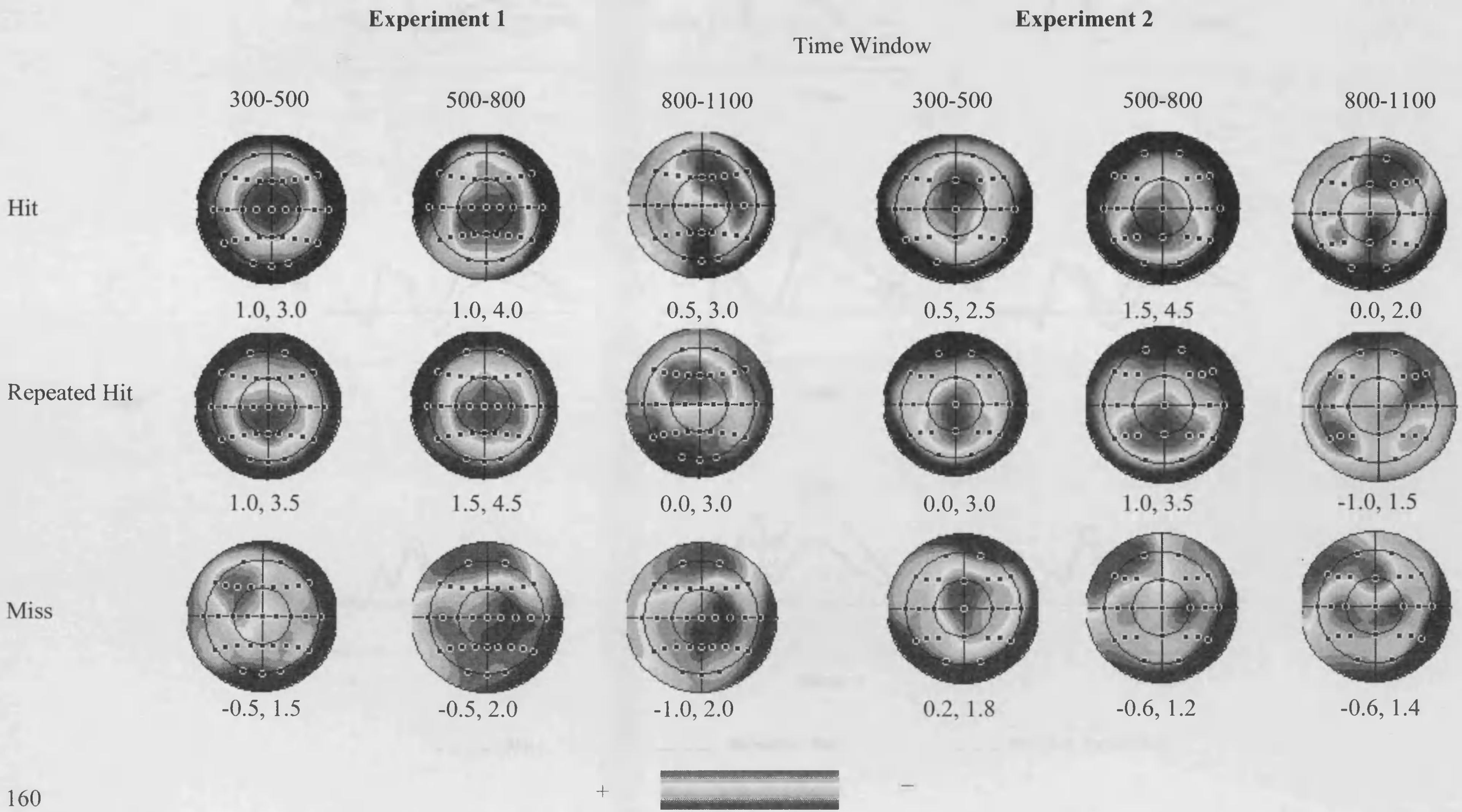


Figure 5.5. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at sites F3/F4, C3/C4, P3/P4, Fz, Cz and Pz in Experiment 2

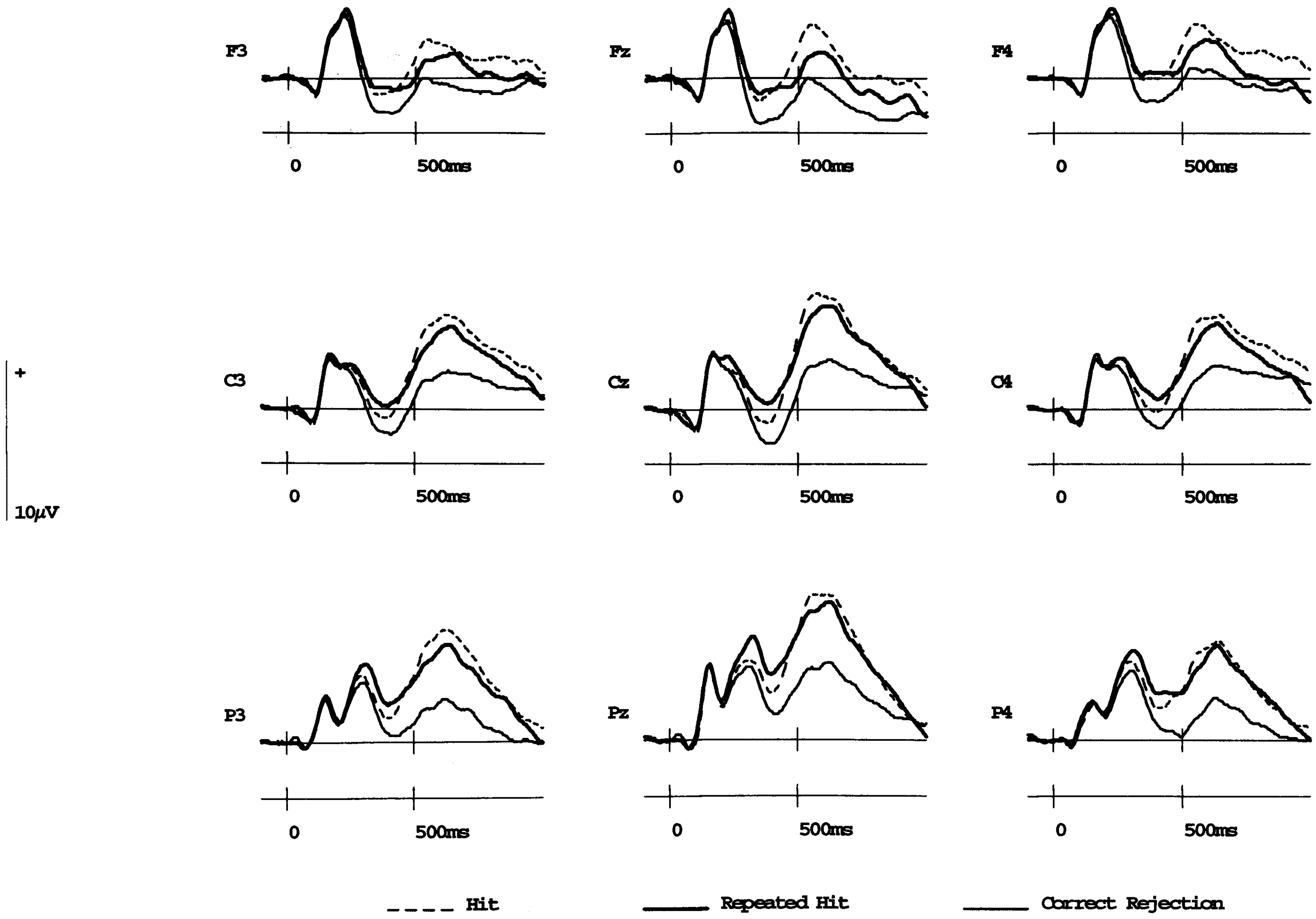


Figure 5.6. Grand averaged ERPs elicited by hits, misses, correct rejections and repeated hits at sites F3, Fz, F4, in Experiment 2.

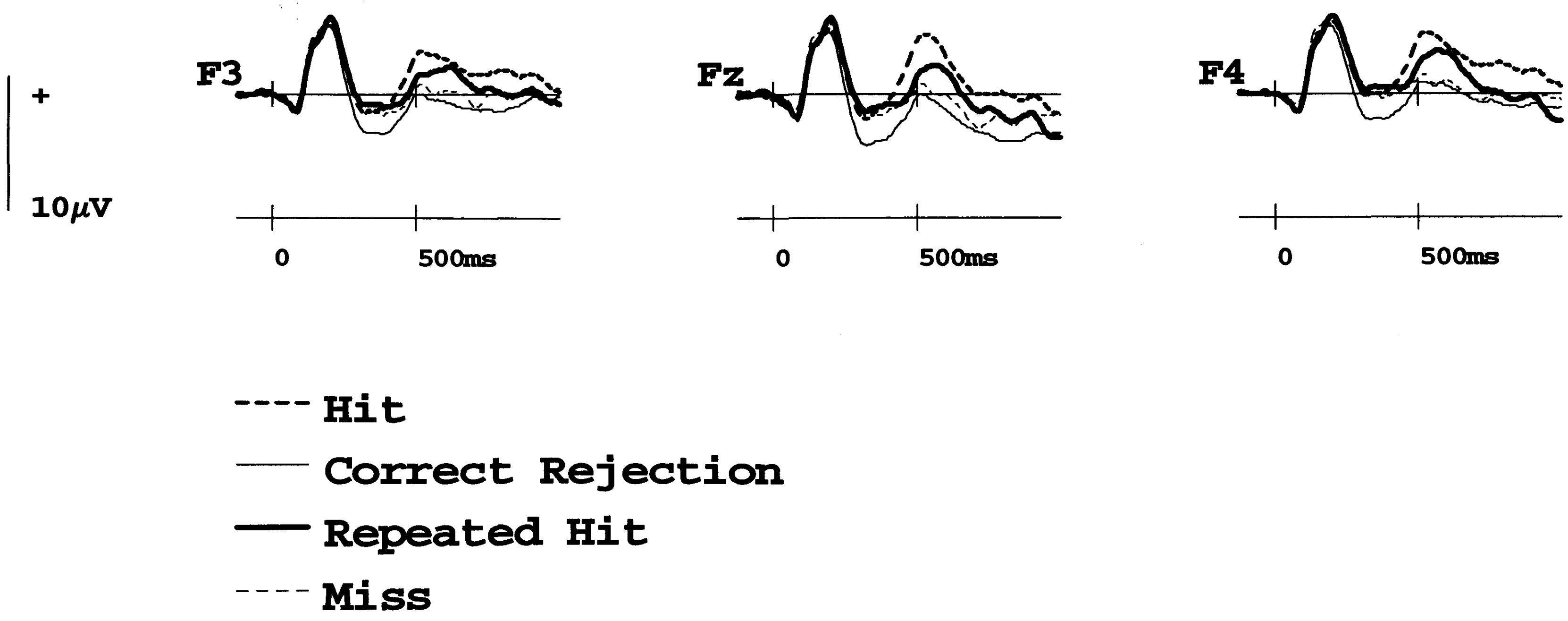


Figure 5.7. Grand averaged ERPs elicited by hits, misses, correct rejections and repeated hits at sites P3/4, P5/6, in Experiment 2.

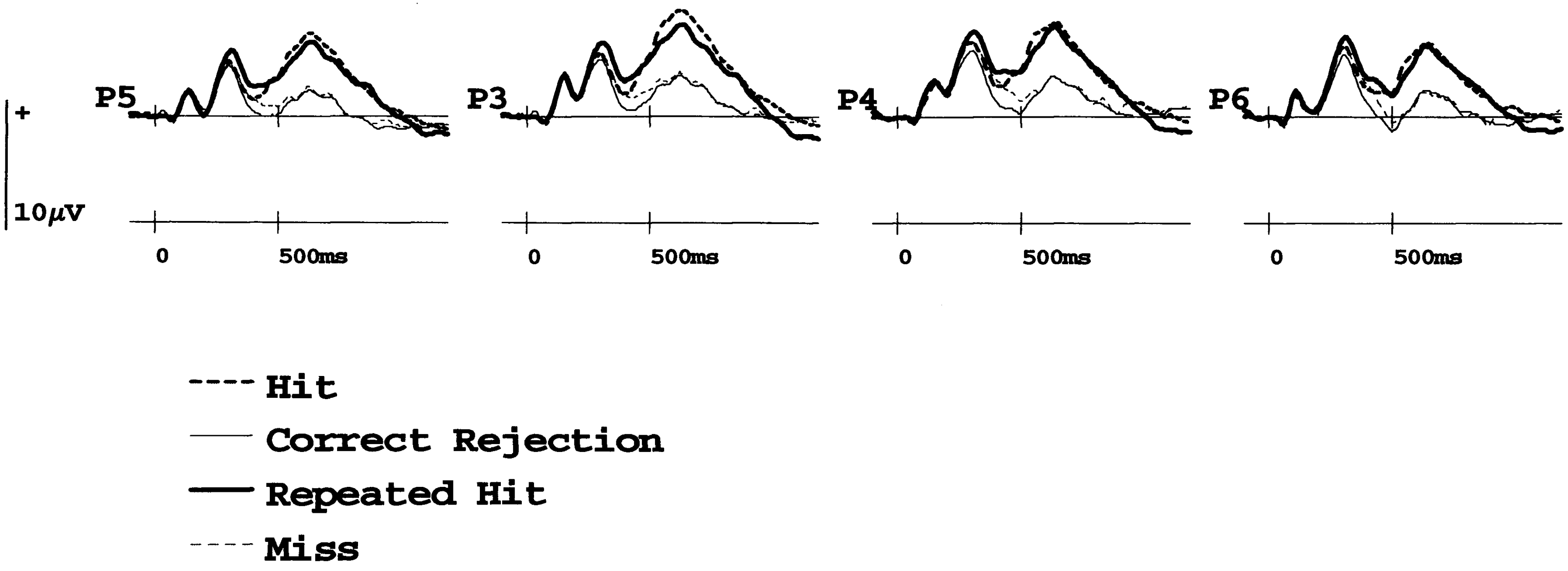
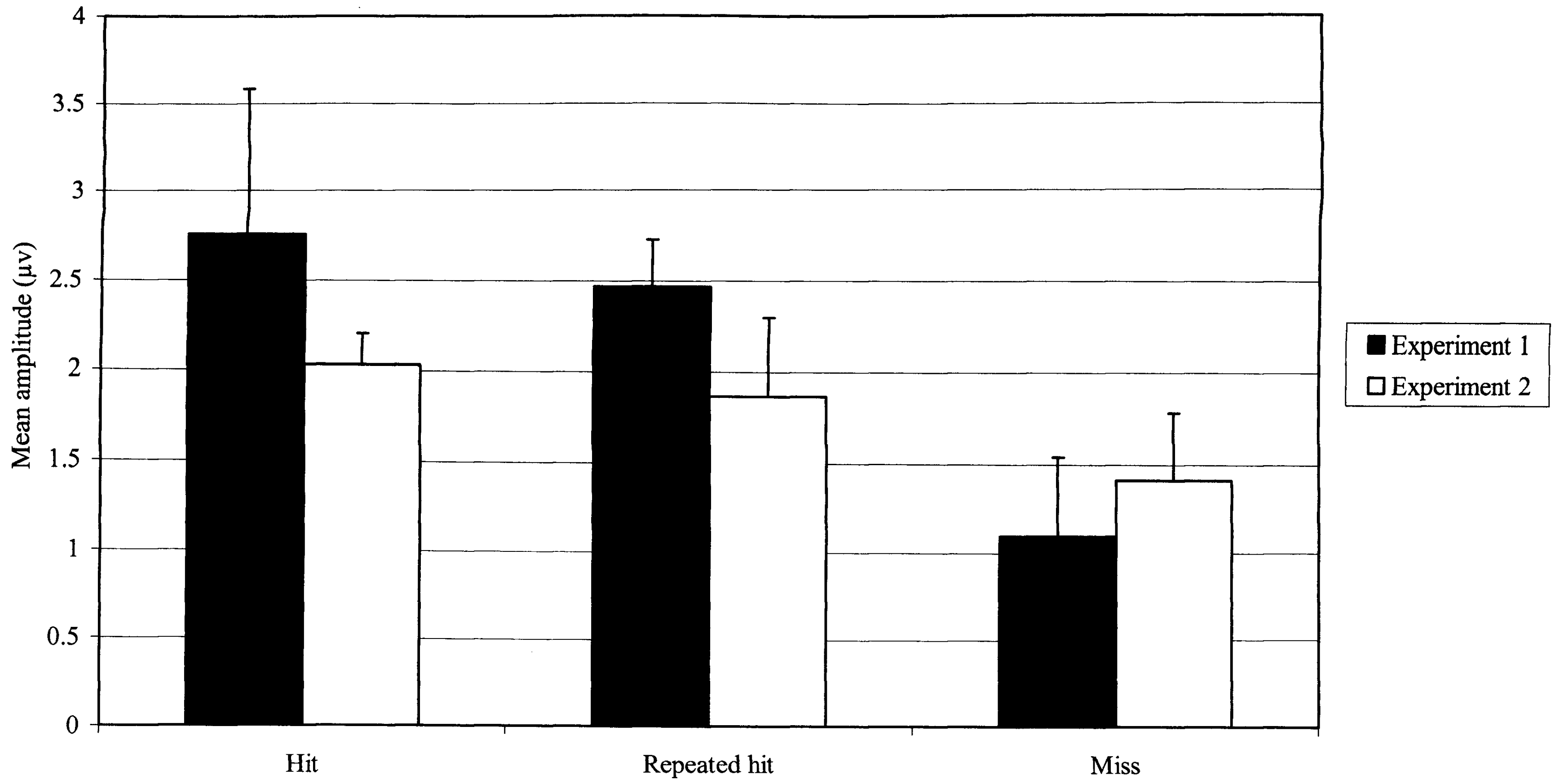


Figure 5.8. A bar graph of the mean amplitudes of the old/new effects for hits, misses and repeated hits across sites F3, Fz and F4 in the 300-500 ms time window in Experiments 1 and 2.



Chapter Six

Experiments 3 and 4

Introduction

In experiments 1 and 2 there were reliable parietal ERP old/new effects for both studied and repeated test items. Data inconsistent with these findings, however, comes from a series of experiments by Dywan and colleagues (Dywan, Segalowitz & Webster, 1998; Dywan, Segalowitz et al, 2001 and Dywan, Segalowitz & Arsenault 2002) in which they utilised the same variant of the exclusion task. Across all of the studies in which the participants were young adults, a left-parietal ERP old/new effect was observed for studied words (targets), whereas no reliable effect was detected for excluded repeated test items (non-targets). What is surprising about these data is that the extensive attenuation of the non-target left-parietal ERP old/new effect occurred even though mean accuracy for targets across studies (.58) was markedly lower than the level required in other studies in order to demonstrate a similar pattern of attenuation of non-target left-parietal effects (Herron & Rugg, 2003, Dzulkifli et al., 2005, 2006). These data suggest that target accuracy might not be the only factor influencing the strategy adopted by participants in this variant of the exclusion task, but as described below, there is also a more mundane explanation.

As outlined previously, the probability disparity across studies is one explanation for the differences between the parietal ERP findings in experiments 1 and 2 and those of Dywan et al. (1998, 2001, 2001). By this account, the greater relative positivity for repeated test words relative to new words in experiments 1 and 2, but not in the work of Dywan et al., is simply a consequence of a larger P300 elicited by this class of stimuli in experiments 1 and 2. The ratio of occurrence of studied and repeated test words is 2:1 in Experiments 1 and 2, and 1:1 in all of the Dywan et al. studies.

Experiment 3 was designed in order to assess whether the disparities between studied and repeated test word ERP old/new effects can be explained by P300 modulations. This was investigated by manipulating the probabilities of occurrence of studied and repeated test words to replicate the 1:1 ratio employed in the Dywan et al. studies, while maintaining all other aspects of the design of Experiment 2.

Experiment 4 was motivated by a need to formally assess the memorability of the repeated test items, as this is not possible from the data gained previously with the binary responses utilised in the paradigm when studied words are targets. Therefore, in Experiment 4 the target/non-target designation was reversed, with repeated test items designated as the targets. This evaluation is critical to the interpretations of the findings in this thesis as a key assumption is that the degree of attenuation of the parietal ERP old/new effects reflects the degree to which recollection of item information is controlled strategically. However, recollection of repeated test items might not always be necessary for successful task performance. In principle participants could mistakenly endorse a repeated test item as a new item and would make the same response as they would if they recollected information relating to the repeated test items. Under these circumstances, it is impossible to interpret unequivocally the ERP old/new effects obtained for the repeated test items in experiments 1 and 2 in terms of recollective processes. By gaining a formal assessment of the memorability of the repeated test items, reasonable inferences can be made about the levels of recollection obtained for these items across the remaining studies presented in this thesis.

Method

Due to the similarities between the designs of the two experiments, they are described jointly, with differences between the two noted where appropriate.

Participants

19 participants completed Experiment 3; the average age was 21 years (range 18 to 30). The data from 3 participants were discarded due to excessive EOG artefact (see General Methods for criteria). Of the remaining 16 participants, 14 were female. 18 participants completed Experiment 4; the average age was 20 years (range 18 to 23) and 13 participants were female. All were right-handed native English speakers. No participants were taking neuroleptic medication at the time of testing or reported a history of mental illness. All were paid at a rate of £7.50/hour and gave informed consent prior to commencing the experiments. No participant completed both experiments.

Stimuli and design

Stimuli were as for experiments 1 and 2 and were presented in the same manner. In Experiment 3, 400 critical words were split initially into eight equal groups of 50 words. One complete task list comprised two study-test cycles. There were 70 words in each study cycle; one complete study list and 20 fillers selected at random from a second list. The fillers were presented only at study. There were 150 words in each test cycle; 50 words presented at study, 50 unstudied (new) words and a further 50 new words which were repeated once after 7-9 intervening words. The numbers of words re-presented after lags 7, 8 and 9 were approximately equal within blocks and equated across blocks. In addition, 5 fillers were placed towards the end of each test list in each cycle in order to ensure that the final repeating words fell within the 7-9 word repeat interval. No words appeared in both study-test cycles. The groups of words were rotated across study and test lists so that, across complete task lists, all words were presented at study as well as at test, at test only, at test only and repeated during test, and also served as fillers at study only. This procedure resulted in the preparation of eight complete task lists. In total, participants saw 70 stimuli in each study phase and 205 stimuli in each test phase.

In Experiment 4, each task list contained the same number of stimuli as in Experiment 3. There were, however, only 320 critical words. These were split randomly into six groups of 50 words and one group of 20 filler words. These fillers were the 20 words that appeared in each of the two study lists and which were not repeated at test. Three lists were assigned randomly to the first study-test cycle, and the remainder to the second cycle. This was the only design difference across the two experiments. Rotating words across study and test lists so that all words appeared at study as well as at test, at test once only, and at test twice, across the two study-test cycles resulted in the creation of six complete task lists. The total number of stimuli seen by participants was the same as in Experiment 3. To reiterate: the difference across experiments was restricted to the numbers of fillers employed.

Procedure

In each study phase, participants completed one encoding task for all words. For both experiments they were asked to read each word aloud. For all participants an asterisk before study words initiated each study trial and remained on the screen for 1000 ms. The screen was then blanked (100 ms) before the study word was presented for 300 ms. Participants were asked to give their response after the study word appeared. The next trial started 2500 ms after the study word was presented.

In both experiments each test trial started with a fixation asterisk (500 ms duration), which was removed from the screen 100 ms prior to presentation of a test word (300 ms duration). The screen was then blanked until the participant responded, and the next trial started 1000 ms after the response. For each test phase in Experiment 3, participants responded with one hand to words that were seen at study ('old words'), and with the other to unstudied test words ('new words') or unstudied test words which repeated during the test phase ('repeated test words'). In Experiment 4 participants responded with one hand to words that were seen at study ('old words') and unstudied test words ('new words') and with the other to unstudied test words which repeated during the test phase ('repeated test words'). Responses were made on a key-pad with the left and right thumbs. The hands required for the binary test judgment were also balanced across participants and all participants were encouraged to respond quickly and accurately. Responses slower than 4000 ms and faster than 300 ms were regarded as errors and were discarded from behavioural and ERP analyses. An average of < 2% of trials per participant were excluded due to this criterion.

ERP acquisition

EEG was recorded as per Experiment 2, with the same acquisition rate, electrode montage, off-line processing stages and exclusion/inclusion criteria.

Results

Behavioural data

Table 6.1 displays the probabilities of correct and incorrect responses to each class of test word. As per the first two experiments, two measures of discrimination (Pr: Snodgrass & Corwin, 1988) were calculated. The first was computed to determine whether participants were able to distinguish between old and new words (p(hit)-p(FA)). The second was computed to determine whether participants were able to distinguish between old words and repeated test words (p(hit) - p(rFA)).

For experiment 3, both Pr values were reliably greater than 0 (Pr values = 0.53 and 0.52: $t(15) = 11.63$, $p<.001$ and $t(15) = 11.90$, $p<.001$), and these two Pr scores did not differ reliably from each other ($p>.05$). For the discrimination involving new words, the mean value of Br (Br = p(FA)/(1-Pr)) was 0.18, while Br for the discrimination involving repeated test words was 0.21. Br scores did not differ reliably from each other, with the values in each case indicating a conservative bias, with participants more likely to make a new than an old response when uncertain (Snodgrass & Corwin, 1988). A one-way ANOVA on the RTs for correct responses (see Table 6.1) revealed no significant differences between response categories.

Table 6.1. Probabilities of correct (p(correct)) and incorrect (p(incorrect)) responses and reaction times in milliseconds (RT) to old, new and repeated test words in experiments 3 and 4.

		Word class		
		Old	New	Repeated Test
Exp. 3	p(correct)	0.62 (0.16)	0.91 (0.12)	0.90 (0.08)
	RT	948 (414)	914 (403)	853 (366)
	p(incorrect)	0.38 (0.16)	0.09 (0.12)	0.10 (0.08)
	RT	980 (368)	1283 (599)	950 (392)
Exp. 4	p(correct)	0.84 (0.08)	0.97 (0.02)	0.82 (0.08)
	RT	899 (300)	775 (225)	874 (217)
	p(incorrect)	0.16 (0.08)	0.03 (0.02)	0.18 (0.08)
	RT	1078 (206)	982 (321)	874 (193)

In Experiment 4, both Pr values were also reliably greater than 0 (Pr values = 0.81 and 0.66: t(17) = 38.70 , p<.001 and t(17) = 33.46, p<.001) and these two Pr scores differed reliably from each other (p>.05). The differences in Pr scores occurred because of superior discrimination between old and repeated test words. Br for the discrimination involving new words was 0.15, whilst Br for the discrimination involving repeated test words was 0.51. Br scores differed reliably from each other (t(17) = 9.45, p<.001), with the values in each case indicating a greater likelihood of participants making a new than an old response when uncertain.

A one-way ANOVA on the RTs for correct responses in Experiment 4 revealed a significant difference between word class (F(1.7,29.6) = 28.48, p<.001). This was because the responses to correctly identified new words were quicker than those for correctly identified old and repeated test words (t(17) = 65.47, p<.001 and t(17) = 38.59, p<.001 respectively). There were no differences in response times for correctly identified old and repeated test words.

ERP data

As for experiments 1 and 2, baseline corrected averaged ERPs (100 ms pre-stimulus baseline) were formed for correctly identified old words (hits), incorrectly identified old words (misses), new words (correct rejections) and new repeated words (repeated hits) in Experiment 3 and were analysed for the 16 participants who contributed sufficient artefact-free trials to these critical response categories. Mean trial numbers for these response categories were 50 (range 22-84), 34 (range 16-53), 158 (range 87-204) and 74 (range 31-94), respectively. For Experiment 4, too few participants made sufficient (16 or more) incorrect judgments to old words (4 participants only) to permit analysis of the ERP data for this response category. Therefore baseline corrected averaged ERPs (100 ms pre-stimulus baseline) were formed for correctly identified old words (hits), new words (correct rejections) and repeated test words (repeated hits) and were analysed for the 18 participants who contributed sufficient artefact-free trials to these critical response categories. Mean trial numbers for these response categories were 47 (range 20-66), 116 (range 47-145) and 57 (range 23-69).

The ERP data were analysed over the same three time windows as for experiments 1 and 2, and two sets of analyses were completed using the same parameters as for the earlier experiments (see details of Midline and Global analyses in Chapter 5). The initial set of analyses was conducted involving the ERP data for correct responses to old, new and repeated test words. Significant effects involving category were again followed up by all possible paired contrasts between the three response categories. For the analyses of data including lateral scalp locations, interactions with the AP and/or HM dimension were followed up by analyses at each level of the relevant factor.

As for the initial experiments, two additional directed analyses were conducted; the first was carried out to consider changes in the mid-frontal ERP old/new effect across the experimental conditions and how these might relate to the hypothesis that at anterior sites near the midline in the 300-500 ms post-stimulus epoch, ERPs are sensitive to item familiarity (Curran, Tepe, & Piatt, 2006; Rugg et al., 1998). The analysis was carried out in the 300-500 ms time window, utilising data from F3, Fz, and F4 only, and included the factors of category and site. The second directed analysis addressed directly any possible changes in the magnitude of the left-parietal ERP old/new effects due to the experimental manipulation, included factors of category, hemisphere, and site (four levels: P3, P4, P5, P6), and was completed over the 500-800 ms time window. For Experiment 3 these analyses were conducted on data for incorrect responses to old words and correct responses to all three word classes, whereas for Experiment 4 they were conducted only on data for correct responses to each word class.

Experiment 3

Hits, correct rejections and repeated hits

Figure 6.1 is relevant to the following statistical analysis and shows the ERPs elicited by hits, correct rejections and repeated hits at electrode sites F3/F4, C3/C4, P3/P4, Fz, Cz and Pz. The figure shows that, from approximately 300 ms onwards, the ERPs elicited by hits and repeated hits are more positive-going than those elicited by correct rejections. There is a greater positivity for repeated hits than for hits which onsets early in the epoch at posterior and central sites and is maximal over posterior parietal sites. This difference attenuates at posterior sites from approximately 500-700 ms, after which hits become more positive-going. At anterior sites from approximately 400 ms to the end of the recording epoch, repeated hits and hits also differentiate, with hits being more positive-going than repeated hits, and this pattern of data becomes evident approximately 100 ms later at central electrode sites.

300-500 ms:

Midline analyses:

The initial midline analysis revealed a main effect of category ($F(1.8, 27.2) = 7.25$, $p<.001$). The follow-up analyses comprised all possible paired contrasts of the three categories, and these revealed a significant old/new effect for hits ($F(1,15) = 12.39$, $p<.01$). There were no significant effects for the contrast between hits and repeated hits. The final contrast revealed that the ERPs evoked by repeated hits were reliably more positively going than those elicited by correct rejections ($F(1,15) = 7.46$, $p<.05$), with an interaction between condition and site ($F(1.3, 18.8) = 5.51$, $p<.05$) which reflected the fact that the greater relative positivity for repeated hits was maximal at Pz.

Global analyses:

The second set of analyses for this time window including the data from lateral scalp locations revealed a main effect of category ($F(1.6, 24.7) = 12.57$, $p<.001$), as well as an interaction between category and site ($F(1.9, 28.7) = 14.76$, $p<0.001$). The follow up analyses comprised all possible paired contrasts of the three categories and are shown in Table 6.2.

The contrast between hits and correct rejections revealed an interaction between category and site, which came about because the greater relative positivity for hits is smallest at inferior sites. For the contrast between repeated hits and correct rejections, there was also a significant interaction between category and site, which reflected the fact that the greater relative positivity for repeated hits was largest at midline sites.

Table 6.2. The outcomes of the paired contrasts between the mean amplitudes associated with hits, correct rejections and repeated hits for the <u>global</u> analyses over the 300-500, 500-800 and 800-1100 ms time windows. CR = correct rejection, RHit = repeated hit, CC = condition, HM = hemisphere, AP = anterior/posterior plane, SI = site, df = degrees of freedom. *** = p <.001, ** = p <.01, * = p <.05, • = p <.1, ns = non-significant. Epsilon values are shown in brackets and in lower case.

	df	Hit vs CR	CR vs RHit	Hit vs RHit
300-500 ms				
CC	1,15	15.03***	33.09***	ns
CC x SI	2,30	$16.11_{(.57)}$***	$34.21_{(.64)}$***	ns
CC x HM x SI	4,60	ns	ns	$4.46_{(.60)}$*
500-800 ms				
CC	1,15	33.57***	19.40***	4.69*
CC x SI	2,30	$39.89_{(.63)}$***	$10.86_{(.59)}$***	$8.35_{(.54)}$**
CC x AP	2,30	ns	$9.22_{(.58)}$**	ns
800-1100 ms				
CC	1,15	32.03***	22.73***	ns
CC x SI	2,30	$23.27_{(.57)}$**	$13.11_{(.60)}$***	ns
CC x AP x SI	4,60	$5.55_{(.70)}$**	ns	ns

For the hits versus repeated hits contrast there was a three-way interaction between category, AP and HM. Further analysis at each of the two levels of the HM factor revealed a significant interaction between category and AP over the left hemisphere only ($F(1.2, 17.6) = 2.97$, $p<.05$). This is because the greater relative positivity for hits is more pronounced at anterior than at posterior locations.

500-800 ms:

Midline analyses:

The initial midline analysis revealed a main effect of category ($F(1.6, 24.6) = 11.75$, $p<.001$). The follow-up analyses revealed that the ERPs evoked by hits were reliably more positive-going than those elicited by correct rejections ($F(1,15) = 43.00$, $p<.001$) and repeated hits ($F(1,15) = 6.06$, $p<.05$). The final contrast between repeated hits and correct rejections revealed a significant interaction between category and site, which came about because the greater positivity for hits is largest at Pz.

Global analyses:

The second set of analyses for this time window revealed a main effect of category ($F(1.7, 25.4) = 17.78$, $p<.001$), as well as an interaction between category and site ($F(2.1, 31.8) = 18.85$, $p<.001$). The follow-up contrasts (shown in the middle portion of Table 6.2) revealed that for hits and correct rejections there was an interaction between category and site ($F(1.2, 18.0) = 39.89$, $p<.001$), indicating that the greater relative positivity for hits is most pronounced at midline sites.

For the contrast between correct rejections and repeated hits, there were interactions between category and AP, and category and site, because the relatively greater positivity for repeated hits was largest at parietal and midline sites. The final contrast revealed that hits were more positive-going than repeated hits ($F(1,15) = 4.69$, $p<.05$), and an interaction between category and site reflected the fact that the greatest relative positivity for hits was at midline sites.

800-1100 ms:

Midline analyses:

The initial analysis revealed a main effect of category ($F(1.8, 27.3) = 9.03$, $p <.001$). The follow-up analyses revealed that the ERPs evoked by hits were reliably more positive-going than those elicited by correct rejections ($F(1,15) = 15.60$, $p <.001$) and repeated hits ($F(1,15) = 9.91$, $p<.01$).

Global analyses:

The second set of analyses for this time window revealed a main effect of category ($F(2.0, 29.7) = 18.56$, $p<.001$), as well as an interaction between category and site ($F(2.4, 35.4) = 12.60$, $p<.001$). For the follow-up contrasts (shown in the lower portion of Table 6.2), there was a three-way interaction between category, AP and site in the contrast between hits and correct rejections. Further analysis at each of the three levels of the AP factor showed a relatively greater positivity for hits at all three levels (frontal: $F(1,15) = 19.78$, $p<.001$, central: $F(1,15) = 28.20$, $p<.001$ and parietal $F(1,15) = 21.24$, $p<.001$). There was a condition by site interaction for central sites only ($F(2.0, 29.6) = 5.09$, $p<.001$) which reflects the fact that the greater relative positivity for hits is largest at sites closest to the midline. The contrast between hits and repeated hits revealed an interaction between category and site, because the greater relative positivity for hits is smallest at inferior sites. There were no significant effects revealed in the contrast between repeated hits and correct rejections.

Mid-frontal ERP old/new effects:

As for experiments 1 and 2, in order to further investigate the mid-frontal old/new effect, an additional directed analysis was conducted. Figure 6.2 is relevant to the following statistical analyses and shows the ERPs elicited by the four critical classes of items at electrode sites F3, Fz and F4. The figure shows that from approximately 300 ms hits are more positive-going than all other classes of item. Repeated hits are also more positive-going than misses and correct rejections, with misses being more positive-going than correct rejections. This pattern of differences continues until approximately 500 ms when the differences between misses and correct rejections become minimal.

The analyses revealed a main effect of category only ($F(2.2, 33.0) = 5.39$, $p<.01$). Paired contrasts within the experiment demonstrated old/new effects for hits ($F(1,15) = 6.46$, $p<.05$) as well as repeated hits ($F(1,15) = 9.94$, $p<.01$). An interaction between category and site ($F(1.9, 29.1) = 3.86$, $p<.05$) reflected the fact that the old/new effect for hits was maximal at Fz. The distributions of these two ERP old/new effects are shown in Figure 6.3, which shows topographic maps illustrating the scalp distributions of the differences between activity evoked by hits and repeated hits and that evoked by correct rejections over the 300-500 ms time window. It is worth noting that the old/new effects for repeated test items and misses both show more centro-parietal maxima than that exhibited by the studied items. One possible reason for this broad distribution is that fact that two distinct processes (with fronto-central and parietal maxima respectively) may be indexed in these contrasts (Rugg et al, 1998). This issue will be returned to in the mid-frontal ERP old/new effect section of the Discussion.

There were no significant effects for the contrasts between both classes of hits and misses, and between hits and repeated hits. There was an interaction between category and site for the contrast between misses and correct rejections ($F(1.8, 26.5) = 4.42$, $p<.05$), which came about because of the greater relative positivity for misses than for correct rejections at Fz but not at F3 and F4. The pattern of differences between the old/new effects for the three classes of items at these mid-frontal electrodes is similar to that in experiments 1 and 2 (see Figure 6.5 for a bar graph showing old/new effects for hits, repeated hits and misses at mid-frontal electrodes, and compare to Figure 5.8 in Chapter 5) See also Figure 10.1 in the General Discussion.

Left-parietal ERP old/new effects:

To further investigate the parietal old/new effects, an additional directed analysis was conducted. This involved the mean amplitudes for hits, misses, repeated hits and correct rejections at P3, P5, P4 and P6 in the 500-800 ms time window. Figure 6.4 is relevant to the following statistical analyses and shows the ERPs elicited by the four classes of items at electrode sites P3/4 and P5/6. The figure shows that in the critical 500-800 ms time window hits and repeated hits are equally more positive-going than misses and correct rejections, with minimal differences between these latter categories.

The initital analyses revealed a main effect of category ($F(2.0, 30.7) = 17.68$, $p<.001$). This was followed up by all possible paired contrasts, and the outcomes of these show that the ERPs evoked by hits and repeated hits were reliably more positive-going than those evoked by correct rejections (hits: $F(1,15) = 59.85$, $p<.001$ and repeated hits: $F(1,15) = 22.67$, $p<.001$) and by misses (hits: $F(1,15) = 23.43$, $p<.001$ and repeated hits: $F(1,15) = 9.34$, $p<.01$). The greater positivity for both classes of old words relative to new is further illustrated in Figure 6.3, which shows topographic maps of the differences in scalp activity between hits and repeated hits respectively against correct rejections, and demonstrate clearly some degree of left hemisphere lateralisation for both old/new effects, although this was not borne out by the statistical analyses. The contrasts between the ERPs evoked by misses and by correct rejections, and by hits and repeated hits revealed no reliable effects over this time window at these posterior locations.

Experiment 4: The statistical outcomes for this experiment are described before the outcomes in Experiment 3 are discussed. In Experiment 4, repeated hits are targets, and studied words are non-targets; the reverse from the target/non-target designation in previous experiments, (as well as subsequent) in this thesis.

Hits, correct rejections and repeated hits

Figure 6.6 is relevant to the following statistical analysis and shows the ERPs elicited by hits, correct rejections and repeated hits at electrode sites F3/F4, C3/C4, P3/P4, Fz, Cz and Pz. The figure shows that from approximately 300 ms onwards the ERPs elicited by targets are more positive-going than those elicited by non-targets and new items. This relatively greater positivity peaks at 600 ms and by the end of the recording epoch has attenuated with non-targets becoming marginally more positive-going, particularly at central and posterior midline sites. The old/new effect for non-targets is relatively small in magnitude from 300 ms until 600 ms where non-targets become more positive-going, particularly at central and right frontal sites.

300-500 ms:

Midline analyses:

The initial midline analysis revealed a main effect of category ($F(1.4, 24.5) = 10.76$, $p<.001$). The follow-up analyses revealed that the ERPs evoked by hits and repeated hits were reliably more positive-going than those elicited by correct rejections ($F(1,17) = 7.15$, $p<.05$ and $F(1,17) = 15.16$, $p<.001$, respectively). ERPs evoked by repeated hits were also more positive-going than those elicited by hits ($F(1,17) = 6.95$, $p<.05$).

Global analyses:

The second set of analyses for this time window including the data from lateral scalp locations revealed a main effect of category ($F(1.6, 27.2) = 14.28$, $p<.001$), as well as an interaction between category and site ($F(1.5, 26.1) = 6.66$, $p<0.01$). The follow-up analyses comprised all possible paired contrasts of the three categories and the results are shown in Table 6.3. As for previous comparable tables, only those terms for which outcomes were reliable in at least one paired contrast are shown.

Table 6.3. The outcomes of the paired contrasts between the mean amplitudes associated with hits, correct rejections and repeated hits for the global analyses over the 300-500, 500-800 and 800-1100 ms time windows. Nomenclature as for Table 5.2, page 137.

	df	RHit vs CR	RHit vs Hit	CR vs Hit
300-500 ms				
CC	1,17	24.73***	6.92*	10.15**
CC x SI	2,34	$9.73_{(.53)}$***	ns	$7.18_{(.67)}$**
CC x AP	2,34	$6.52_{(.79)}$**	ns	ns
500-800 ms				
CC	1,17	39.01***	32.26***	ns
CC x SI	2,34	$39.83_{(.54)}$***	$31.16_{(.56)}$***	$5.67_{(.65)}$*
800-1100 ms				
CC	1,17	10.10**	ns	11.53**

The contrast between repeated hits and correct rejections revealed an interaction between category and site, which was due to the relatively greater positivity for repeated hits being largest at sites closest to the midline. There was also an interaction between category and AP, which reflected the fact that the old/new effects were largest at central sites. Repeated hits were also more positive-going than hits in this time window. For the contrast between hits and correct rejections there was a significant interaction between category and site which reflected the fact that the relatively greater positivity for hits was largest at midline sites.

500-800 ms:

Midline analyses:

The initial midline analysis revealed a main effect of category ($F(1.3, 22.5) = 35.78$, $p<.001$). The follow-up analyses revealed ERP old/new effects for hits and repeated hits ($F(1,17) = 8.42$, $p<.01$ and $F(1,17) = 43.58$, $p<.001$, respectively). Repeated hits were also reliably more positive-going than hits ($F(1,17) = 33.18$, $p<.001$).

Global analyses:

The second set of analyses for this time window revealed a main effect of category ($F(1.5, 25.0) = 31.19$, $p<.001$), as well as an interaction between category and site ($F(1.6, 27.0) = 31.65$, $p<.001$). The follow up paired contrast results are shown in Table 6.3.

The contrast between repeated hits and correct rejections revealed an interaction between category and site which was due to the relative greater positivity for repeated hits being largest at midline sites. For the contrast between correct rejections and hits there was an interaction between category and site because of the relative greater positivity for hits at midline sites. The final contrast between hits and repeated hits revealed an interaction between category and site that came about because the relatively greater positivity for repeated hits was maximal at midline sites.

800-1100 ms:

Midline analyses:

The initial analysis revealed no significant effects; no follow-up analyses were conducted.

Global analyses:

The second set of analyses for this time window revealed a main effect of category ($F(1.4, 23.4) = 7.34$, $p<.01$). The follow-up contrast results are shown in Table 6.3. These revealed reliable positive-going old/new effects for hits and repeated hits. There were no significant effects in the contrast between hits and repeated hits.

Mid-frontal ERP old/new effects:

The directed analysis of the mid-frontal ERP old/new effects involved the mean amplitudes for hits, repeated hits and correct rejections at F3, Fz and F4 in the 300-500 ms time window. Figure 6.7 is relevant to the following statistical analyses and shows the ERPs elicited by the three classes of items at these electrode sites. The figure shows that from approximately 300 ms repeated hits are more positive-going than hits and correct rejections, with minimal differences between hits and correct rejections. This differentiation at frontal sites continues throughout the recording epoch.

The analyses revealed a main effect of category only ($F(1.7, 28.3) = 14.25, p<.001$). Paired contrasts within the experiment demonstrated that hits ($F(1,17) = 5.80, p<.05$) as well as repeated hits ($F(1,17) = 20.03, p<.001$) were both more positive-going than correct rejections at these mid-frontal electrode sites. Repeated hits were also more positive-going than hits ($F(1,17) = 11.42, p<.005$) with this relative greater positivity maximal at Fz ($F(2.0, 33.4) = 3.70, p<.05$). This can clearly be seen in Figure 6.3, which shows a topographic map illustrating the scalp distribution of the differences between activity evoked by repeated hits and that evoked by hits over the 300-500 ms time window.

Left-parietal ERP old/new effects:

The parietal old/new effects directed analysis involved the mean amplitudes for hits, repeated hits and correct rejections at P3, P5, P4 and P6 in the 500-800 ms time window. Figure 6.8 is relevant to the following statistical analyses and shows the ERPs elicited by the three classes of items at electrode sites P3/4 and P5/6. The figure shows that in the critical 500-800 ms time window repeated hits are more positive-going than hits and correct rejections, with minimal differences between hits and correct rejections. This greater relative positivity for repeated hits is maximal at P3/4.

The further analysis revealed a main effect of category ($F(1.4, 24.0) = 31.69$, $p <.001$). This was followed up by all possible paired contrasts, and the outcomes of these showed that ERPs evoked by repeated hits were reliably more positive-going than those evoked by correct rejections ($F(1,17) = 39.76$, $p<.001$) and this relative greater positivity was maximal at midline sites ($F(2.1, 35.7) = 5.04$, $p<.05$). The greater positivity for repeated hits relative to correct rejections is illustrated in Figure 6.3 (right-hand lower panel) which shows a topographic map of the differences in scalp activity between repeated hits and correct rejections, and demonstrates clearly that the difference between the two conditions is maximal over central scalp regions. Repeated hits were also reliably more positive-going than hits ($F(1,17) = 31.38$, $p<.001$). The contrast between the ERPs evoked by hits and by correct rejections revealed no reliable effects over this time window.

Discussion

For experiments 1 and 2 parietally distributed ERP old/new effects were observed for correct responses to both studied and repeated test words. This is in stark contrast to the findings of Dywan et al. (1998, 2001, 2002) who utilised the same paradigm. Within the three publications of Dywan and colleagues there is little evidence for a relatively greater positivity for correct responses to repeated test words in comparison to correct rejections at parietal locations in the 500-800 ms time window.

One account for the disparities across studies arises from the fact that, in experiments 1 and 2, the ratio of studied words to repeated test words was 2:1, in comparison to the 1:1 ratio in the studies of Dywan et al. This item imbalance is relevant because of the P300 ERP component. The P300 (P3b) potential is particularly sensitive to the relative probabilities of classes of stimuli, as well as their task-relevance (Donchin & Coles, 1988; Polich, 2007). By this account, the greater relative positivity for repeated test words relative to new words in experiments 1 and 2 but not in the work of Dywan et al. is simply a consequence of a larger P300 being elicited by the repeated test words in experiments 1 and 2 (see data for Pz shown in Figures 5.1 and 5.7 in Chapter 5).

The motivation for Experiment 3 was to assess the impact on the left-parietal ERP old/new effects for hits and repeated hits of changing the probabilities of occurrence of these items to match the 1:1 ratio in the Dywan et al. studies. In the following sections there will be a discussion of the ERP findings of differences according to condition in the 300-500 ms time window and how these are relevant to the functional interpretation of the mid-frontal ERP old/new effect. This will be preceded by a discussion of the critical behavioural and ERP experimental findings relevant to the principal focus in these two experiments: the left-parietal ERP old/new effects that were obtained

Left-parietal ERP old/new effects

The 500-800 ms epoch is one in which left-parietal ERP old/new effects are typically assessed (Friedman & Johnson, 2000; Mecklinger, 2000; Wilding & Sharpe, 2003), and in this time wndow the directed analyses showed reliable ERP old/new effects for targets in both experiments, and for non-targets in Experiment 3 only (cf. Bridson, Fraser, Herron, & Wilding, 2006). Targets were denoted as studied words in Experiment 3, and as repeated test words in Experiment 4. There was a trend for the left-parietal ERP old/new effect for targets in Experiment 3 to be larger than the effect for non-targets.

The pattern of data obtained in Experiment 3 is the same as that obtained in experiments 1 and 2, and if the magnitude of left-parietal ERP old/new effects is an index of the extent to which recollection was engaged, then the findings are consistent with the view that participants did not prioritise recollection of studied words over repeated test words any more so in Experiment 3 than they did in experiments 1 and 2.

The change in the probability of occurrence of the repeated test words relative to studied words to match that used in the Dywan et al. studies did not, therefore, attenuate the parietal ERP old/new effect for the repeated test items. These findings lead to the conclusion that the disparity in findings across studies is most likely not due to a probability imbalance, which might have led to a relatively greater contribution of the P300 to parietal old/new effects for repeated test items in experiments 1 and 2 than in the studies reported by Dywan et al. (1998, 2001, 2002).

This conclusion draws added support from the fact that, at posterior scalp locations in Experiment 3 there was some degree of left hemisphere lateralisation for both old/new effects, (illustrated in Figure 6.3) although this was statistically reliable. In so far as the left-parietal ERP old/new effect has a left hemisphere bias that is not characteristic of the P300 (Azimian-Faridani & Wilding, 2006: Rugg & Allan, 2000), then the data are inconsistent with a P300 probability imbalance account.

There are two additional and compelling reasons, moreover, for rejecting the response probability account of the data. First, ERP old/new effects for words encoded in the same task employed here (read aloud) have been reported in exclusion tasks where the words encoded under these conditions were designated as targets, but the proportions of targets, non-targets and new test words were equal (Herron & Rugg, 2003b).

Second, Herron et al. (2003) conducted an ERP study in which old/new recognition memory judgments were required, and where, across blocks, the ratios of new to old test items were 3:1, 1:1, and 1:3. Over the 500-800 ms period at left-parietal scalp sites, the positive-going ERP old/new effects that were obtained were of equal magnitude across these different ratios of old and new words. The 1:3 old/new ratio is directly comparable to the ratio of targets to the other (combined) classes of test stimuli in experiments 1 and 2 (for prior work relevant to the invariance of parietal old/new effects across other rations of old and new test items, see Friedman, 1990; Rugg & Nagy, 1989; Smith & Guster, 1993). These observations argue against a response probability account of the data in these experiments, and further support for this view stems from the fact that qualitatively similar findings to those in Experiment 3 were found in experiments 1 and 2 where studied words designated as targets comprised 40% of the test stimuli (see Chapter 5). The remaining possible reasons behind the disparities between the findings in experiments 1, 2 and 3 and those of Dywan et al. (1998, 2001, 2002) will be returned to later.

Target accuracy

By virtue of having the repeated test items as targets the mean level of target accuracy for Experiment 4 (0.82) was higher than in any case when studied words were targets (see the previous three experiments). This is most likely due to the shorter lag between first and second presentations of the repeated test items compared to the studied items. This experiment is also unlike the previous three in that, at parietal locations in the 500-800 ms time window, there was a complete absence of a left-parietal ERP old/new effect for the non-targets (studied items). When taken together with the previously presented experiments, the differential attenuation of non-target parietal old/new effects replicates findings in four other cases (Dzulkifli et al., 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a; Herron & Rugg, 2003b; Wilding et al., 2005). In keeping with the findings in each of these pairs of experiments, the attenuation of the ERP old/new effects for non-targets that is reported in Experiment 4 occurred in an experiment in which the likelihood of a correct target judgment was much higher than in previous studies where there had been no observed attenuation (see experiments 1, 2 and 3). The findings of Experiment 4 therefore support the view that participants adopt strategies in exclusion tasks, whereby the extent to which recollection of information of targets is likely determines the extent to which recollection of information about non-targets will be prioritised (Herron & Rugg, 2003b).

The levels of target accuracy across experiments 1, 2 and 3 are comparable to those reported in previous exclusion studies (cf. Dzulkifli et al., 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a, 2003b; Wilding et al., 2005) where some degree of attenuation of non-target old/new effects has been reported. Why, therefore, is there no comparable degree of attenuation in experiments 1-3? As described previously, it may be the case that, in comparison to the tasks demands in standard study-test exclusion tasks, and the version of the paradigm used in Experiment 4, in experiments 1-3 participants experience a greater degree of difficulty in controlling recollection of the repeated test items because of the short lag between their first and second presentation. Therefore, the previous findings may be due to relatively lower degrees of difficulty in controlling the recollection of the non-target categories employed in those experiments. In order to assess this, one way is to provide a greater incentive to process selectively information about targets, by increasing the likelihood of recollecting information about targets. The issue of target/non-target accuracy levels in this paradigm will be addressed in Experiment 5.

Mid-frontal ERP old/new effect

Focusing now on the data acquired from 300-500 ms post-stimulus at anterior scalp locations; does the data contribute to one interpretation offered for findings in previous research (Curran, 2000), which is that frontally distributed ERP old/new differences in this time window are related to familiarity?

The directed analysis of the mid-frontal ERP old/new effect confirmed that there were reliable ERP old/new effects for both studied and repeated test items in both experiments. Whilst there were no differences between the two classes of old item and misses in Experiment 3, misses were more positive-going than correct rejections, as indicated by an interaction between category and site, which reflected a greater relative positivity for misses at Fz only. This pattern of differences between conditions is similar to that in experiments 1 and 2 (see Figure 6.5 for a bar graph of the mean amplitudes of the old/new effects for hits, misses and repeated hits across frontal sites in the 300-500 ms time window, which is directly comparable to the data shown in Figure 5.8 in Chapter 5). The data is in line with the proposal that an anteriorly distributed modulation occurring in this time window is an index of familiarity (for a comprehensive review, see Curran et al., 2006), although, because of the absence of reliable differences between the ERPs elicited by misses and by the two classes of hit, it is not as statistically compelling as in the earlier experiments.

Furthermore, the distributions of the old/new effects for repeated hits and misses within this time window (see Figure 6.3) show maxima with a somewhat more posterior loci than would be anticipated if they were solely reflecting mid-frontal ERP old/new effects. This may be due to the coexistence of two distinct processes in this time period. It has been proposed that two functionally distinct ERP old/new effects, with fronto-central and parietal scalp distributions respectively, are evident in the 300-500 ms post-stimulus time-window (Azimian-Faridani & Wilding, 2006; Rugg et al., 1998). Rugg et al. (1998) linked the posterior effect with implicit memory, since in their study the effect differentiated only the old/new status of test items and not the accuracy of memory judgments. The data shown in Figure 4 are consistent with this account, as at posterior sites correct responses to studied words and repeated test words, as well as incorrect responses to studied words, are more positive-going than correct rejections. The ERPs at the posterior locations thus index the old/new status of the test items but do not predict the accuracy of memory judgments. This pattern of data fulfils one criterion for being an index of implicit memory, but in this study, as in all prior studies to date where this has been demonstrated, the effect has not been accompanied by a behavioural index of implicit memory such as priming (Azimian-Faridani & Wilding, 2006).

Concluding remarks

The directed analysis of the mid-frontal ERP old/new effects confirmed that within both experiments there were reliable old/new effects for both classes of old items and that misses were also more positive-going than correct rejections at midline anterior sites only for Experiment 3. Furthermore, in Experiment 4, repeated hits were reliably more positive-going than hits. The pattern of data obtained here is in line with the proposal that an anteriorly distributed modulation occurring in the 300-500 ms time window indexes familiarity (Rugg et al, 1998), because at anterior sites only, the ERPs elicited by correct responses to targets and non-targets were more positive-going than those elicited by correct rejections. This pattern of data is consistent with the view that frontally distributed ERP old/new differences (appearing between 300 and 500 ms) are related to familiarity (Curran, 2000).

For Experiment 3 there were reliable parietal ERP old/new effects for both studied and repeated test items, with the same pattern of differences as for experiments 1 and 2. For Experiment 4, where the target/non-target designation was reversed, there were reliable parietal ERP old/new effects for the repeated test items only. Experiment 4 was primarily designed in order to formally assess the memorability of the repeated test items, and to this end the high level of target accuracy obtained suggests that information relating to the repeated test items could be recollected when required. This is an important distinction to make, in light of the fact that, in the previous versions of the paradigm where the studied items are targets, new items and non-targets share the same response. As a result, there is no way of assessing the behavioural data in experiments 1, 2, and 3 to determine whether repeated test items have been recollected or not and therefore to interpret confidently the parietal ERP findings in terms of the engagement of recollection processes. Consequently it is now reasonable to suggest that the repeated test items can be recollected when required and that when studied words are classified as targets the high levels of response accuracy for repeated test items are not due to the misclassification of these words as new items.

The lack of any attenuation of the parietal ERP old/new effect for repeated test words in Experiment 3 also continues to place the findings at odds with those reported in three previous studies (Dywan et al., 1998; Dywan et al., 2001; Dywan et al., 2002). This disparity remains despite the fact that the probability of occurrence of the repeated test items relative to the studied items in Experiment 3 was equated to a 1:1 ratio comparable to that employed in the three Dywan et al. studies. The probability disparity across studies does not, therefore, explain the differences between the parietal ERP findings of these experiments and those of Dywan et al. (1998, 2001, 2001). What other aspects of the experimental designs could impact on the electrical record in this way?

Dywan et al. employed shorter study and test blocks than those employed in experiments 1, 2 and 3, and while the encoding task was the same, Dywan et al. employed a 5 second inter-stimulus interval (ISI), while the ISI in experiments 1, 2 and 3 was 2.4 seconds. The mean frequency of occurrence of the stimuli in experiments 1, 2 and 3 was 1-7 occurrences per million, while in the studies due to Dywan et al., the means were in excess of 120 occurrences per million (Dywan et al., 2002; Dywan et al., 1998; Dywan et al., 2001). The procedures on each test trial were similar across these sets of experiments, suggesting that the reasons for the disparities in the ERP findings are not due to the individual test trial structures.

The shorter study and test phases in the studies due to Dywan et al., together with the longer study time for each item, might have been expected to have led to superior accuracy at test in those studies in comparison to experiments 1, 2 and 3 reported here. It is likely, however, that the reason for the broadly similar levels of accuracy across those studies and the ones presented here arises because any accuracy advantages conferred by these factors are offset by the disparities in word frequency across studies. Low frequency words give rise to superior recognition memory accuracy relative to high frequency words (Mandler, Goodman, & Wilkes-Gibbs, 1982), and this advantage is conferred by an increased likelihood of recollection and an increased likelihood of items being judged old on the basis of familiarity (Gardiner & Java, 1990, 1993). It seems reasonable to assume, therefore, that the use of lower frequency words in experiments 1, 2 and 3 than in the experiments due to Dywan et al., in combination with the differences in study time and study list length, explains the similar levels of accuracy that were obtained in these experiments.

The most pertinent issue here, however, is why, despite the similar levels of memory accuracy, and qualitatively similar patterns of reaction times at test, the left-parietal ERP old/new effects for non-targets were markedly more attenuated in the Dywan et al. studies. While it is not possible to rule out the prospect that these differences are only due to the different study-test intervals across studies, the ways in which this factor could be responsible are not clear-cut.

The most likely candidate for the disparities is the differences in word frequencies across experiments. In the studies due to Dywan et al., the moderate to high frequency repeated test items, when re-presented, were possibly less likely to be associated with recollection than the low frequency repeated test items in experiment 1, 2 and 3. As a result of this, the marked attenuation of non-targets in the studies due to Dywan et al. is not a consequence of adopting a strategy of prioritising recollection of target over non-target information, but a reflection of the limited availability of information that would support recollection in these experiments. This is supported by the findings that left-parietal ERP old/new effects are typically smaller for high than for low frequency words (Rugg & Doyle, 1992), and that this is true even when words from the two frequency classes are associated with recollection (Rugg, Cox, Doyle, & Wells, 1995). These observations can in principle resolve the contrasting findings across studies, and in addition, if correct, mean that the findings of Dywan et al. do not challenge the view that the principal determinant of the conditions under which non-target left-parietal ERP old/new effects are attenuated is the likelihood of recollecting information about targets (Herron & Rugg, 2003a).

The other noteworthy aspect of the present data is that fact that, in experiments 1, 2 and 3, where targets were studied items, there has been no reliable attenuation of parietally distributed ERP old/new effects for the non-targets. These three experiments are consistent, therefore, with the view that, because of their short lag between presentation and re-presentation at test, repeated test items are ones over which little control of retrieval processes can be exerted. This possibility is broadly consistent with the fact that in previous studies, there has been at least some degree of attenuation of parietal old/new effects for non-targets where comparable levels of target accuracy to those in experiments 1-3 have been reported (Dzulkifli et al., 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a, 2003b; Wilding et al., 2005). An alternative account, however, is that, in this incarnation of the exclusion task, the levels of target accuracy are not sufficiently high to encourage adoption of a strategy of relying on information about targets only. This was tested in Experiment 5.

Figure 6.1. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at sites F3/F4, C3/C4, P3/P4, Fz, Cz and Pz in Experiment 3.

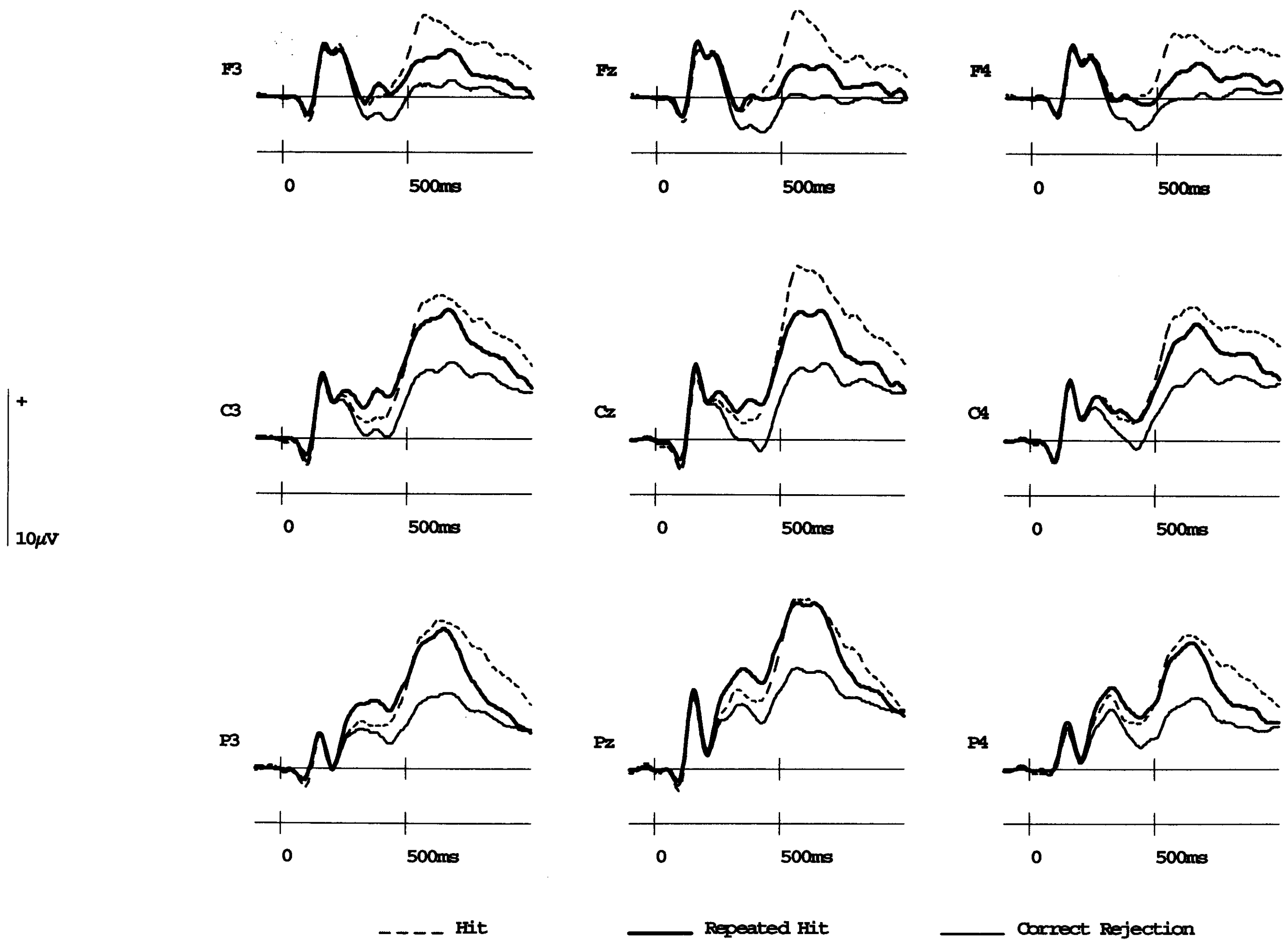


Figure 6.2. Grand averaged ERPs elicited by hits, misses, correct rejections and repeated hits at sites F3, Fz, F4 in Experiment 3.

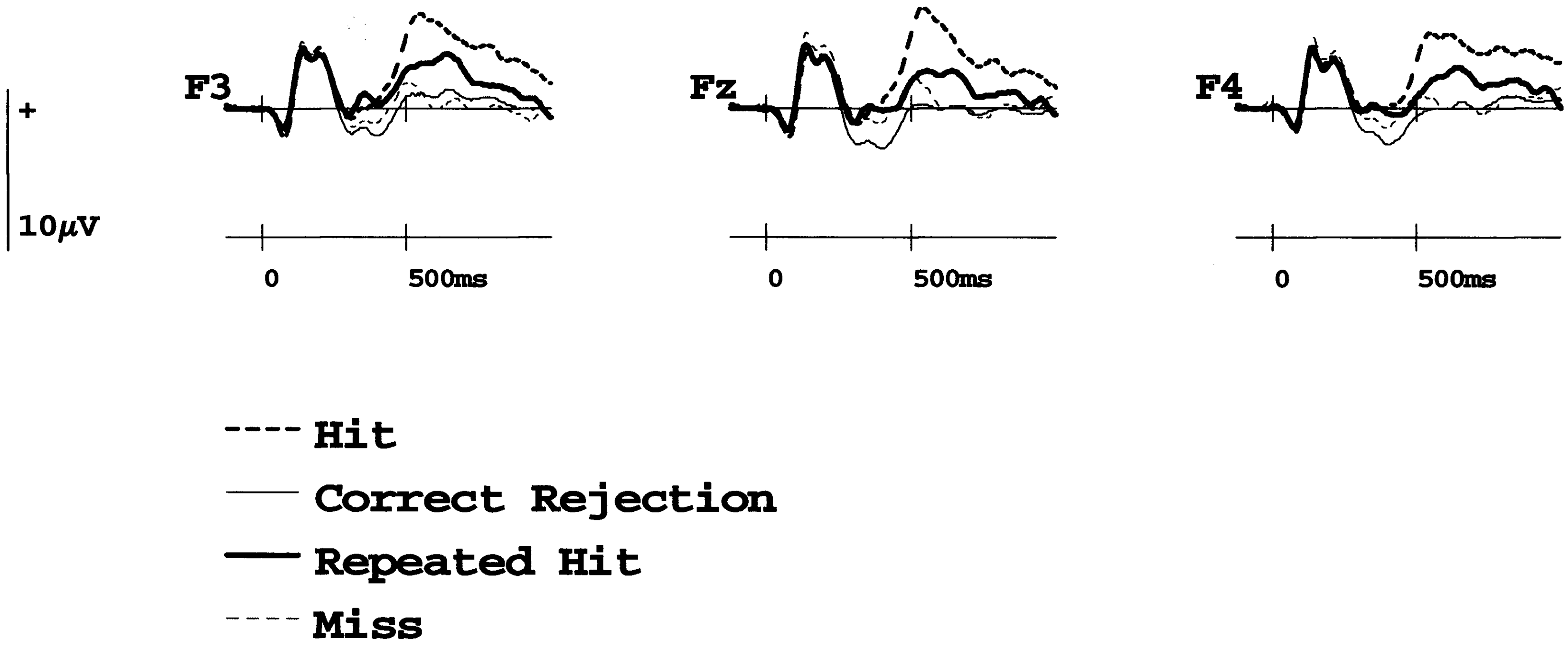


Figure 6.3. Scalp distributions of the ERP old/new effects for hits and repeated Hits in experiments 3 and 4 and for misses in Experiment 3. The data are shown for three post-stimulus epochs: 300-500, 500-800 and 800-1100 ms. The maps were computed from scores obtained by subtracting mean amplitudes from the ERPs evoked by correct rejections from hits, repeated hits and misses. The paired values below each map denote the maxima and minima of the amplitude differences between response categories, which can be interpreted relative to the colour bar at the foot of the figure.

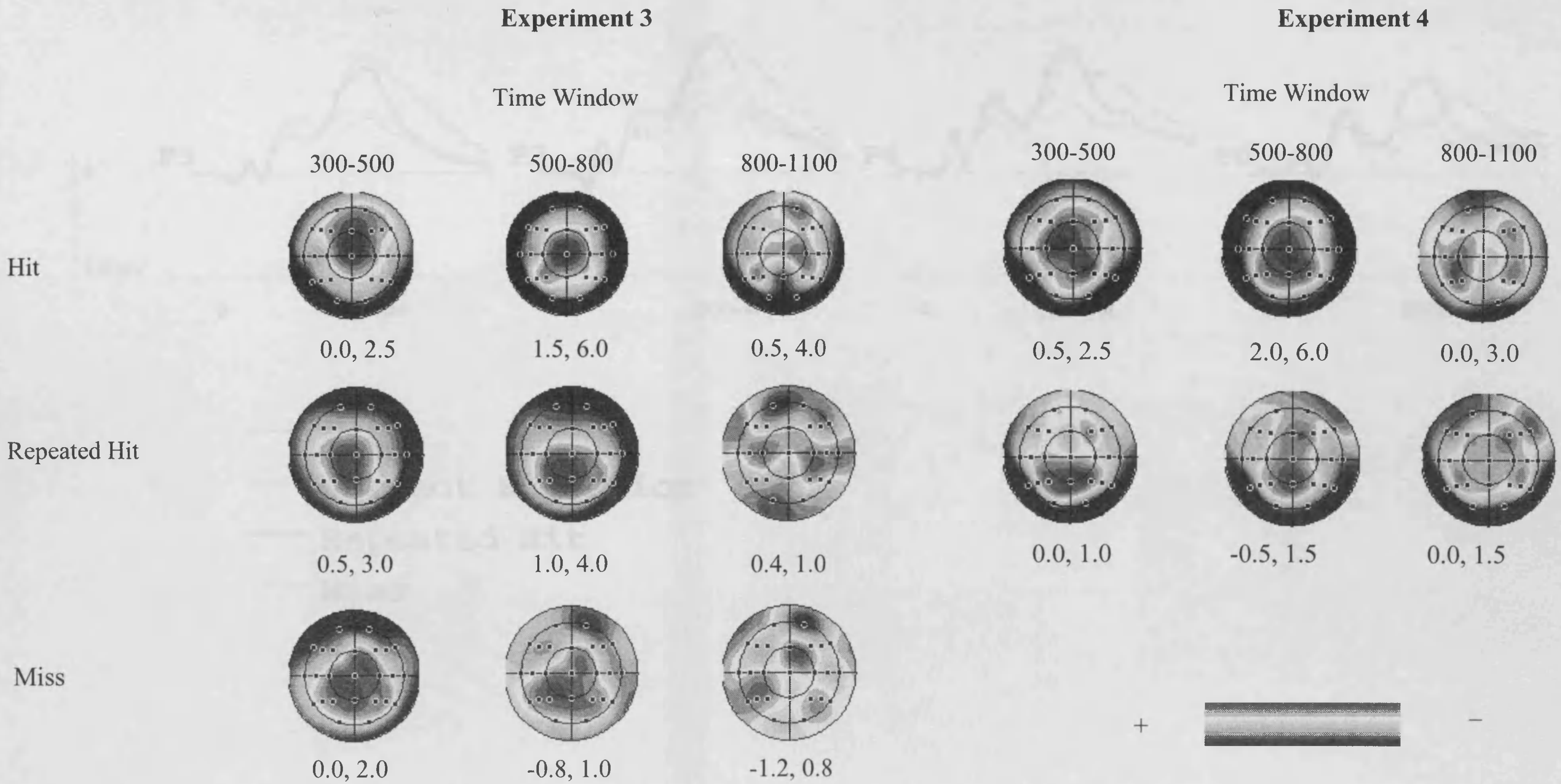


Figure 6. 4. Grand averaged ERPs elicited by hits, misses, correct rejections and repeated hits at sites P3/4, P5/6 in Experiment 3.

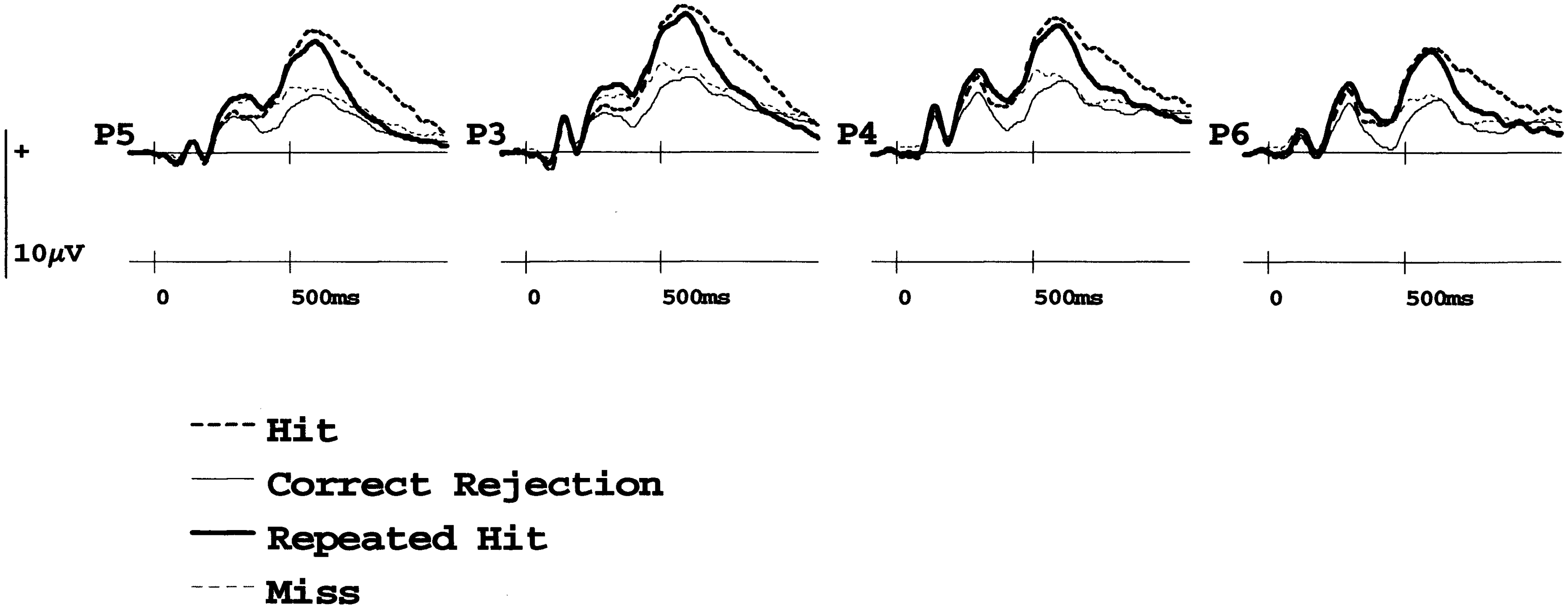


Figure 6.5. A bar chart of the mean amplitudes of the old/new effects for hits, repeated hits and misses averaged across sites F3, FZ and F4 in Experiment 3.

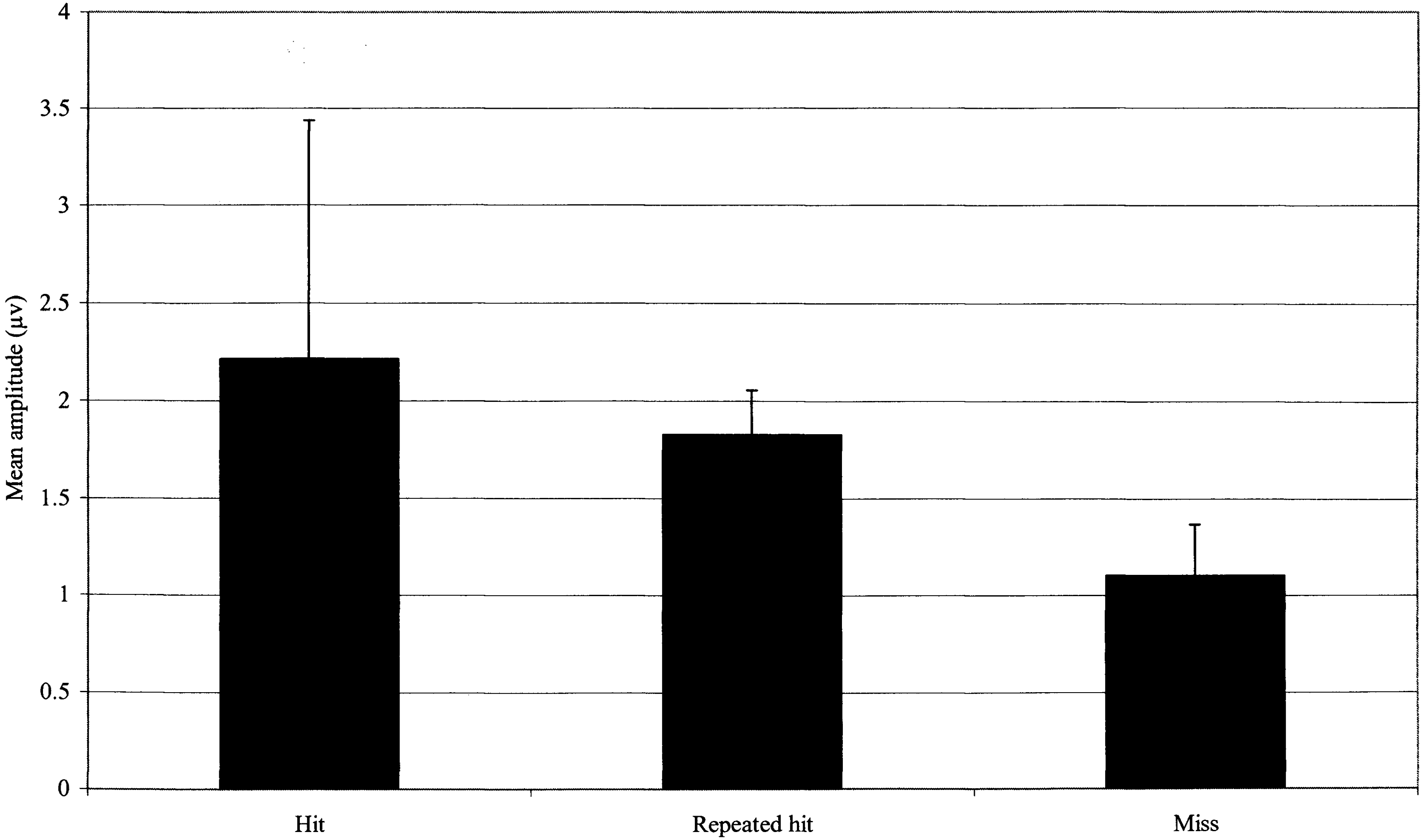


Figure 6.6. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at sites F3/F4, C3/C4, P3/P4, Fz, Cz and Pz in Experiment 4.

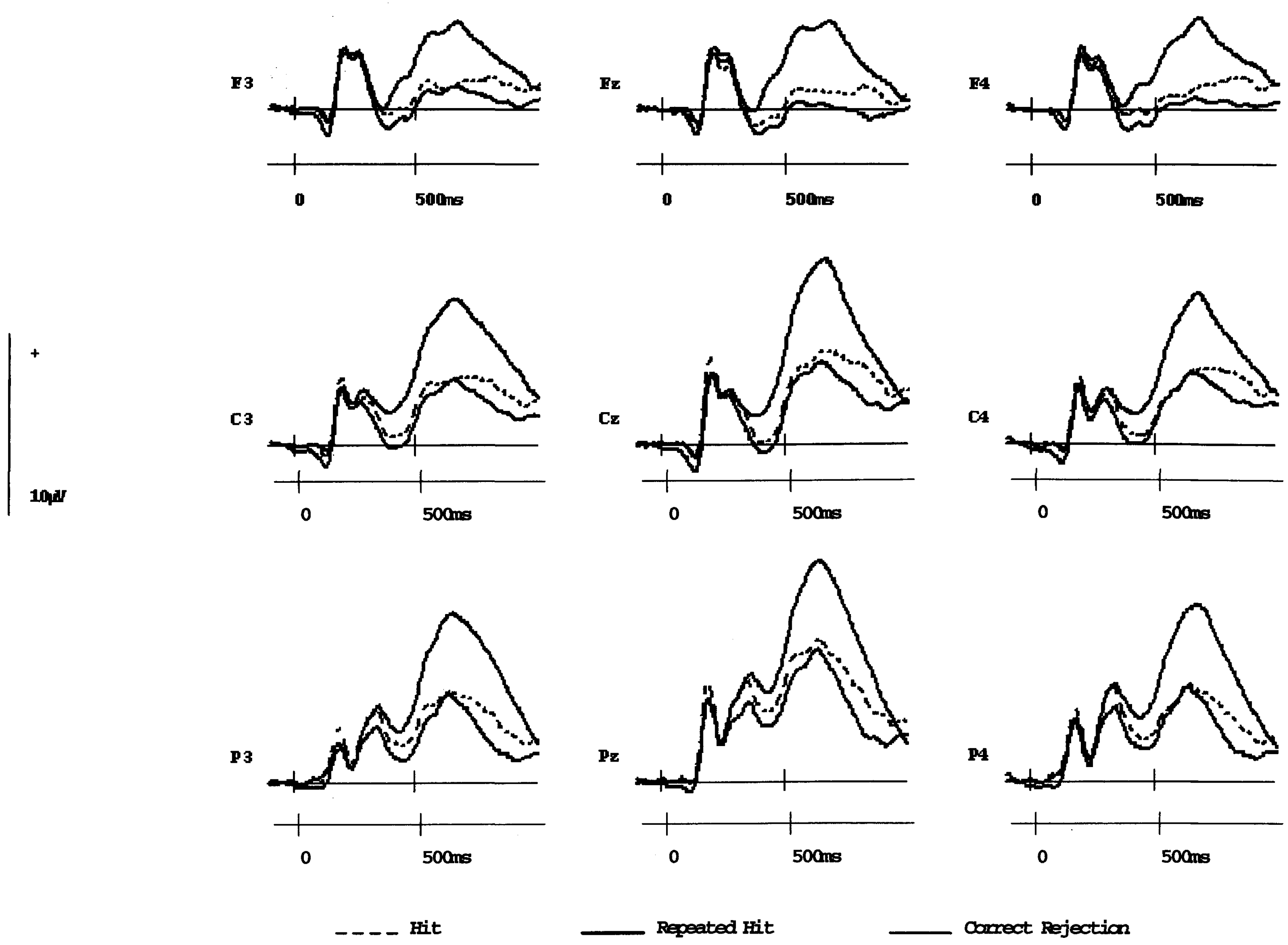


Figure 6.7. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at sites F3, Fz, F4 in Experiment 4.

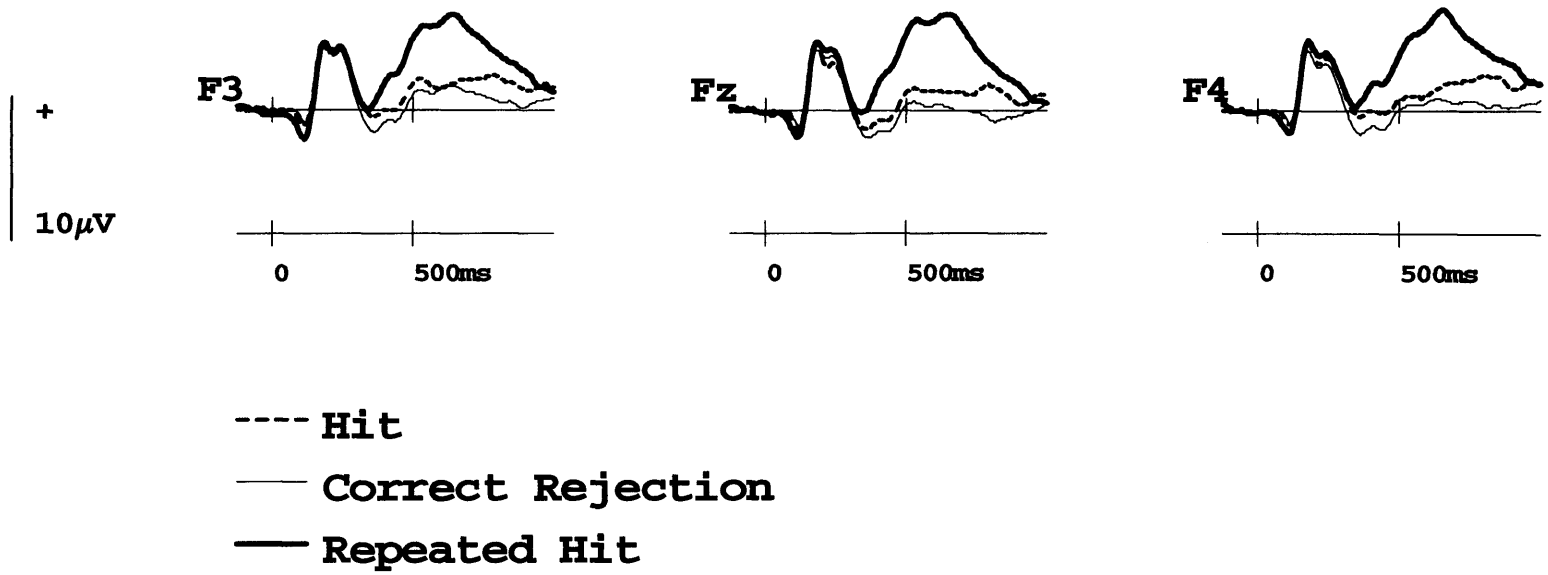
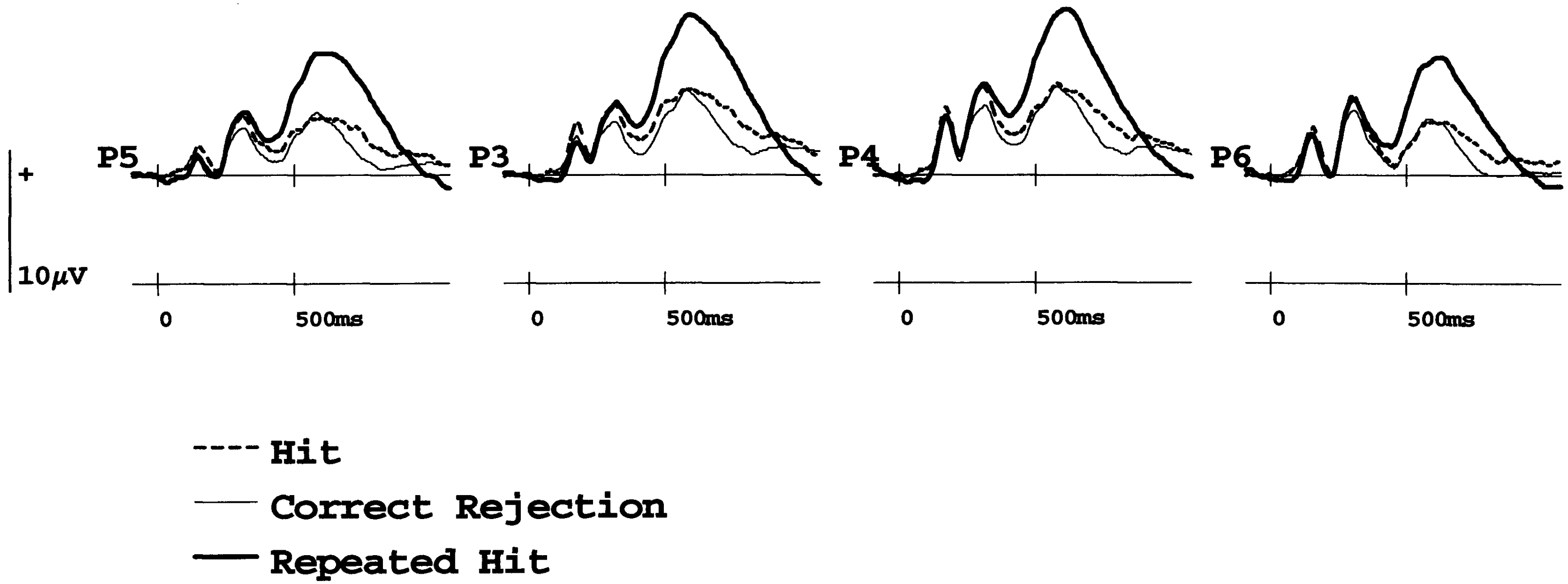


Figure 6.8. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at sites P3/4 and P5/6 in Experiment 4.



Chapter Seven

Experiment 5

Introduction

In experiments 1, 2 and 3 there were reliable parietal ERP old/new effects for both studied items (targets) and repeated test items (non-targets). This pattern of differences remained when the ratios of studied to repeated test items were either 2:1 or 1:1 (compare in particular experiments 2 and 3). The levels of target accuracy in these experiments have been comparable to the levels shown in experiments where there has been some degree of attenuation of the non-target old/new effects in comparison to the target effects (Dzulkifli, Herron, & Wilding, 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a, 2003b). One possibility, therefore, is that, irrespective of the level of target accuracy, restricting recollection to information about targets only cannot be accomplished when the non-targets are items that are repeated at short lags, and as a result presumably have strong memory representations. If this account were correct, then the findings in experiments 1-3 would be important in so far as they identify one of the boundary conditions under which recollection can be restricted to task–relevant information.

An important caveat, however, is that the designs of the previous studies in which degrees of attenuation of the non-target left-parietal ERP old/new effect have been reported involved presentation of items in two different contexts at study. For example, Wilding & Rugg (1997) utilised auditorily presented words delivered by either a male or female speaker. Dzulkifli & Wilding (2005) reported old/new effects in a study where participants studied words initially, all of which were concrete nouns. For half of the words, the task was to decide how difficult the object denoted by each word would be to draw. For the remainder, the task was to generate uses for the object denoted by each word. Also in the two exclusion task experiments reported by Herron & Rugg (2003a), participants completed one identical and one different encoding task. The common task that was required for half of the study words in each experiment was to incorporate each word into a sentence and to say it aloud. For the second task in Experiment 1, participants were asked to rate words for pleasantness, while in Experiment 2 the second task was simply to read aloud each word that was presented.

In experiments 1-3, by contrast, all studied items were subjected to the same encoding operations, and the target/non-target distinction is between studied words and repeated test words. It may be the case that, under these circumstances, the levels of target accuracy necessary to observe attenuation of parietal old/new effects – and therefore to license claims about selective recollection of task relevant information – need to be higher in this incarnation of the exclusion procedure. Experiment 5 was designed in order to assess this possibility.

This possibility can be tested by increasing the level of target accuracy. Two ways to accomplish this are to (i) shorten study and test list lengths, as it has been shown that increasing list length impairs recognition (Murnane & Shiffrin, 1991), and therefore, reducing list length should facilitate recognition and provide greater levels of target accuracy, and/or (ii) change the encoding task that is required for the study items; as information processing moves from shallow perceptual processing to more elaborative semantic-associative encoding, the strength of memory traces increases (Craik & Lockhart, 1972). The option of reducing study and test list lengths was chosen as this preserves the same encoding task across studies, preventing any possible encoding task confound in across study comparisons.

Method

Participants

19 participants completed Experiment 5; the data from three participants was discarded prior to analysis due to poor performance on the task (target accuracy below 50%). Of the remaining 16 participants, 11 were female, and the average age was 20 years (range 19 to 27). No participants were taking neuroleptic medication at the time of testing or reported a history of mental illness. All were paid at a rate of £7.50/hour and gave informed consent prior to commencing the experiments.

Stimuli and design

Stimulus and presentation parameters were as for Experiment 3. For the study and test list structures 400 critical words were split into sixteen equal groups of 25 words. One complete word task list comprised four study lists and four test lists. There were 25 words (one whole group) on each study list. There were 125 words on each test list. These comprised the 25 words presented at study (one complete 25-word group) along with 50 unstudied words, and a further 25 unstudied words which then repeated once after 7-9 intervening words. The numbers of words re-presented after lags of 7, 8, and 9 words were approximately equal. No words appeared in both test lists. Rotating the groups of words across study and test lists, so that all words were presented at study and test as well as at test only, either as new words or as repeats, resulted in the creation of 16 complete task lists. The order of presentation of words in the study lists was determined randomly for each participant. In total, each participant saw 600 presentations of words (100 study words, 500 test words).

Procedure

Prior to commencing either experiment, participants were informed that they would be presented with a series of words on the computer screen. In each study phase, participants completed one encoding task for all words: they were asked to read each word aloud. For all participants an asterisk before study words initiated each study trial and remained on the screen for 1000 ms. The screen was then blanked (100 ms) before the study word was presented for 300 ms. Participants were asked to give their response after the study word appeared. The next trial started 2500 ms after the study word was presented.

Each test trial started with a fixation asterisk (500 ms duration), which was removed from the screen 100 ms prior to presentation of a test word (300 ms duration). The screen was then blanked until the participant responded, and the next trial started 1000 ms after the response. Response requirements were as for experiments 1,2 and 3. The hands required for the binary test judgment were also balanced across participants and all participants were encouraged to respond quickly and accurately. Responses slower than 4000 ms and faster than 300 ms were regarded as errors and were discarded from behavioural and ERP analyses. An average of < 2% of trials per participant were excluded due to this criterion.

EEG acquisition

These procedures were the same as for Experiment 3 (for specific details see Chapter 6).

Results

Behavioural Data

Table 7.1 shows response accuracies and reaction times (RTs) for correct and incorrect responses to targets, non-targets and correct rejections. As for experiments 1-4 two measures of discrimination (Pr: Snodgrass & Corwin, 1988) were calculated. Pr was reliably greater than 0 for both studied and repeated test words (Pr values = 0.75 and 0.66: $t(15) = 33.57$, $p<.001$ and $t(15) = 17.35$, $p<.001$), and these two Pr scores differed reliably from each other ($t(15) = 4.23$, $p<.001$).

Measures of response bias ($Br = p(FA)/(1 - Pr)$ were also calculated. For the discrimination involving new words the mean value across participants of Br was 0.13, while Br for the discrimination involving repeated test words was 0.32. Br scores differed reliably from each other ($t(15) = 7.25$, $p<.001$), with the values in each case indicating a more conservative bias for the discrimination involving new words (Snodgrass & Corwin, 1988).

Table 7.1. Probabilities of correct (p(correct)) and incorrect (p(incorrect)) responses and reaction times in milliseconds (RT) to old, new and repeated test words in Experiment 5.

	Word class		
	Old	New	Repeated Test
p(correct)	0.79 (0.07)	0.96 (0.05)	0.88 (0.13)
RT	883 (442)	788 (356)	815 (364)
p(incorrect)	0.21 (0.07)	0.04 (0.05)	0.12 (0.13)
RT	1026 (584)	1454 (537)	1227 (462)

A one-way ANOVA on the RTs for correct responses revealed significant differences between word class ($F(1.7, 25.4) = 8.46$, $p<.005$). Follow up paired comparisons showed that this was because the RTs for correct responses to new and repeated test words were quicker than those for correct responses to old words ($F(1,15) = 12.76$, $p<.005$ and $F(1,15) = 6.99$, $p<.05$ respectively). There was no significant difference between the RTs for correct responses to new and repeated test words.

ERP data

There are 6 possible response categories that ERPs could in principle be acquired for: correctly and incorrectly identified old, new and repeated test words. As for Experiment 4 too few participants made sufficient (16 or more) incorrect judgments to old, new and repeated test words (6, 2 and 2 participants respectively) to permit analysis of the ERP data for these response categories. Therefore baseline corrected averaged ERPs (100 ms pre-stimulus baseline) were formed for correctly identified old words (hits), new words (correct rejections) and repeated test words (repeated hits) and were analysed for the 16 participants in each experiment who contributed sufficient artefact-free trials to these critical response categories. Mean trial numbers for these response categories were 59 (range 28-76), 219 (range 93-295) and 64 (range 28-95). As for experiments 1, 2, 3 and 4, the ERP data were analysed over three time windows: 300-500, 500-800 and 800-1100 ms. The analysis strategy matched that employed in the previous experiments (see Chapter 5 page 133).

Hits, correct rejections and repeated hits

Figure 7.1 is relevant to the following statistical analysis and shows the ERPs elicited by hits, correct rejections and repeated hits at electrode sites F3/F4, C3/C4, P3/P4, Fz, Cz and Pz. The figure shows that from approximately 300 ms onwards the waveforms differentiate between the three conditions in a graded manner. Hits are most positive-going, followed by repeated hits then correct rejections. The old/new effect for hits is larger in magnitude and sustained until the end of the epoch at posterior sites. At anterior sites the greater relative positivity for hits becomes attenuated at approximately 700 ms. This earlier attenuation of the old/new effect for hits is most evident at right frontal sites. Repeated hits are also more positive-going than correct rejections at frontal and central sites from 250 ms until approximately the end of the recording epoch, whereas at parietal sites the greater relative positivity reverses after 900 ms. It is only at frontal sites from around 650 ms that repeated hits become more positive-going than hits.

300-500 ms:

Midline analyses:

The initial midline analysis revealed a main effect of category ($F(1.8, 27.2) = 14.78$, $p<.001$). The follow up analyses comprised all possible paired contrasts of the three categories, and these revealed positive-going old/new effects for both hits and repeated hits ($F(1,15) = 22.47$, $p<.001$ and $F(1,15) = 9.69$, $p<.01$). The final contrast revealed that the ERPs evoked by hits were reliably more positively going than those elicited by repeated hits ($F(1,15) = 7.79$, $p<.05$).

Global analyses:

The second set of analyses for this time window including the data from lateral scalp locations revealed a main effect of category ($F(1.6, 23.8) = 15.46$, $p<.001$), as well as an interaction between category and AP ($F(2.6, 38.5) = 3.80$, $p<0.05$). The follow-up analyses comprised all possible paired contrasts of the three categories and the outcomes are shown in the upper portion of Table 7.2. The contrast between hits and correct rejections revealed an interaction between category and site, which came about because the relatively greater positivity for hits was smallest at sites furthest from the midline. For the contrast between repeated hits and correct rejections there was a significant interaction between category and AP, which reflected the fact that the relatively greater positivity for repeated hits was largest at anterior sites.

For the hits versus repeated hits contrast there was a three-way interaction between category, AP and site. Further analysis at each of the three levels of the AP factor showed a relatively greater positivity for hits at central and parietal sites only ($F(1,15) = 5.11$, $p<.05$ and $F(1,15) = 8.67$, $p<.05$ respectively). There was also a condition by site interaction at central sites ($F(2.8, 41.9) = 4.28$, $p<.05$), which reflected the fact that the relatively greater positivity for hits was largest at central superior sites.

Table 7.2. The outcomes of the paired contrasts between the mean amplitudes associated with hits, correct rejections and repeated hits for the global analyses over the 300-500, 500-800 and 800-1100 ms time windows. Nomenclature as for Table 5.2, page 137.

	df	Hit vs CR	CR vs RHit	Hit vs RHit
300-500 ms				
CC	1,15	20.06 ***	15.02***	4.87*
CC x SI	2,30	$16.51_{(.58)}$***	ns	$10.08_{(.58)}$**
CC x AP	2,30	ns	$7.37_{(.63)}$***	ns
CC x AP X SI	3,40	ns	ns	$3.40_{(.65)}$*
500-800 ms				
CC	1,15	14.45**	13.38***	ns
CC x SI	1,15	$13.34_{(.55)}$**	ns	$8.35_{(.57)}$**
CC x AP	1,20	$7.10_{(.55)}$*	ns	$19.66_{(.62)}$***
CC x AP x SI	3,40	$5.08_{(.70)}$**	ns	$5.34_{(.86)}$**
800-1100 ms				
		No significant effects observed		

500-800 ms:

Midline analyses:

The initial midline analysis revealed a main effect of category ($F(1.5, 22.3) = 8.58$, $p<.005$). The follow-up analyses revealed that the ERPs evoked by hits were reliably more positive-going than those elicited by correct rejections ($F(1,15) = 13.58$, $p<.001$). A significant interaction between category and site ($F(1.4, 21.1) = 8.55$, $p<.001$) reflected the fact that this relatively greater positivity for hits was largest at Pz. Repeated hits were also significantly more positive-going than correct rejections ($F(1,15) = 9.02$, $p<.01$). The final contrast between repeated hits and repeated hits revealed a significant interaction between category and site ($F(1.4, 21.2) = 8.31$, $p<.005$) which reflected the greater relative positivity for hits at Pz.

Global analyses:

The second set of analyses for this time window revealed a main effect of category ($F(1.6, 24.4) = 8.87$, $p<.01$), as well as interactions between category and site ($F(1.7, 25.6) = 10.02$, $p<.001$) and category and AP ($F(1.5, 23.2) = 10.74$, $p<.001$). These were all moderated by a three-way interaction involving category, AP and site ($F(4.4, 66.2) = 4.71$, $p<.01$).

The follow-up contrast (Table 7.2) between hits and correct rejections revealed a three-way interaction involving category, AP and site. Further analysis at each of the three levels of the AP factor showed a relatively greater positivity for hits at central and parietal sites only (central: $F(1,15) = 14.25$, $p<.005$ and parietal $F(1,15) = 16.32$, $p<.001$). There were also significant interactions between category and site at central and parietal sites (central: $F(1.8, 26.6) = 5.19$, $p<.05$ and parietal: $F(2.2, 33.6) = 7.31$, $p<.005$). These reflect the fact that the relatively greater positivity for hits was largest at central and parietal superior sites. Repeated hits were also reliably more positive-going than correct rejections ($F(1,15) = 13.38$, $p<.005$).

The final contrast between hits and repeated hits revealed a three-way interaction involving category, AP and site. Further analysis at each of the three levels of the AP dimension showed a relatively greater positivity for hits at parietal sites only ($F(1,15) = 10.01$, $p<.005$). There were also significant interactions between category and site at central and parietal sites (central: $F(2.1, 31.6) = 5.05$, $p<.05$ and parietal: $F(2.5, 38.2) = 3.67$, $p<.05$), reflecting the fact that the relatively greater positivity for hits was smallest at inferior sites.

800-1100 ms:

Midline and Global analyses:

The initial analyses revealed no significant effects, so no further analyses were conducted.

Mid-frontal ERP old/new effects:

An additional directed analysis was conducted a per previous experiments. Figure 7.2 is relevant to the following statistical analyses and shows the ERPs elicited by the three classes of items at electrode sites F3, Fz, F4, The figure shows that from approximately 300 ms hits and repeated hits are more positive-going than correct rejections, with hits being more positive-going than repeated hits. This pattern of distribution continues until approximately 700ms where repeated hits become more positive-going than hits, particularly at F4.

The direct analyses revealed a main effect of category ($F(1.7, 25.9) = 14.56$, $p<.001$) and an interaction between category and site ($F(3.3, 49.2) = 3.51$, $p<.05$). Paired contrasts within the experiment demonstrated that hits ($F(1,15) = 20.33$, $p<.001$) as well as repeated hits ($F(1,15) = 15.59$, $p<.001$) were both more positive-going than correct rejections at these mid-frontal electrode sites. There was a condition by site interaction for the contrast between the two classes of hits ($F(1.9, 28.1) = 6.04$, $p<.01$), because the greater relative positivity for hits was largest at Fz.

Left-parietal ERP old/new effects:

The parietal old/new effects directed analysis was conducted as per previous experiments. Figure 7.4 is relevant to the following statistical analyses and shows the ERPs elicited by the four classes of items at electrode sites P3/4 and P5/6. The figure shows that in the critical 500-800 ms time window hits are substantially more positive-going than repeated hits and correct rejections, with repeated hits exhibiting a slightly greater positivity than correct rejections, particularly at left-hemisphere sites P3 and P5.

The further analyses revealed a main effect of category ($F(1.3, 20.0) = 13.15$, $p<.001$). This was followed up by all possible paired contrasts, and the outcomes of these showed a reliable old/new effect for hits ($F(1,15) = 17.35$, $p<.001$), moderated by an interaction with site ($F(1.7, 24.8) = 3.89$, $p<.05$). This reflected the fact that the greater relative positivity for hits was largest at P3. This is further illustrated in

Figure 7.3 which shows a topographic map of the differences in neural activity at the scalp between hits and correct rejections in the 500-800 ms time window. A clear degree of left lateralisation is observable. The ERPs evoked by repeated hits were also reliably more positive-going than correct rejections ($F(1, 15) = 6.96$, $p<.05$), as shown in Figure 7.3. There was no statistical evidence of left lateralisation for the parietal effect within this contrast. The contrast between the ERPs evoked by hits and repeated hits revealed a significant effect of category ($F(1, 15) = 9.88$, $p<.01$), reflecting the relatively greater positivity for hits.

Discussion

The motivation for the study described in this chapter was to assess the possibility that in this variant of the exclusion task the levels of target accuracy need to be higher than in a standard exclusion task in order to observe attenuation of non-target parietal old/new effects. Higher levels of response accuracy were achieved by shortening study and test list lengths. The behavioural and parietal ERP findings relevant to the main aim of this experiment will be discussed in the following section. No comment on the mid-frontal ERP old/new effects is made below, as the results in this experiment do not provide new information in comparison to that for the earlier experiments in this thesis.

Left-parietal ERP old/new effects

As intended, reducing the study and test list lengths in Experiment 5 increased the mean level of target accuracy (0.79) relative to experiments 1, 2 and 3 (mean level of target accuracy across experiments = 0.65). The directed analyses of the left-parietal ERP old/new effects revealed reliable old/new effects for targets and for non-targets, although the latter was significantly attenuated in comparison to the size of the effect for the former. The findings are consistent with the hypothesis that high target accuracy encourages participants to adopt a target-specific retrieval strategy (Herron & Rugg, 2003a).

The attenuation of the non-target left-parietal ERP old/new effects across experiments replicate previous findings (Dzulkifli et al., 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a, 2003b; Wilding et al., 2005), in that it occurred in an experiment in which the likelihood of a correct target judgment was much higher than in previous studies where there had been no observed attenuation (see experiments 1, 2 and 3). These findings are therefore consistent with the view that participants adopt strategies in exclusion tasks whereby the extent to which recollection of information about targets is likely determines the extent to which recollection of information about non-targets will be prioritised (Herron & Rugg, 2003b).

Of further relevance here are the characteristics of the paradigm in which these findings occurred. In the variant on the exclusion task used here, all study items are subjected to the same encoding operations. In the subsequent retrieval task, studied words are presented alongside new words, a proportion of which are repeated after an intervening lag (repeated test items). The use of the studied items as targets Experiment 5 is likely to have led to the non-target (repeated test) items being associated with strong memory representations, by virtue of the short lag between first and second presentations. One question not addressed by the prior studies that have utilised this paradigm is whether, for these repeated test words recollection of task-relevant information can be controlled. It is possible that, by virtue of their relatively recent occurrence, selective recovery of information about targets might not be accomplished when test words repeating after relatively short lags are non-targets. The findings in Experiment 5, however, are consistent with the view that participants were able to exert considerable control over the conditions under which recollection of task-relevant information occurred. This was possible even when the information associated with non-targets is likely to have been accessed readily, as is evident from the high levels of response accuracy for non-targets.

Also at issue here were the boundary conditions under which recollection of some kinds of information can be prioritised at the expense of others. Experiment 5 showed that when studied words are targets it is possible for the recollection of repeated test item information to be controlled. The attenutation of the parietal ERP old/new effect for studied items in Experiment 4 showed that likewise it is possible for the recollection of studied word information to be controlled when repeated test words are designated as targets. The findings are therefore consistent with the view that recollection of target information can be prioritised over non-target information whether the target class of item was either the studied words or the repeated test words. Overall, the findings converge on the view that the likelihood of recollecting information about targets is the principal (if not the only) determinant of conditions under which target and non-target old/new effects will either converge or diverge, and by extension the principal determinant of the conditions under which selective control of recollection is exerted in exclusion tasks.

One explanation for why participants might adopt a strategy of prioritising targets over non-targets is cognitive economy: it is an efficient means of completing the task at hand. Relying on target recollection only, however, is never the optimal strategy if the aim is to complete the task as accurately as possible but this approach gains increasing utility as the likelihood of recollecting information about targets increases.

These considerations concerning cognitive economy also raise the possibility that factors other than the likelihood of recollecting information about targets may encourage the economical use of resources and a strategy of prioritising some forms of task relevant information over others. One of these factors is the time available to make a response, and this was investigated in Experiment 6 by limiting the time period in which participants had to make memory judgments. The rationale for this approach is that, when the time available to make responses is limited, participants might default to an approach whereby they rely only on the success or failure to recollect information about targets, irrespective of the likelihood of recovering such information.

Concluding remarks

There were reliable parietal ERP old/new effects for targets and non-targets. However, there was a significant attenuation of the parietal ERP old/new effect for non-targets relative to that for the targets. If the left-parietal ERP old/new effect is an index of recollection, then the findings within experiment 5 strengthen the view of Herron & Rugg (2003b) that it is the degree to which recollection of information of targets is likely that determines primarily the extent to which recollection of information about non-targets will be prioritised (Herron & Rugg, 2003b). It is of interest, however, that the level of accurate responding for targets in this incarnation of the exclusion task is markedly higher than in other experiments in which a different exclusion design has been employed and in which attenuation of non-target ERP old/new effects has been observed. This issue is returned to in the General Discussion, in the context of a consideration of how familiarity as well as recollection may contribute to judgments in some exclusion tasks.

One way in which it may be useful to consider the findings in the experiments described in this thesis to this point is with respect to the concept of cognitive economy. Natural intelligences represent the world in ways which filter out irrelevant information and allow them to function in a challenging environment. This seems to hold for the ways in which participants approach the task used here. When there is sufficient target information to complete the task successfully, as in Experiment 5, there is no need for the added process of recollecting non-target information, and as such, recollection of non-target information is strategically controlled. The categorisation of when non-target information is necessary for task responses allows for the provision of maximum relevant information with the least cognitive effort (Rosch, 1978), a key principle of cognitive economy. Rosch (1999) refers to cognitive economy as the means by which an organism acquires a substantial amount of information without having to undergo a search of all finite resources. In the broadest sense, cognitive economy has to do with avoiding the interference of cognitive processes relating to the processing of task irrelevant information.

If cognitive economy is a likely explanation for the adoption of specific retrieval strategies, then it might be possible to encourage participants to adopt a target-specific recollection strategy by means other than manipulating the levels of target accuracy. This was explored in Experiment 6, which is a direct replication of Experiment 3 (where the findings suggest that such a strategy was not implemented) but with the addition of an enforced limit on the time period in which participants were asked to make a test response. The reasoning for this approach is that, when the time available to make responses is shortened, participants might be forced into relying on recollecting information about targets only, irrespective of the likelihood of recovering such information, because this would be the most economical way of employing cognitive resources to complete the task as well as it is possible to do so. Furthermore, defining the boundary conditions under which cognitive economy is potentially implemented, in the completion of this variant of the exclusion task, will help delineate a principled set of requirements for when the prioritisation of recollection of target information occurs, and the factors that facilitate strategic recollection.

Figure 7.1. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at sites F3/F4, C3/C4, P3/P4, Fz, Cz and Pz in Experiment 5.

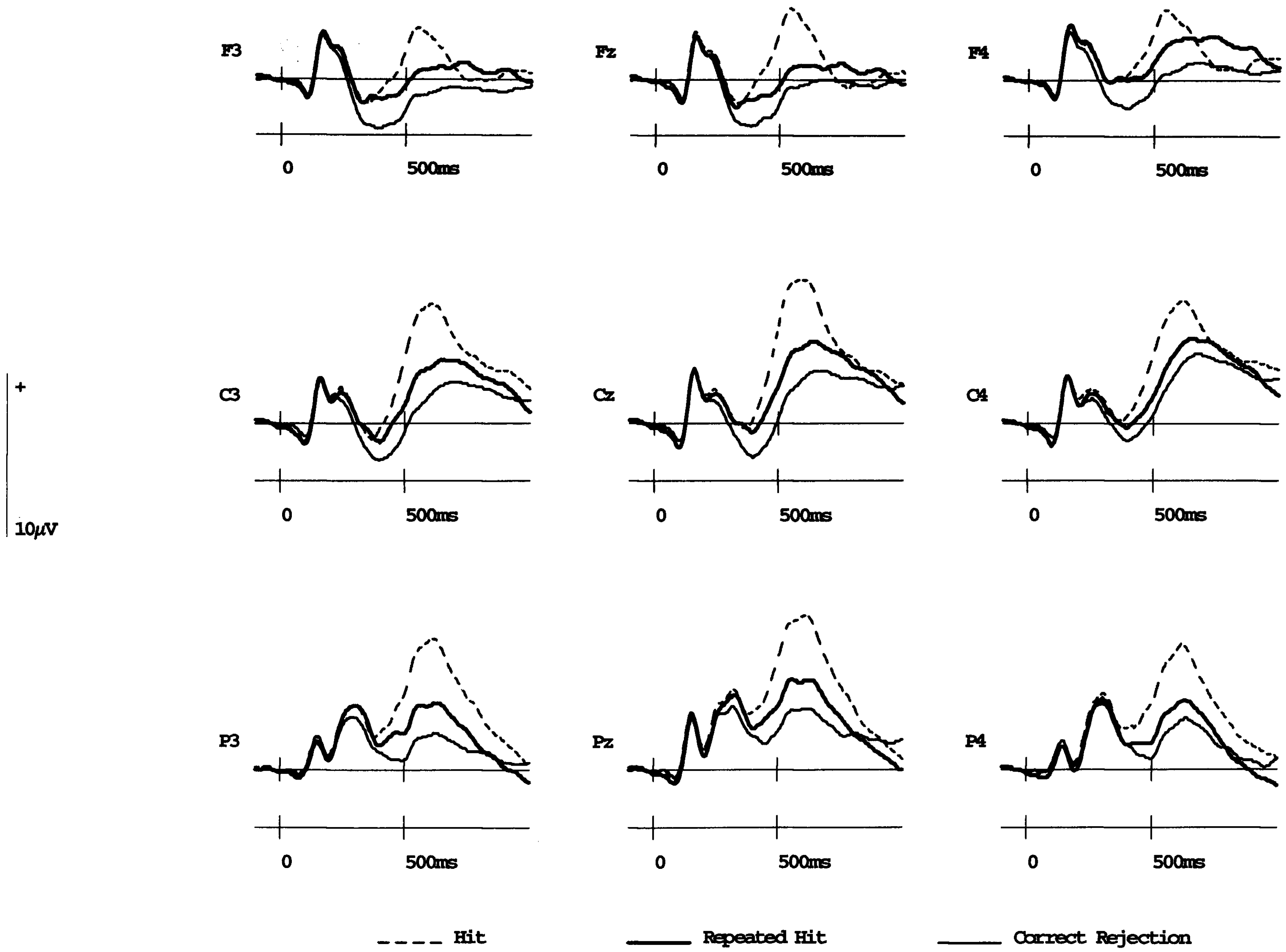


Figure 7.2. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at sites F3, Fz, F4, in Experiment 5.

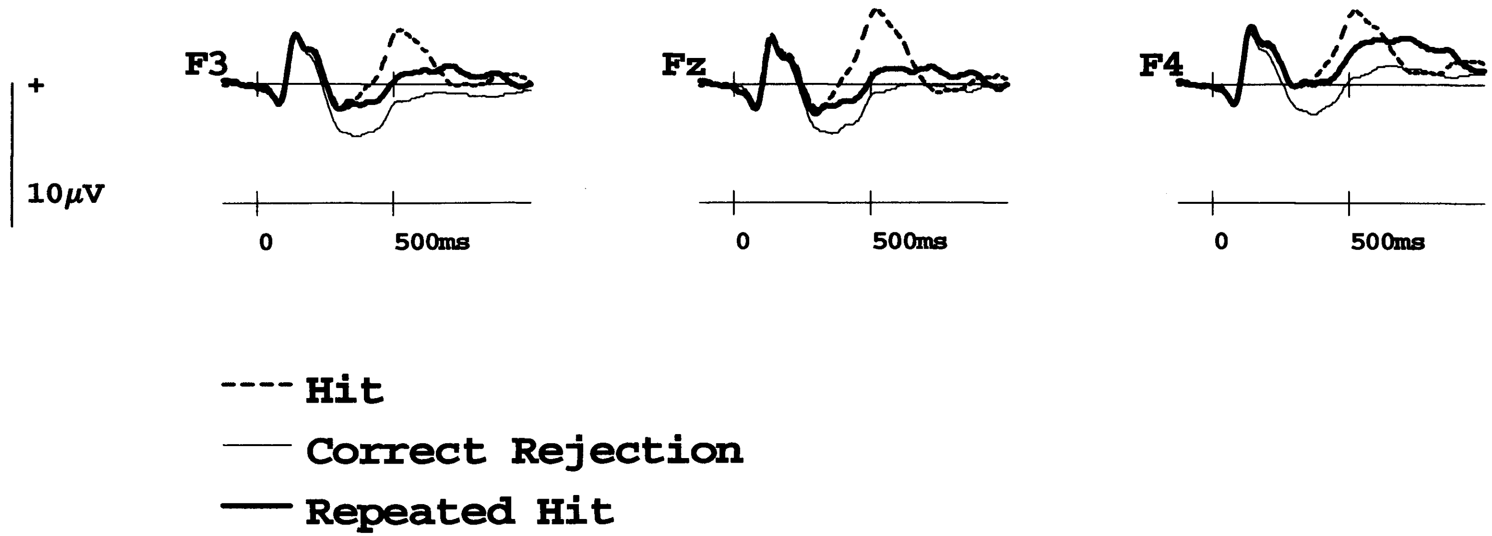


Figure 7.3. Scalp distributions of the ERP old/new effects for hits and repeated hits in Experiment 5. The data are shown for three post-stimulus epochs: 300-500, 500-800 and 800-1100 ms. The maps were computed from scores obtained by subtracting mean amplitudes from the ERPs evoked by new items from targets and non-targets. The paired values below each map denote the maxima and minima of the amplitude differences between response categories, which can be interpreted relative to the colour bar on the right-hand side of the figure.

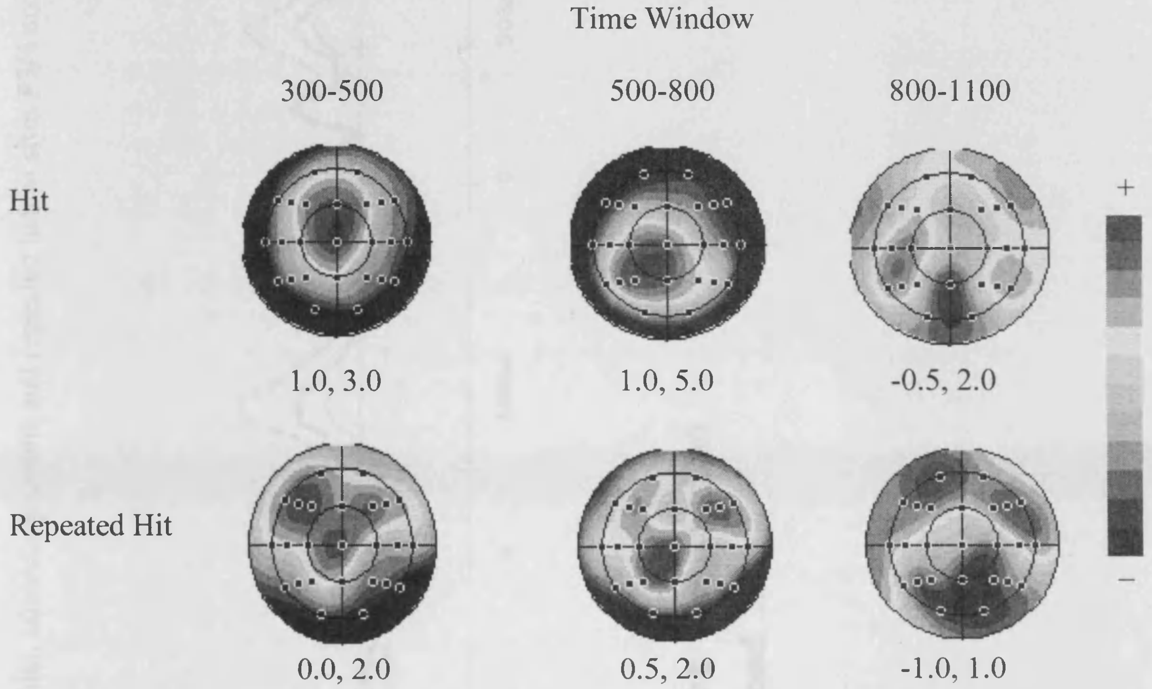
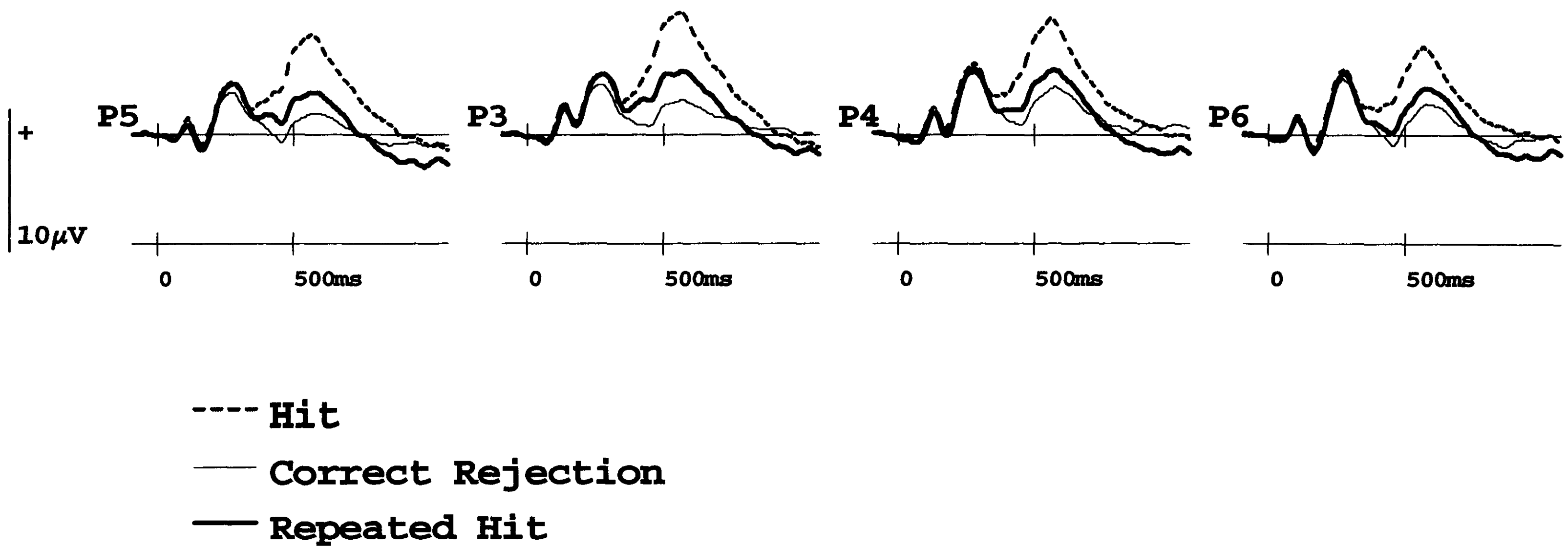


Figure 7.4. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at sites P3/4 and P5/6 in Experiment 5.



Chapter Eight

Experiment 6

Introduction

In experiments 1, 2, 3 and 4 the left-parietal ERP old/new effect was evident for targets as well as for non-targets in all test phases, consistent with the view that participants recollected information about both of these classes of test word. These findings contrast with those of Experiment 5, in which the same task was used, and in which a significantly attenuated left-parietal ERP old/new effect was found for non-targets. For this study, however, the accuracy of correct target judgments was markedly higher. In summary, Experiment 5 showed that, in this particular paradigm, when accuracy for targets is sufficiently high, a significantly attenuated left-parietal ERP old/new effect can be observed for non-targets. However, when accuracy for task judgments is lower (as in experiments 1, 2 and 3), both classes of items elicit left-parietal ERP old/new effects. The motivation behind Experiment 6 was to carry out a further investigation into the boundary conditions that may influence the implementation of strategic control of recollection.

The fact that a selective strategy of prioritising recollection of task related information to targets was implemented successfully in Experiment 5 indicates that participants were able to exert considerable control over the conditions under which recollection of task-irrelevant information occurred within this particular incarnation of the exclusion task. The experiments are consistent, therefore, with the view that, even when there is only a short lag between presentation and re-presentation at test, repeated test items are ones over which some control of retrieval processes can be exerted.

Cognitive economy is one possible explanation for why participants might adopt a strategy of prioritising target information over non-target information, as commented on in the preceding chapter. As discussed at that point, it might be possible to encourage participants to adopt this same strategy (relying on recollection of information about targets to a greater degree than on recollection of information about non-targets) by means other than manipulating the levels of target accuracy, such as by restricting the time available for task responses. The rationale for this approach is that, when the time available to make responses is limited, an economical approach would be to rely upon one source of information rather than two in order to complete the task. When time to respond is limited, therefore, participants might default to an approach whereby they complete the task by relying only on whether they succeeded or failed to recollect information about targets, irrespective of the likelihood of recovering information about targets. This hypothesis was tested in Experiment 6, which replicates Experiment 3, but with the use of a limited time period of 1 second in which participants must make test responses.

Method

Participants

16 right-handed people (12 female) were paid at the rate of £7.50/hour and gave informed consent prior to participating in the experiment. The average age of the participants was 29 years (range 19 to 30). Participants were all right-handed native English speakers. No participants were taking neuroleptic medication at the time of

testing or reported a history of mental illness. All were paid at a rate of £7.50/hour and gave informed consent prior to commencing the experiments.

Stimuli and design

Stimuli and study and test list structures were as for Experiment 3.

Procedure

The study phase and overall experiment testing conditions were as for Experiment 3. The only differences between the two experiments are that the test phase structure was slightly different in Experiment 6. Each test trial started with a fixation asterisk (500 ms duration), which was removed from the screen 100 ms prior to presentation of a test word (1000 ms duration). The participant was asked to respond during the presentation of the test word, and the next trial started 500 ms after stimulus offset. As for experiments 1, 2, and 3, participants responded with one hand to words that were seen at study ('old words'), and with the other to unstudied test words ('new words') and unstudied test words which repeated during the test phase ('repeated new words'). Responses were made on a key-pad with the left and right thumbs. The thumbs used for responses were balanced across participants. Participants were instructed that it was important for them to make their responses during the 1 second that the test stimulus was on screen. There was a 5 minute practice phase prior to the study phase to allow the participants to gain an idea of how much time they would have to respond. Items used in the practice phase were not re-presented in the study or test phases.

EEG acquisition

EEG was recorded as for experiments 2-5. All trials on which participants did not respond within the 1000 ms presentation of the stimulus were rejected (mean proportion of trials not responded to in time <1%).

Results

Behavioural data

Table 8.1 displays the probabilities of correct responses to each class of test word. Two measures of discrimination (Pr: Snodgrass & Corwin, 1988) were calculated as for all previous experiments. In both cases Pr was reliably greater than 0 (Pr values = 0.49 and 0.45: $t(15)=14.74$, $p<.001$ and $t(15) = 15.76$, $p<.001$). These two Pr scores did not differ reliably. Measures of response bias ($Br = p(FA)/(1 - Pr)$) were also calculated. The value of Br for the discrimination involving new words was 0.14, while for the discrimination involving repeated new words Br was 0.19. Br scores did not differ reliably from each other, with the values in each case indicating a moderately conservative bias (Snodgrass & Corwin, 1988).

A one-way ANOVA on the RTs for correct responses revealed significant differences between word class ($F(1.7,25.1) = 31.87$, $p<.001$). Paired contrasts showed that this was due to RTs for hits being significantly longer than those for correct rejections and repeated hits ($t(15) = 5.80$, $p<.001$ and $t(15) = 7.04$, $p<.001$ respectively). There was no significant difference between RTs for correct rejections and repeated hits.

Table 8.1. Probabilities of correct (p(correct)) and incorrect (p(incorrect)) responses and reaction times in milliseconds (RT) to old, new and repeated test words in Experiment 6.

	Word class		
	Old	New	Repeated test
p(correct)	0.56 (0.10)	0.93 (0.04)	0.89 (0.07)
RT	691 (100)	631 (116)	630 (119)
p(incorrect)	0.44 (0.10)	0.07 (0.04)	0.11 (0.07)
RT	635 (132)	744 (121)	723 (109)

ERP data

Too few participants made sufficient (16 or more) false alarms to new and repeated test words (8 and 2 participants respectively) to permit analysis of the ERP data for these response categories. Therefore baseline corrected averaged ERPs (100 ms pre-stimulus baseline) were formed for correctly identified old words (hits), incorrectly identified old words (misses), new words (correct rejections) and repeated test words (repeated hits) and were analysed for the 16 participants who contributed sufficient artefact-free trials to these critical response categories. Mean trial numbers for these response categories were 50 (range 31-71), 37 (range 17-65), 227 (range 133-282) and 73 (range 44-93), respectively.

The ERP data were analysed over three time windows: 300-500, 500-800 and 800-1000 ms. As for the previous experiments, two sets of analyses were completed. In the first set (the Midline analyses) the analyses were restricted to 3 midline locations (Fz, Cz and Pz). In the other set of analyses (the Global analyses), data from lateral electrode locations was included (Chapter 5, page 133, for specific details).

Two additional directed analyses were conducted on data for incorrect responses to old words and correct responses to all three item classes at frontal and parietal sites in the 300-500 and 500-800 ms epochs, as described previously (see Chapter 5 for details).

Hits, correct rejections and repeated hits

Figure 8.1 is relevant to the following statistical analysis and shows the ERPs elicited by hits, correct rejections and repeated hits at electrode sites F3/F4, C3/C4, P3/P4, Fz, Cz and Pz. The figure shows that from approximately 300 ms onwards the ERPs elicited by hits and repeated hits are more positive-going than those elicited by correct rejections at anterior sites. There is a greater positivity for repeated hits than for hits which onsets at approximately 250 ms and is maximal over posterior parietal sites. This difference attenuates from approximately 600 ms, after which at anterior sites hits become more positive-going, and this pattern of data becomes evident approximately 100 ms later at central and parietal electrode sites and is sustained through to the end of the recording epoch.

300-500 ms:

Midline analyses:

The initial midline analysis revealed a main effect of category ($F(1.5, 21.8) = 12.92$, $p<.001$). The follow-up analyses comprised all possible paired contrasts of the three categories, and these revealed that the ERPs evoked by hits and repeated hits were reliably more positive-going than those elicited by correct rejections ($F(1,15) = 13.44$, $p<.001$ and $F(1,15) = 50.27$, $p<.001$ respectively). A condition by site interaction for the contrast between hits and repeated hits ($F(1.2, 18.1) = 5.54$, $p<.05$) reflected the fact that at frontal sites hits were more positive-going, whilst at central and parietal sites the relatively greater positivity was for repeated hits.

Global analyses:

The second set of analyses for this time window including the data from lateral scalp locations revealed a main effect of category ($F(1.4, 21.5)= 12.70$, $p<.001$), as well as an interaction between category and site ($F(1.7, 24.8) = 12.46$, $p<.001$). The follow-up analyses comprised all possible paired contrasts of the three categories and the outcomes are shown in Table 8.2.

The contrast between hits and correct rejections revealed a four-way interaction between category, HM, AP and site. Further analysis at each of the three levels of the AP factor showed a relatively greater positivity for hits at frontal ($F(1,15) = 6.75$, $p<.05$) and central ($F(1,15) = 6.33$, $p<.05$) sites only. There were also significant interactions between category and site at frontal ($F(1.2, 17.9) = 16.56$, $p<.001$) central ($F(1.1, 16.6) = 4.31$, $p<.05$), and parietal ($F(1.2, 17.8) = 10.98$, $p<.005$) locations, which reflected the fact that the relatively greater positivity for hits was largest at frontal and central superior sites, however at parietal inferior sites there was a greater positivity for correct rejections. These interactions, however, do not explain the initial interaction with HM, which on inspection of Figure 8.3 is most likely due to the slight left lateralisation of the greater relative positivity for hits at anterior sites.

For the contrast between repeated hits and correct rejections there was a three-way interaction between category, AP and HM. Further analysis at each of the three levels of the AP factor showed a relatively greater positivity for repeated hits at all three AP levels (frontal: $F(1,15) = 27.25$, $p<.001$, central: $F(1,15) = 33.99$, $p<.001$ and parietal: $F(1,15) = 29.45$, $p<.001$). There were also significant interactions between category and site at all locations (frontal: $F(1.2, 17.4) = 20.61$, $p<.001$, central: $F(1.7, 25.0) = 21.48$, $p<.001$ and parietal: $F(1.2, 18.4) = 28.07$, $p<.001$) which reflected the fact that the relatively greater positivity for repeated hits was maximal at sites closest to the midline.

Table 8.2. The outcomes of the paired contrasts between the mean amplitudes associated with hits, correct rejections and repeated hits for the global analyses over the 300-500, 500-800 and 800-1000 ms time windows. Nomenclature as for Table 5.2 (page 137).

	df	Hit vs CR	CR vs RHit	Hit vs RHit
300-500 ms				
CC	1,15	8.35*	39.47***	ns
CC x SI	2,30	$14.8_{(.55)}$***	$46.03_{(.60)}$***	ns
CC x HM	2,30	ns	6.40*	ns
CC x AP x SI	2,30	ns	ns	$3.65_{(.65)}$*
CC x AP x HM	2,30	ns	$3.95_{(.85)}$**	ns
CC x AP x HM x SI	3,40	$2.82_{(.82)}$*	ns	ns
500-800 ms				
CC	1,15	40.88***	47.01***	ns
CC x SI	1,15	$35.26_{(.58)}$*	$12.72_{(.67)}$***	$19.65_{(.55)}$***
CC x AP x SI	3,40	$3.73_{(.66)}$*	ns	$4.32_{(.71)}$*
800-1000 ms				
CC	1,15	18.05***	ns	15.03***
CC x SI	1,15	$19.93_{(.54)}$*	ns	$19.96_{(.53)}$***
CC x AP x SI	3,40	$4.40_{(.62)}$*	ns	$8.99_{(.62)}$*

There were significant interactions between category and HM at central ($F(1,15) = 5.83$, $p<.05$) and parietal ($F(1,15) = 18.48$, $p<.001$) sites only. These reflected the fact that the relatively greater positivity for repeated hits was largest over the left-hemisphere across central and posterior sites but not at frontal scalp locations.

For the final contrast between hits and repeated hits there was a three-way interaction between category, AP and site. Further analysis at each of the three levels of the AP factor showed an interaction between category and site at central sites only ($F(1,15) = 7.77$, $p<.05$) which was due to the greater relative positivity for repeated hits at central superior sites.

500-800 ms:

Midline analyses:

The initial midline analysis revealed a main effect of category ($F(1.4, 21.6) = 31.19$, $p<.001$). The follow-up analyses revealed reliable ERP old/new effects for hits and repeated hits ($F(1,15) = 44.51$, $p<.001$ and $F(1,15) = 35.55$, $p<.001$ respectively). The final contrast revealed that the ERPs evoked by hits were reliably more positive-going than those elicited by repeated hits ($F(1,15) = 14.46$, $p<.005$).

Global analyses:

The second set of analyses for this time window revealed a main effect of category ($F(1.6, 23.7)= 28.53$, $p<.001$), as well as an interaction between category and site ($F(1.6, 24.0) = 29.21$, $p<.001$), which was moderated by a three-way interaction between category, AP and site ($F(4.2, 63.1) = 3.33$, $p<.05$).

The follow-up contrasts (Table 8.2) show that between hits and correct rejections there was a three-way interaction between category, AP and site. Further analysis at each of the three levels of the AP factor showed a relatively greater positivity for hits at all three AP levels (frontal: $F(1,15) = 17.44$, $p<.001$, central: $F(1,15) = 47.67$, $p<.001$ and parietal $F(1,15) = 45.59$, $p<.001$). There were also significant interactions between category and site at all three levels of the AP factor (frontal: $F(1.3, 20.2) = 23.42$, $p<.001$, central: $F(1.2, 17.5) = 41.72$, $p<.001$ and parietal: $F(1.3, 19.3) = 42.29$, $p<.001$) which reflected the fact that the relatively greater positivity for hits was consistently smallest at inferior sites. Examination of Figure 8.1 shows that the initial three-way interaction was most likely because the old/new effects are larger at posterior superior sites.

For the contrast between correct rejections and repeated hits there was an interaction between category and site. This interaction was due to the relatively greater positivity for repeated hits being largest at sites closest to the midline. The final contrast between hits and repeated hits revealed a three-way interaction between category, AP and site. Further analysis at each of the three levels of the AP factor showed a relatively greater positivity for hits at central sites only ($F(1,15) = 5.12$, $p<.05$). There were also a significant interaction between category and site at central sites ($F(2.2, 33.1) = 4.62$ $p<.05$), reflecting the fact that this relatively greater positivity for hits was maximal at central superior sites. There was also an interaction between category and site at parietal locations ($F(1.7, 24.9) = 3.77$, $p<.05$), reflecting the fact that there was a relatively greater positivity for repeated hits at P8 whereas across all other parietal locations hits were consistently more positive-going.

800-1000 ms:

Midline analyses:

The initial midline analysis revealed a main effect of category ($F(1.3, 19.5) = 12.04$, $p<.001$). The follow-up analyses revealed that the ERPs evoked by hits were reliably more positive-going than those elicited by correct rejections ($F(1,15) = 12.44$, $p < .005$) and repeated hits ($F(1,15) = 14.51$, $p<.005$). The final contrast revealed no reliable differences between correct rejections and repeated hits.

Global analyses:

The second set of analyses for this time window revealed a main effect of category ($F(1.7, 25.4)= 13.65$, $p<.001$), as well as an interaction between category and site ($F(1.3, 19.2) = 18.71$, $p<.001$), which was moderated by a three-way interaction between category, AP and site ($F(4.0, 59.9) = 5.72$, $p<.001$).

The follow-up contrasts (Table 8.2) show that between hits and correct rejections there was a three-way interaction between category, AP and site. Further analysis at each of the three levels of the AP factor showed a relatively greater positivity for hits at all three AP levels (frontal: $F(1,15) = 12.31$, $p<.001$, central: $F(1,15) = 27.35$, $p<.001$ and parietal $F(1,15) = 26.94$, $p<.001$). There were also significant interactions between category and site at all three levels of the AP factor (frontal: $F(1.4,18.6) = 18.25$, $p<.001$, central: $F(1.3, 19.5) = 25.36$, $p<.001$ and parietal: $F(1.4,18.3) = 32.30$, $p<.001$). These reflected the fact that the relatively greater positivity for hits was consistently largest at superior sites. Examination of Figure 8.1 shows that the most likely reason for the initial three-way interaction is that the ERP old/new effects are smallest at anterior sites. For the contrast between correct rejections and repeated hits there were no reliable effects.

The final contrast between hits and repeated hits revealed a three-way interaction between category, AP and site. Additional analysis at each of the three levels of the AP factor showed significant interactions between category and site at frontal ($F(1.4, 16.9) = 7.89$, $p<.01$), central ($F(1.3, 15.3) = 6.71$ $p<.01$), and parietal sites ($F(1.1, 15.3) = 18.16$, $p<.001$) which reflected the greater relative positivity for hits being largest at sites closest to the midline. There was a main effect of category at central sites ($F(1,15) = 8.49$, $p<.05$) only, reflecting the fact that the relatively greater positivity for hits was maximal at central midline locations.

Mid-frontal ERP old/new effects:

To further investigate the mid-frontal old/new effect, an additional directed analysis was conducted. This involved the mean amplitudes for hits, misses, repeated hits and correct rejections at F3, Fz and F4 in the 300-500 ms time window. Figure 8.2 is relevant to the following statistical analyses and shows the ERPs elicited by the four classes of items at electrode sites F3, Fz, and F4. The figure illustrates that from approximately 300 ms hits and repeated hits are both more positive-going than misses and correct rejections, with minimal differences between the latter two classes of item.

The analyses revealed a main effect of category only ($F(2.0, 30.6) = 5.08$, $p<.05$). Paired contrasts revealed that hits ($F(1,15) = 13.01$, $p<.05$) as well as repeated hits ($F(1,15) = 28.32$, $p<.001$) were both more positive-going than correct rejections at these mid-frontal electrode sites. The contrast between hits and correct rejections also revealed an interaction with site ($F(1.9, 28.6) = 4.47$, $p<.05$) which reflects the fact that the mid-frontal ERP old/new effect for studied words is largest at Fz. This is shown in Figure 8.3, which includes a topographic map of the differences in neural activity at the scalp between hits and correct rejections over the 300-500 ms time window. The contrast between misses and correct rejections revealed no significant effects. There were also no significant effects for the contrasts between both classes of hits and misses. The final contrast between hits and repeated hits revealed an interaction between category and site ($F(1.9, 28.7) = 3.68$, $p<.05$) because of a greater relative positivity for hits at F3 and FZ, with the reverse being true at F4.

Left-parietal ERP old/new effects:

This analysis involved the mean amplitudes for hits, misses, repeated hits and correct rejections at P3, P5, P4 and P6 in the 500-800 ms time window. Figure 8.4 is relevant to the following statistical analyses and shows the ERPs elicited by the four classes of items at electrode sites P3/4 and P5/6. The figure shows that in the critical 500-800 ms time window there are large ERP old/new effects for both hits and repeated hits, with little difference between misses and correct rejections. The ERP old/new effect for hits is sustained throughout the recording epoch, whereas the ERP old/new effect for repeated hits becomes attenuated after 900 ms.

The directed analyses revealed a main effect of category ($F(2.2, 32.5) = 26.23$, $p < .001$). This was followed up by all possible paired contrasts, and the outcomes of these showed that ERPs evoked by hits and repeated hits were reliably more positive-going than those evoked by correct rejections (hits: $F(1,15) = 49.27$, $p<.001$, repeated hits: $F(1,15) = 35.38$, $p<.001$) and misses (hits: $F(1,15) = 35.28$, $p<.001$, repeated hits: $F(1,15) = 27.75$, $p<.001$). There were also interactions between category and site for the contrasts between repeated hits and correct rejections ($F(2.8, 42.3) = 14.87$, $p<.001$) and hits and correct rejections ($F(1.8,26.7) = 4.82$, $p<.05$) which reflected the fact that the relatively greater positivities for both hits and repeated hits were smallest at P4. The greater positivity for hits and repeated hits relative to correct rejections is further illustrated in Figure 8.3, which shows scalp distributions of the ERP old/new effects for hits and repeated hits. The data are shown for the 500-800 ms epoch in the middle panel and demonstrate a degree of left hemisphere lateralisation for both old/new effects. The contrast between hits and misses also showed an interaction between category and site ($F(1.8,26.8) = 3.86$, $p<.05$) which was because of the greater relatively positivity for hits at P3. The two contrasts between the ERPs evoked by hits and repeated hits, and misses and correct rejections revealed no reliable effects over this time window.

Discussion

At issue here were the boundary conditions under which recollection of some kinds of information can be prioritised at the expense of others. The findings in experiments 1, 2 and 3 are consistent with the view that it is not possible for the recollection of non-target information to be controlled within the paradigm utilised in all of the experiments presented here. The findings in Experiment 5, however, show that with a higher level of target accuracy it is possible for information relating to the target items to be prioritised over that for the non-target items.

The motivation for the study described in this chapter was to assess the impact of limiting the available response time for making task judgments on the patterns of left-parietal ERP old/new effects observed. As such both the behavioural and ERP experimental findings relevant to this key issue will be discussed first in the following sections. The sections will conclude with a brief discussion of further ERP findings of differences according to condition that occur in the 300-500 ms time window and their relevance to the functional interpretation of the mid-frontal ERP old/new effect.

Left-parietal ERP old/new effects

An attenuated parietal old/new effect was observed for non-targets in Experiment 5, perhaps because participants probed each test cue judged to be old specifically for source information diagnostic of a target, and that this retrieval strategy was facilitated by the fact that memory for targets was reliable. Experiment 6 tested the hypothesis that limiting the time available to make task responses would result in the adoption of a similar retrieval strategy and result in attenuation of the left-parietal ERP old/new effect for non-targets. This hypothesis was examined by incorporating a response time limit of 1 second in the same paradigm as employed in Experiment 3. Memory for targets was poorer in Experiment 6 than in Experiment 3 (probability of a correct target response was 0.56 compared to 0.62), and mean RTs for correct responses to targets were quicker (691 ms compared to 948 ms). However, the directed analyses of the modulations of parietal ERP old/new effects for targets and non-targets revealed that the ERP old/new effects were reliable for both targets and non-targets in the 500-800 ms time window. This pattern of data replicates that of experiments 1, 2 and 3 and is consistent with the view that participants did not prioritise the recollection of target information in order to complete the task. Conversely, in the later time window of 800-1000 ms there was a significant attenuation of the old/new effect for non-targets. This greater relative positivity for correct target judgments shows a bilateral distribution maximal at central sites (see Figure 8.3) that is not characteristic of a parietal ERP old/new effect. The effect is also maximal at 800 ms, which is after the approximate time window in which task responses were made, and this suggests that this modulation most likely does not reflect the engagement of a strategy of prioritising the recollection of target information in order to make accurate task judgments.

Therefore, the imposition of a limited test response time was insufficient to influence the strategic retrieval processes that are engaged during this variant of the exclusion task when target accuracy is not that high. The findings consequently, support the view of Herron & Rugg (2003b) that it is the degree to which the recollection of information of targets is likely that determines of the extent to which recollection of information about non-targets will be prioritised (Herron & Rugg, 2003b). The findings do not however, rule out the possibility that a strategy of prioritising target information over non-target information could be achieved by imposing a shorter deadline, or through the use of an additional task which might limit the available resources.

An additional task-load was imposed on participants in two studies conducted by Dywan, Segalowitz & Webster (1998). They found that, in the standard version of the paradigm employed here, older participants (mean age 69.8 years) were relatively poor at correctly rejecting repeated test items and showed parietal old/new effects for both these items and for studied items. Young participants (mean age 23.9 years) showed a superior ability to correctly reject the repeated test items but exhibited a parietal old/new effect for the studied items only. In a follow up experiment, the young participants completed the same task with additional task demands. The additional task requirements were that participants had to listen to a string of random numbers between 1 and 9 and to press a mouse key with the index finger of their non-dominant hand whenever they heard 3 odd numbers in a row. Under these divided attention conditions, the young participants showed the same pattern of behaviour as the old participants, and the same pattern of ERP old/new effects (Dywan, Segalowitz, & Webster, 1998).

Dywan et al. (1998) argued that the younger participants exercised greater selective attention, and that the fact that repeated test items did not elicit a parietal old/new effect reflected this control. Of interest of course is at what level this attentional control is hypothesised to operate; whether recollection itself or the use of recollected information was subject to control. It is possible that recollection of non-targets was itself actively inhibited. Alternatively, non-target information may have been available to episodic retrieval, but control processes prevented this information from being attended to. This point will be returned to later in the thesis. These previous findings suggest that in some circumstances increasing task demands does influence the strategic control of retrieval. The findings of this experiment suggest that response demands do not.

Mid-frontal ERP old/new effect

The directed analysis of the mid-frontal ERP old/new effect confirmed that there were reliable ERP old/new effects for both studied and repeated test items. There were no differences between the two classes of old item and misses, and misses were also not reliably different in magnitude to correct rejections. There were, however, reliable differences between hits and repeated hits, with hits being more positive-going. The data does not contradict the proposal that an anteriorly distributed modulation occurring in this time window is an index of familiarity (for a comprehensive review, see Curran et al, 2006), but there would be stronger support for this functional interpretation of the mid-frontal ERP old/new effect had misses been of an amplitude reliably less positive-going than that associated with hits and repeated hits, but more positive-going than correct rejections, as discussed in Chapter 6.

Concluding remarks

At parietal electrode sites in the 500-800 ms time window ERP old/new effects were found for targets and non-targets, replicating the findings of experiments 1, 2 and 3. Furthermore, this pattern of data was obtained even when the time in which test responses had to be made was reduced.

The main issue here was the boundary conditions under which recollection of some kinds of information can be prioritised at the expense of others. Experiment 5 showed that it was possible for the recollection of non-target information to be controlled in this paradigm. Experiment 6 was designed in order to determine whether factors other than the accuracy of target judgments influence the conditions under which strategic recollection processes are engaged. The reason for introducing a response deadline at test was to see if by limiting the time available to make responses participants would default to an approach whereby they relied on the success or failure of recollecting information about targets to complete the task successfully. However, the fact that there were significant left-parietal ERP old/new effects for both targets and non-targets provides little evidence to suggest that this manipulation encouraged the implementation of a strategy of prioritising the recollection of target information.

Figure 8.1. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at sites F3/F4, C3/C4, P3/P4, Fz, Cz and Pz in Experiment 6.

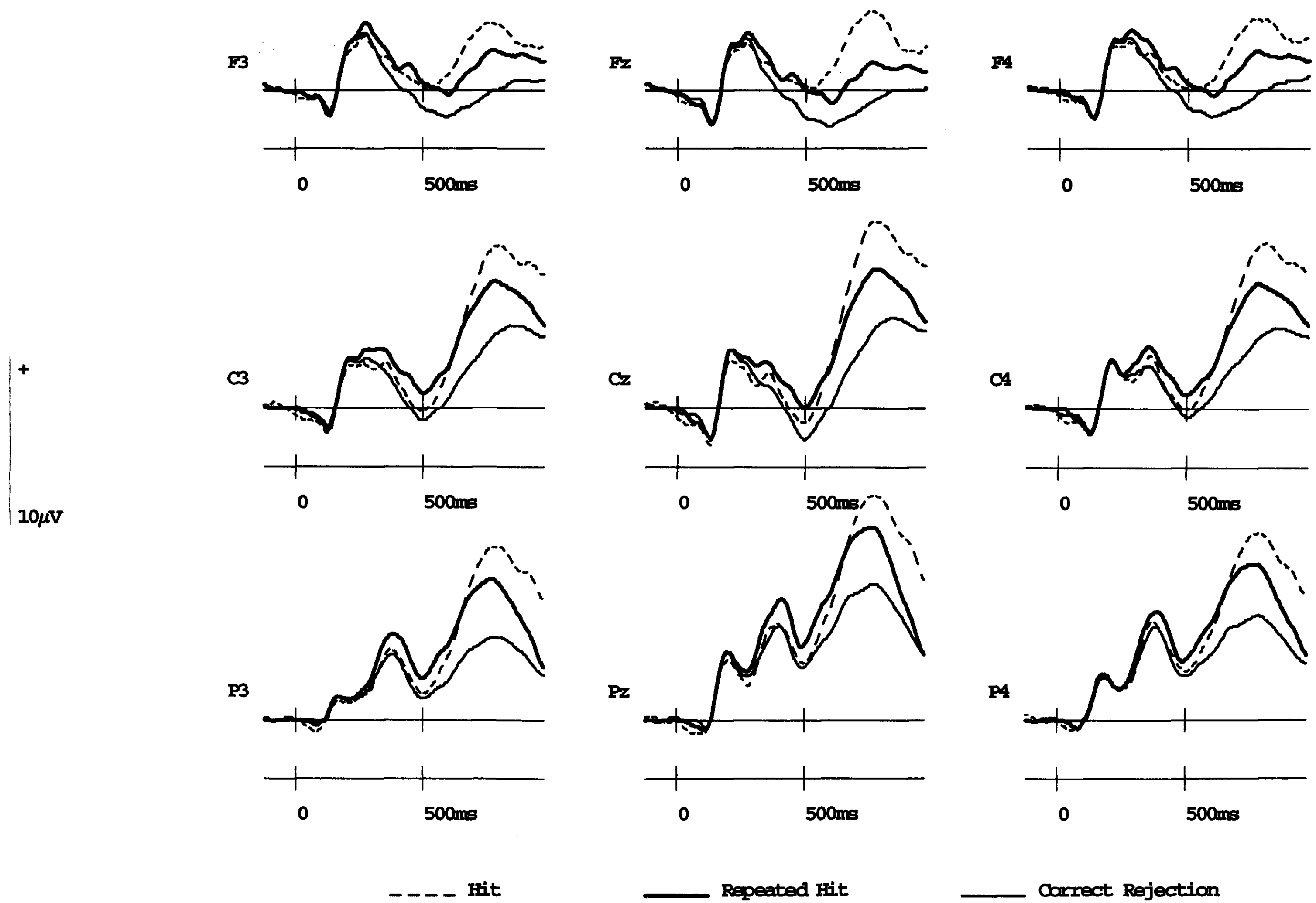


Figure 8.2. Grand averaged ERPs elicited by hits, misses, correct rejections and repeated hits at sites F3, Fz, F4 in Experiment 6.

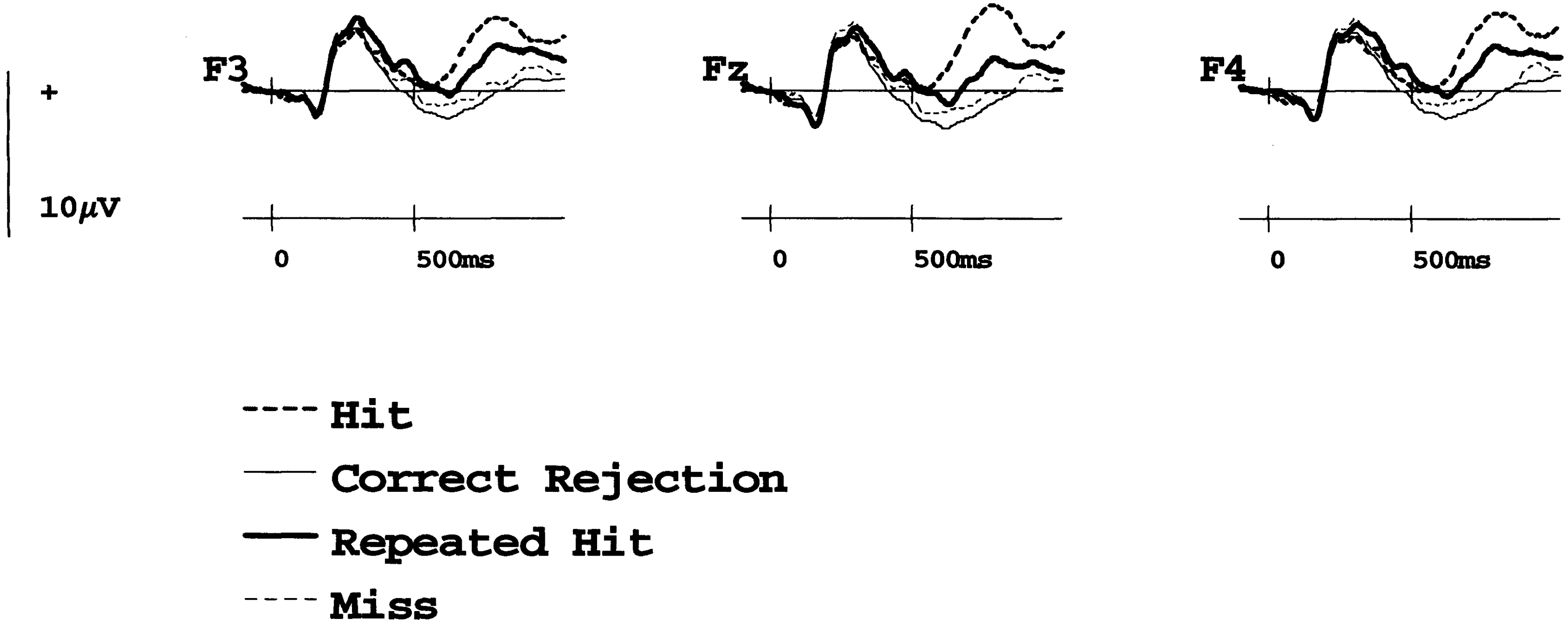


Figure 8.3. Scalp distributions of the ERP old/new effects for hits, repeated hits and misses in Experiment 6. The data are shown for three post-stimulus epochs: 300-500, 500-800 and 800-1000 ms. The maps were computed from scores obtained by subtracting mean amplitudes from the ERPs evoked by correct rejections from hits, misses and repeated hits. The paired values below each map denote the maxima and minima of the amplitude differences between response categories, which can be interpreted relative to the colour bar on the right-hand side of the figure.

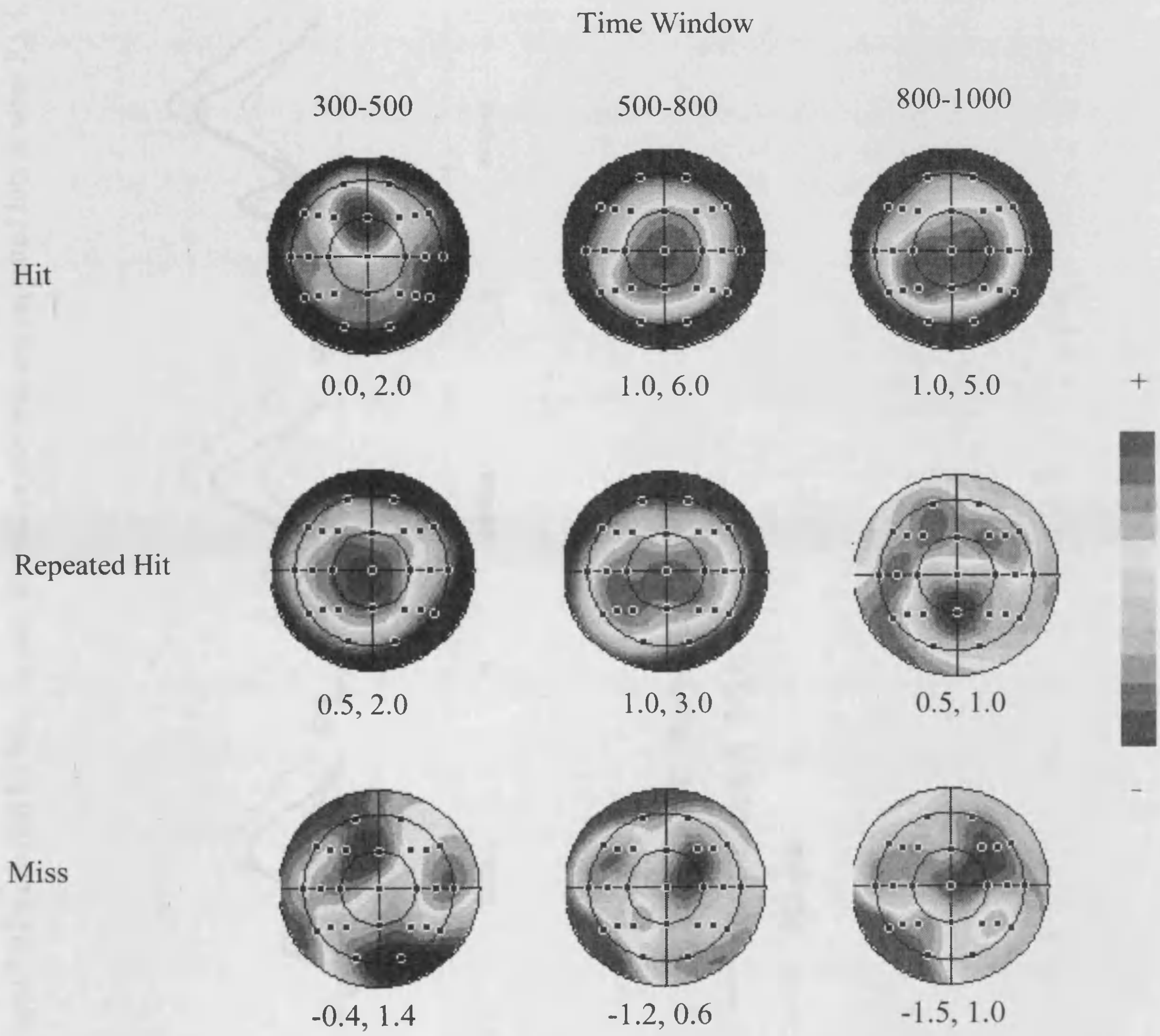
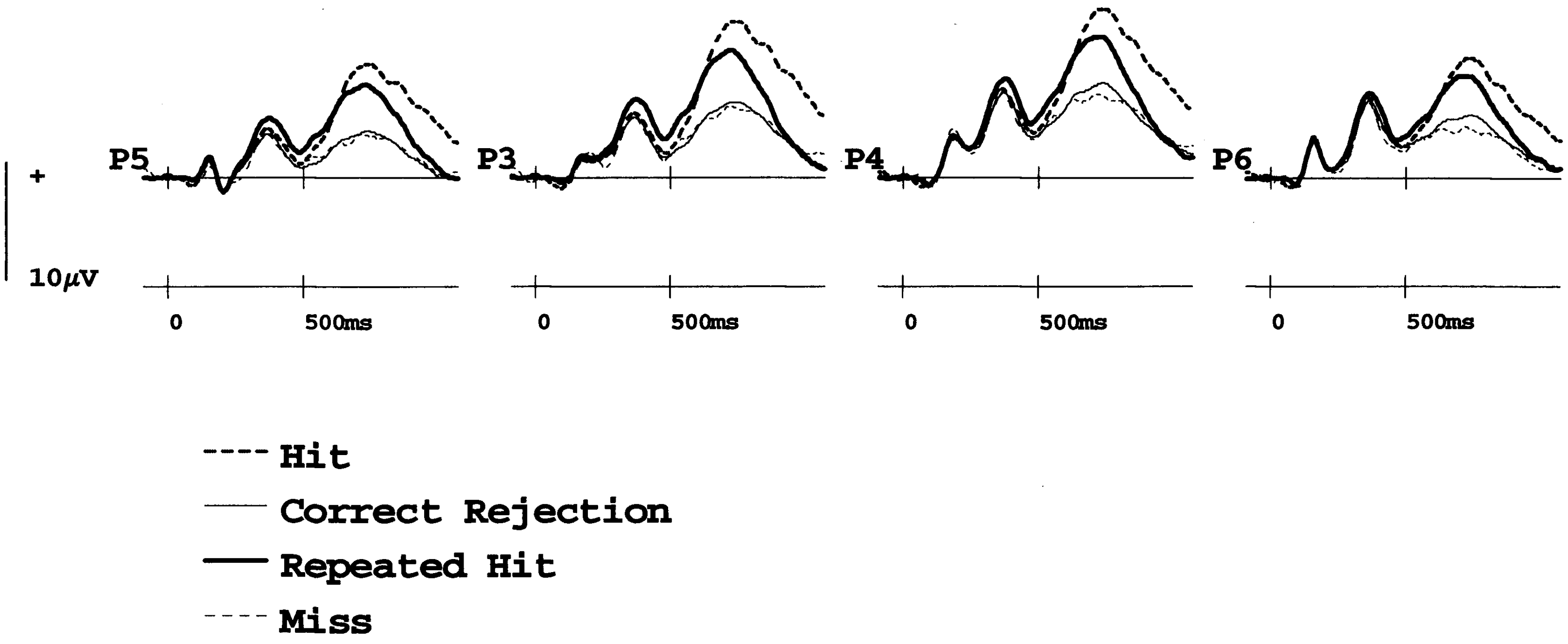


Figure 8.4. Grand averaged ERPs elicited by hits, misses, correct rejections and repeated hits at sites P3/4, P5/6 in Experiment 6.



Chapter Nine

Experiment 7

Introduction

The purpose of the study described in this chapter is to explore the functional information that MEG data can provide in memory retrieval tasks. Since the introduction of magnetoencephalography (MEG) (Cohen, 1968; Cohen, 1972), this non-invasive method has been compared with EEG to determine how they may be used as complementary encephalographic techniques. Theoretical studies (Geselowitz, 1970; Grynszpan & Geselowitz, 1973; Cohen & Hosaka, 1976; Cuffin & Cohen, 1979; Meijs et al., 1987; Hämäläinen & Sarvas, 1989), and an experimental study by Barth et al. (1986), have shown that MEG currents are uninfluenced by the skull (Kaufman et al., 1981), unlike EEG, where the signal is distorted. The amplitude of the magnetic current is also governed by two basic laws. The law of Biot and Savart states that the magnetic field falls off with the square of distance from a current source. Secondly, a radially orientated current element produces no magnetic field outside a concentrically homogeneous volume conductor (Sarvas, 1987). These two laws have given rise to the anecdotal assumptions (Tallon-Baudry, Bertrand & Pernier, 1999) that, unlike EEG, MEG is insensitive to tangential sources, and that it is also insensitive to deep sources. This is despite several papers (e.g. Hari, Joutsiniemi & Sarvas, 1988; Lutkenhoner, 1996) showing that deep sources can be localised and that source orientation is not a significant factor limiting localisation accuracy (Leahy et al., 1998, Hillebrand & Barnes, 2001).

In spite of these differences in sensitivity to cortical activity, MEG and EEG are similar in many respects since they are both due to neuronal currents (Barth & Sutherling, 1988; Okada & Nicholson, 1988; Okada, 1989; Barth & Di, 1990; Lopez, Chan, Okada & Nicholson, 1991; Okada, Whu & Kyuhou, 1997) (see Figure 9.1.for details), hence both techniques provide real-time information about neural and cognitive processing. Comparisons of source localisation in MEG and EEG in humans have shown that these techniques are in some instances capable of providing very similar localisations, but discrepant localisations in other cases (Cohen and Cuffin, 1983; Wood et al., 1985; Sutherling et al., 1988; Sutherling et al., 1991; Nakasato et al., 1994). In general, the account of the differences given above provides reasons why source localisation should be superior for MEG than for EEG.

The question addressed here is a related one, with the key issue being the functional information that MEG may provide when analyses are restricted to surface potentials. This is of interest as MEG signals at a given sensor (or cluster of sensors) may index activity from fewer overlapping fields and neuronal generators than EEG signals, because of the relative insensitivity of the technique to deep sources due to the signal falling off rapidly over distance, and the absence of signal smearing by media lying between source and sensor.

Due to these properties, analysis of event-related field (ERF) surface potentials may provide functional information complementary to that which can be obtained by analysing ERPs: signals with different functional properties may be obscured in EEG but not MEG because for EEG signal distortion may not permit a separation of the signals at proximal electrode locations.

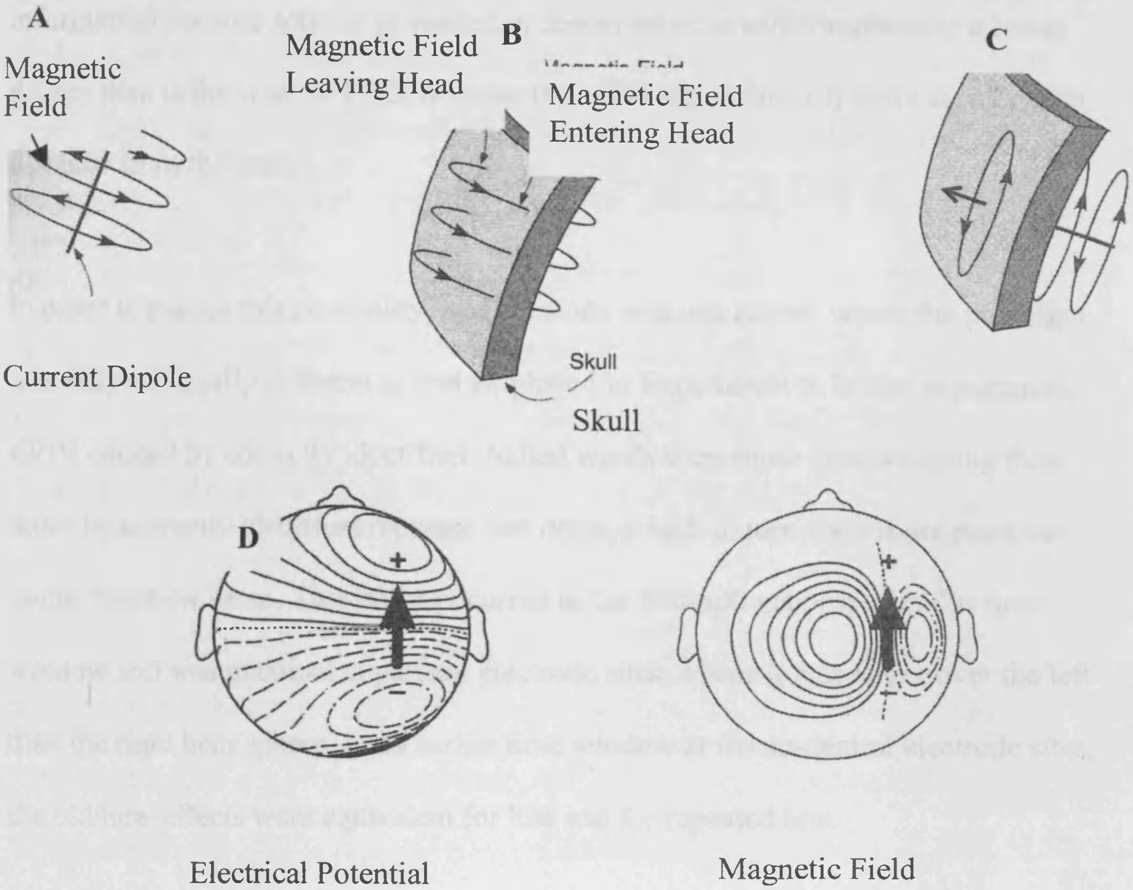


Figure 9.1. Relationship between an electrical dipole and the associated magnetic field. An electrical dipole has a magnetic field running around it (A), and when the dipole is roughly parallel to the surface of the head (tangential), the magnetic field leaves and re-enters the head (B). If the dipole is oriented radially with respect to the head, the dipole does not have any magnetic field outside the head (C). When a dipole runs parallel to the surface of the head (represented by the arrow in D), there is a broad region of positive voltage at the positive end (solid lines) and a broad region of negative voltage at the negative end (dashed lines), separated by a line of zero voltage (represented by the dotted line). The magnetic field, in contrast, consists of magnetic flux leaving the head on one side of the dipole (solid lines) and re-entering the head on the other side (dashed lines), separated by a line of no net flux (dotted line). Image adapted from Luck (2005).

Additionally, signals at a given sensor for MEG may provide clearer functional information because activity generated in deeper sources will contribute to a lesser degree than is the case for EEG, because the MEG signal falls off more rapidly with distance from the source.

In order to pursue this possibility, a MEG study was conducted, where the paradigm was only minimally different to that employed in Experiment 5. In that experiment, ERPs elicited by correctly identified studied words were more positive-going than those by correctly identified repeated test items, which in turn were more positive-going than new items. This effect occurred in the 500-800 ms post-stimulus time window and was maximal at parietal electrode sites, where it was larger over the left than the right hemisphere. In an earlier time window at fronto-central electrode sites, the old/new effects were equivalent for hits and for repeated hits.

These findings provide temporal guides for analysis of ERF old/new effects. If ERFs are also sensitive to these processes, then ERF effects with similar time courses, somewhat similar scalp distributions, and similar sensitivities to manipulations should be obtained. The forgoing observations, however, raise the possibility that not all ERP old/new effects will be evident in the magnetic record, that functionally comparable modulations may not be equally sensitive to experiment manipulations, and that there are ERF old/new effects with no electrical homologue.

There are only a small number of MEG studies of recognition memory, and in only a subset of these has the data been presented in a way that permits questions about the sensitivity of scalp-recorded ERFs to cognitive processes to be resolved. One reason for this is that in some experiments data from source space only has been reported, occasionally with surface potentials shown but not analysed (Duzel et al., 2005; Lee, Simos, Sawrie, Martin & Knowlton, 2005; Dhond, Witzel, Dale & Halgren, 2005). In other experiments, the contrasts have been restricted to differences between only a pair of experiment conditions (Walla et al., 1999; Tendolkar et al., 2000; Walla et al., 2001; Duzel et al., 2003). For example, Tendolkar et al. reported an ERF effect with spatio-temporal characteristics akin to the left-parietal ERP old/new effect, and which differentiated between old and new words to which correct recognition memory judgments were made (Tendolkar et al., 2000).

While this contrast is sufficient to provide indicators of the spatio-temporal correspondence between ERP and ERF effects of interest, claims that effects obtained in the two modalities are functionally equivalent, or in fact index distinct processes, depend ultimately upon how the effects in question vary according to experiment manipulations. This requires at least three conditions.

In one study that fits this criterion (Staresina, Bauer, Deecke & Walla, 2005), ERF old/new effects were acquired in a task where participants made old/new judgments to words, and for the old words also made a binary distinction between items for which the old judgment was a high or a low confidence response. The analyses comprised paired contrasts between the ERFs associated with misses and with hits, separated according to confidence. The initial analyses revealed no effects that differentiated old items split according to confidence, but there were effects that differentiated these response categories from the ERFs associated with misses between 300 and 500 ms (Staresina et al., 2005). There was some evidence that two sets of generators were responsible for the effects, but functional specification and fractionation of the modulations is constrained by the fact that, at least in this experiment, they were sensitive only to whether old items attracted a correct or an incorrect response. The small effects that were obtained suggest that these findings will benefit from subsequent studies in which related contrasts are made.

In summary, the sensitivity of MEG to the multiple processes that support memory judgments is not well established. Consequently, Experiment 7 was designed to identify MEG correlates of memory processes in an exclusion task. At issue is the utility of analysing surface fields acquired in MEG studies as a means of complementing the functional claims that can be made on the basis of analysing event-related potentials.

Methods

Participants

17 right-handed people (14 female) were paid at the rate of £7.50/hour and gave informed consent prior to participating in the experiment. Data from 1 participant (female) was excluded due to poor performance on the task (probability of a correct judgment to a new word was 0.04). The average age of the remaining participants was 21 years (range 18 to 23). Participants were all right-handed native English speakers. No participants were taking neuroleptic medication at the time of testing or reported a history of mental illness. All were paid at a rate of £7.50/hour and gave informed consent prior to commencing the experiments.

Stimuli and Design

Stimuli at both study and test were as for Experiment 5, (see Chapter 7).

Procedure

The study phase was preceded by a 20 min period during which participants were fitted with 3 head localisation coils (see below) and seated beneath the MEG device. Study and test phases were completed in a magnetically shielded testing chamber. In each study phase, participants completed one encoding task for all words. They were asked to say aloud the presented study word. An asterisk before study words initiated each study trial and remained on the screen for 500 ms. The screen was then blanked (100 ms) before the study word was presented for 300 ms. Participants were asked to give their response after each study word appeared. The next trial started 1000 ms after the previous study word offset.

Each test trial started with a 'Blink Now' screen (1500 ms duration) followed by a fixation asterisk (500 ms duration), which was removed from the screen 100 ms prior to presentation of a test word (300 ms duration). The screen was then blanked until the participant responded, and the next trial started 1700 ms afterwards. Test responses were as for Experiment 5. Responses were made on a key-pad with the index and middle fingers of the same hand. The fingers and hands used for responses were balanced across participants. Participants were also instructed to restrict their blinking to only when the 'Blink Now' screen was presented.

MEG acquisition

The MEG was a whole-head system (275channel) manufactured by CTF Systems Inc. (Canada). An additional 29 reference channels were recorded for noise cancellation purposes and the primary sensors were analysed as synthetic third order gradiometers (Vrba, 2001). 3 of the 275 channels were turned off due to excessive sensor noise. The sampling rate was 1200 Hz and recordings were filtered offline with a bandpass of 0.03 to 40 Hz. The coordinates of the MEG data sets were based on the participants' nasion and left and right preauricular points in relation to the sensor locations. Intra-individual head movement was kept to a minimum, and head position was localised at the start and finish of each study-test block. Data were epoched off-line into 2000 ms epochs, with a 200 ms pre-stimulus baseline, relative to which all mean amplitudes were computed. Trials containing large artefact and those containing obvious blink related activity were rejected (mean number of trials rejected per participant = 8%).

Results

Behavioural Data

Table 9.1 displays the probabilities of correct and incorrect responses to each class of test word.

Two measures of discrimination (Pr: Snodgrass & Corwin, 1988) were calculated as in previous experiments. In both cases Pr was reliably greater than 0 (Pr values = 0.61 and 0.51: $t(15)=21.02$, $p<.001$ and $t(15) = 14.87$, $p<.001$). These two Pr scores differed reliably from each other ($t(15) = 5.63$, $p<.001$) due to discrimination between old words and new words being superior to that between old words and repeated test words.

Table 9.1. Probabilities of correct (p(correct)) and incorrect (p(incorrect)) responses and reaction times in milliseconds (RT) to old, new and repeated test words in Experiment 7.

	Word class		
	Old	New	Repeated test
p(correct)	0.67 (0.15)	0.93 (0.08)	0.84 (0.12)
RT	929 (329)	827 (300)	887 (395)
p(incorrect)	0.33 (0.15)	0.07 (0.08)	0.16 (0.12)
RT	996 (165)	1111 (376)*	1035 (307)

* includes data from the 15 participants who made at least 1 incorrect response to new items.

Measures of response bias (Br) were also calculated. For the discrimination involving new words the value of Br was 0.19, while Br for the discrimination involving repeated test words was 0.34. Br scores differed reliably from each other ($t(15) = 6.17$, $p<.001$), with the values indicating a more conservative bias for new words (Snodgrass & Corwin, 1988).

A one-way ANOVA on the RTs for correct responses revealed significant differences between category ($F(1.3, 19.9) = 6.10$, $p<.05$). Follow up paired comparisons showed that RTs for correct responses to new words were quicker than those for correct responses to old words and repeated test words ($t(15) = 7.74$, $p<.05$ and $t(15) = 12.53$, $p<.01$ respectively). A one-way ANOVA on the RTs for incorrect responses, for the 15 participants who provided at least 1 incorrect old word judgment, revealed significant differences between word class ($F(1.9, 26.9) = 3.67$, $p<.05$). Paired comparisons showed that RTs for incorrect responses to old words were quicker than those for incorrect responses to new words ($t(14) = 7.49$, $p<.05$).

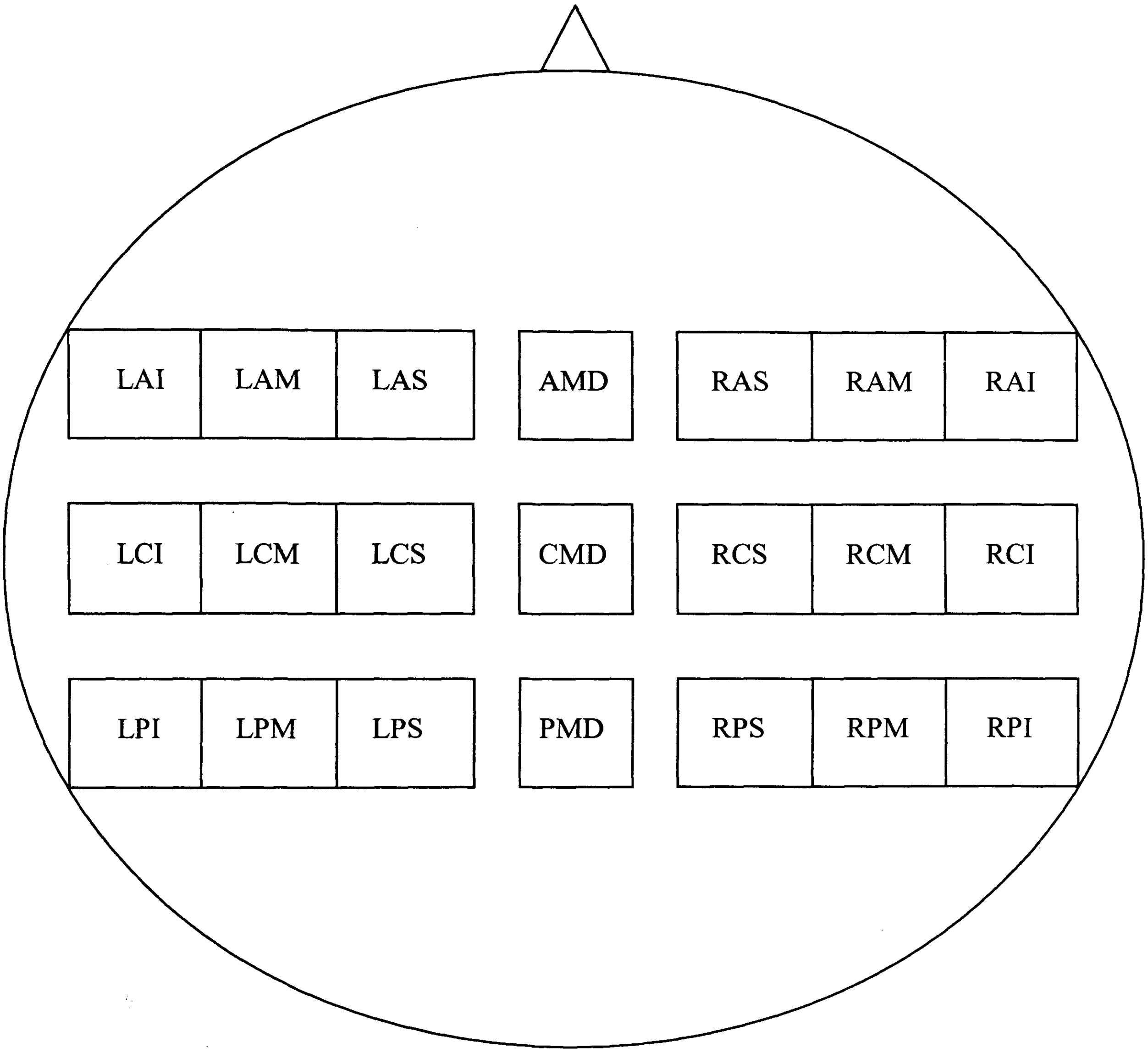
ERF data

ERFs could in principle be obtained for 6 response categories: correctly and incorrectly identified old, new and repeated test words. Too few participants made sufficient (16 or more) incorrect judgments to old, new and repeated test words (2, 10 and 8 participants respectively) to permit analysis of the ERF data for these response categories. As a consequence, the data from the correctly identified old words (hits), new words (correct rejections) and repeated test words (repeated hits) were analysed for the 16 participants who contributed sufficient artefact-free trials to the hit, correct rejection and repeated hit response categories. Mean trial numbers for these response categories were 63 (range 40-83), 267 (range 190-293) and 79 (range 56-91), respectively.

For the ERF data analyses, 4 or 5 MEG sensor channels were clustered into groups in regions of interest (ROI). The ERP experiments within this thesis have used the International 10-20 system (Jasper, 1958) electrode locations. Thus, the ROIs for Experiment 7 were selected a priori, based approximately on the electrode locations used in experiments 1-6 (see Figure 9.2 for locations of ROIs, and Appendix 9.2 for full electrode array). Mean amplitudes were then calculated for each participant across the clustered sensor channels at each ROI. The sensor clusters are labelled according to the ROI, and these labels will be used hereafter to describe the cluster regions.

Due to the underlying differences in MEG and EEG acquisition the analysis strategy for the ERF data predominantly concentrated on the timing of functionally related effects, and as such used the time windows in which the reliable ERP modulations were found for Experiment 5. A broad range of locations were included in the analyses in order to identify modulations in the ERF that may occur across the scalp. Therefore, the ERF data were analysed over three time windows: 300-500, 500-800 and 800-1100 ms. For the three time windows, one set of analyses were completed (Global analyses), in which data only from lateral electrode regions were included. Visual inspection of the ERF waveforms (see Appendix 13 for grand averaged data at all sensor locations) showed minimal item related differences at midline sites, as such no statistical analyses were conducted on the midline data.

Figure 9.2. ROI locations. L= left, R = right, A= anterior, C= central, P= posterior, S = superior, M= mid-lateral, I = inferior, MD= midline.



For the analyses including lateral locations, the data comprised ERFs acquired from 18 ROIs, an equal number at left and right hemisphere sites at anterior (LAS, LAM, LAI, RAS, RAM, and RAI), central (RCS, RCM, RCI, LCS, LCM, and LCI) and posterior (RPS, RPM, RPI, LPS, LPM, and LPI) locations. These analyses included the factors of category, location in the anterior/posterior plane (AP), location in the left-right plane (HM: left hemisphere, right-hemisphere) and site (inferior, mid-lateral, and superior). The analyses were conducted on the data from all 16 participants for correct responses to old, new and repeated test words. Significant effects involving category were followed up by all possible paired contrasts between the three response categories. For the analyses including lateral scalp regions, interactions with the AP and/or HM dimension were followed up by analyses at each level of the relevant factor.

Two additional directed analyses were also conducted. The first was carried out to assess changes across conditions in the approximate region of the mid-frontal ERP old/new effect, and was carried out in the 300-500 ms time window. The analyses included data from inferior and midlateral locations only, and included the factors of category and site (four levels: LAI, LAM, RAI and RAM). The second directed analysis addressed directly changes across conditions relating to the left-parietal ERP old/new effects and included factors of category, hemisphere, and site (four levels: LPS, LPM, RPS and RPM), and was completed over the 500-800 ms time window. The results of the midline and global analyses for all 16 participants are reported first followed by the findings for the two directed analyses.

Hits, repeated hits and correct rejections

Figure 9.3 is relevant to the following statistical analysis and shows the ERFs elicited by hits, correct rejections and repeated hits at left and right anterior, central and posterior inferior, and mid-lateral ROIs. The figure also shows that the distribution of effects at LAS and RAS are polarity reversals of each other and as such most likely represent the opposing ends of a single source dipole. The same is true, although to a lesser degree, of LPS and RPS. The figure shows that from approximately 250 ms until 550 ms at the left anterior locations repeated hits and hits are both more positive-going than correct rejections, with repeated hits being more positive-going than hits. From 600 ms this latter difference becomes reversed, but with both classes of old item remaining more positive-going than correct rejections. At the left posterior locations from 200–450 ms correct rejections are more positive-going than hits and repeated hits, with minimal differences between the two classes of old item. After 500 ms hits become more positive-going than both repeated hits and correct rejections, between which there are no discernible differences.

300-500 ms

Global analyses:

The analyses revealed a three-way interaction between category, AP and HM ($F(2.4,35.8) = 19.64$, $p<.001$) plus a four-way interaction between category, AP, HM and site ($F(3.7,55.2) = 4.81$, $p<.01$). The follow-up analyses comprised all possible paired contrasts of the three categories.

Table 9.2 shows the outcomes of the paired contrasts in the global analyses for all three time windows. For the 300-500 ms time window the contrast between hits and correct rejections revealed two three-way interactions between category, AP and HM ($F(1.7, 25.2) = 31.41$, $p<.001$) and category, AP and site ($F(2.8, 41.8) = 3.05$, $p<.05$).

Table 9.2. The outcomes of the paired contrasts between the mean amplitudes associated with hits, correct rejections and repeated hits for the <u>global</u> analyses over the 300-500, 500-800 and 800-1100 ms time windows. CR = correct rejection, RHit = repeated hit, CC = condition, HM = hemisphere, AP = anterior/posterior plane, SI = site, df = degrees of freedom. *** = p<.001, ** = p<.01, * = p<.05, ns = non-significant. Epsilon values are shown in brackets.

	df	Hit vs CR	RHit vs CR	Hit vs RHit
300-500 ms				
CC x HM	1,15	ns	10.14**	ns
CC x AP x HM	2,30	$31.41_{(.84)}$***	$37.08_{(.72)}$***	ns
CC x AP x SI	4,60	$3.05_{(.70)}$*	ns	ns
CC x AP x HM x SI	4,60	ns	$9.82_{(.44)}$***	ns
500-800 ms				
CC x HM	1,15	42.87***	14.83***	10.92*
CC x AP x HM	2,30	$16.4_{(.88)}$***	$34.51_{(.82)}$***	ns
CC x AP x SI	4,60	$3.59_{(.63)}$*	ns	ns
CC x HM x SI	4,60	$6.48_{(.80)}$**	$6.12_{(.99)}$**	ns
CC x AP x HM x SI	4,60	$21.08_{(.72)}$***	$5.11_{(.54)}$**	$6.84_{(.63)}$***
800-1100 ms				
CC x HM	1,15	ns	ns	$4.76_{(.33)}$*
CC x AP x HM	2,30	$3.77_{(.97)}$*	$11.30_{(.73)}$***	ns
CC x HM x SI	4,60	$5.60_{(.93)}$*	ns	ns
CC x AP x HM x SI	4,60	$9.45_{(.59)}$***	ns	$3.83_{(.66)}$**

Further analysis at each of the three levels of the AP factor showed significant interactions between category, HM and site at anterior and posterior ROIs only (anterior: $F(1.6, 24.6) = 5.22$, $p<.05$, and posterior: $F(1.5, 22.1) = 4.77$, $p<.05$) which reflected, at anterior sites, a relatively greater positivity for hits in the left hemisphere, maximal at superior sites, with an opposing greater relative positivity for correct rejections in the right hemisphere. At posterior sites there was a greater relative positivity for correct rejections in the left hemisphere, maximal at superior sites, and an opposing greater relative positivity for hits in the right hemisphere, maximal at mid-lateral sites.

For the contrast between repeated hits and correct rejections there was a significant four-way interaction involving category, AP, HM and site ($F(1.8, 26.8) = 9.82$, $p<.001$). Further analysis at each of the three levels of the AP factor showed a significant interaction between category, HM and site at anterior ROIs ($F(1.4, 21.0) = 12.39$, $p<.001$). This reflected a greater relative positivity for repeated hits at left hemisphere inferior sites with the reverse being true at the corresponding right hemisphere sites. At posterior ROIs there was also an interaction between category and HM ($F(1, 15) = 3.95$, $p<.01$) which was due to the relatively greater positivity for correct rejections in the left hemisphere, with the reverse being true in the right hemisphere. For the hits versus repeated hits contrasts there were no significant differences.

500-800 ms

Global Analyses:

An interaction between category and HM ($F(2.0, 29.4) = 24.23$, $p<.001$) was obtained alongside significant three-way interactions between category, AP and HM ($F(3.0, 45.4) = 14.70$, $p<.001$), and category, HM and site ($F(2.9, 43.9) = 3.89$, $p<.01$). These were all moderated by a four-way interaction involving category, AP, HM and site ($F(3.6, 54.3) = 10.95$, $p<.001$).

For the 500-800 ms time window (middle portion Table 9.2) the highest order interaction in the contrast between hits and correct rejections involved category, AP, HM and site ($F(2.9, 43.0) = 21.08$, $p<.001$). Further analysis at each of the three levels of the AP factor showed significant interactions between category, HM and site at anterior and posterior sites only (anterior: $F(1.4,20.8) = 24.50$, $p<.001$ and posterior: $F(1.6, 24.1) = 17.64$, $p<.005$) which reflected a greater relative positivity for hits in left hemisphere inferior sites with the reverse being true at the corresponding right hemisphere sites.

The contrast between correct rejections and repeated hits also revealed a significant four-way interaction involving category, AP, HM and site ($F(2.1, 32.2) = 5.11$, $p<.01$). Analysis at each of the AP levels revealed interactions between category, HM and site at anterior sites only ($F(1.5, 22.1) = 18.72$, $p<.001$) which reflected a greater relative positivity for repeated hits at inferior sites in the left hemisphere, with the reverse being true at the corresponding sites in the right hemisphere.

The final contrast between hits and repeated hits revealed a significant four-way interaction involving category, AP, HM and site ($F(2.5, 38.0) = 6.84$, $p<.001$). Analysis at each of the three levels of the AP factor showed significant interactions between category and HM at anterior and posterior ROIs (anterior: $F(1,15) = 13.43$, $p<.005$, and posterior: $F(1,15) = 5.96$, $p<.05$). At anterior ROIs this was due to the relatively greater positivity for hits at LAI, with the reverse being true at RAI. This pattern of data was reversed at posterior ROIs.

800-1100 ms:

Global Analyses:

Revealed a significant three-way interaction between category, AP and HM ($F(2.9, 43.1) = 3.58$, $p<.05$) and a four-way interaction between category, AP, HM and site ($F(4.0,59.7) = 5.52$, $p<.001$). For the 800-1100 ms time window (lower portion Table 9.2) the highest order interaction in the contrast between hits and correct rejections was a four-way interaction involving category, AP, HM and site ($F(2.3, 35.2) = 9.45$, $p<.001$). Analysis at each of the three levels of the AP factor showed significant interactions between category, HM and site at anterior ROIs only ($F(1.3, 18.8) = 13.18$, $p<.001$). These were due to the relatively greater positivity for hits at inferior left hemisphere and superior right hemisphere ROIs.

The contrast between hits and repeated hits also revealed a significant four-way interaction involving category, AP, HM and site ($F(2.6, 39.5) = 3.83$, $p<.05$). Analysis at each of the three levels of the AP factor showed a significant interaction between category and HM and site at posterior ROIs only ($F(1,15) = 5.35$, $p<.05$).

This reflected the greater relative positivity for hits across the left hemisphere, with the reversed pattern observed across the right hemisphere.

The final contrast between correct rejections and repeated hits revealed a significant interaction between category, AP and HM ($F(1.5, 22.0) = 11.30$, $p<.001$). Further analysis at each of the AP levels showed an interaction between category and HM at anterior sites only ($F(1,15)= 6.66$, $p<.05$), which reflected the greater relative positivity for repeated hits at ROIs in the left hemisphere.

Mid-frontal ERP old/new effects:

To further investigate changes in ERFs across condition that may reflect the magnetic equivalent of the mid-frontal old/new effect, an additional directed analysis was conducted. This involved the mean amplitudes for hits, repeated hits and correct rejections at LAI, LAM, RAI and RAM ROIs in the 300-500 ms time window, as illustrated in Figure 9.4. The topographic maps in Figure 9.6 are relevant to the following statistical analyses and show the distribution of the ERF old/new effects for hits and repeated hits over the 300-500ms time window. In both figures the anterior old/new differences are maximal at left-hemisphere inferior sites. The analyses revealed an interaction between category and site ($F(2.2, 33.9) = 10.77$, $p<.001$). Paired contrasts within the experiment revealed a category by site interaction for the contrast between hits and correct rejections ($F(1.3, 19.5) = 5.61$, $p<.05$) which reflected the greater relative positivity for hits at LAI, with an opposing greater relative positivity for correct rejections at RAI. There was also a category by site interaction for the contrast between correct rejections and repeated hits ($F(1.7, 25.1) = 34.29$, $p<.001$). This came about due to a greater relative positivity for repeated hits at LAI, whilst at RAI the greater positivity was for correct rejections. There was also a category by site interaction for the contrast between hits and repeated hits ($F(1.3, 19.7) = 4.73$, $p<.05$) which reflected the greater relative positivity for repeated hits at LAM and for hits at RAM.

Left-parietal ERP old/new effects:

To further investigate any relation between ERFs and ERPs relating to recollection and the parietal old/new effect, a further additional directed analyses was conducted. This involved the mean amplitudes for hits, repeated hits and correct rejections in the LPS, LPM, RPS and RPM ROIs in the 500-800 ms time window (as illustrated in Figure 9.5). Figure 9.6 shows topographic scalp maps relevant to the following statistical analyses. They show the differences in scalp activity between the two classes of old item and correct rejections. At the posterior sites there is a greater relative positivity for hits over correct rejections at sites close to the midline. This old/new effect is not present for repeated hits. Further analyses revealed an interaction between category and HM ($F(1.8, 27.2) = 4.05$, $p<.05$). This was followed up by all possible paired contrasts, and the outcomes of these revealed interactions between category and HM for both the contrasts between hits and correct rejections ($F(1, 15) = 6.09$, $p<.05$) and the contrast between hits and repeated hits ($F(1, 15) = 7.34$, $p<.05$). These reflected the greater relative positivity for hits at LPS/LPM. There were no significant effects for the contrast between repeated hits and correct rejections.

Discussion

Experiment 7 explored the question of whether event-related fields (ERFs) provide functional homologues of ERP old/new effects that have been identified in electrophysiological studies of memory retrieval, as well as whether there are effects specific to one or other of these real-time measures of neural activity. This was carried out by replicating Experiment 5, in which there were distinct differences in the magnitudes of parietal ERP old/new effects for correct responses to targets and non-targets, and comparable mid-frontal ERP old/new effects. The patterns of response accuracy were markedly similar in the two experiments (see Tables 7.1 and 9.1), and the following section begins with a discussion of the critical ERF parietal data from Experiment 7 and its correspondence with the left-parietal ERP old/new effect data from Experiment 5. This is followed by discussions of the associations between the mid-frontal ERP data from Experiment 5, and two distinct fronto-temporal ERF old/new effects, one occurring from 300-500 ms post-stimulus, the other somewhat later from 500-800 ms.

Left-parietal ERF old/new effects

In Experiment 5, at parietal locations in the 500-800 ms time window, ERPs elicited by correct responses to targets were more positive-going than those elicited by correct responses to non-targets, and both of these classes of item were more positive-going than correct rejections. In Experiment 7 a similar pattern of data was observed within the 500-800 ms time window at posterior scalp locations, with a greater relative positivity for correct responses to targets than for correct responses to non-targets or new words which did not differ significantly. The spatial extent of the effect in MEG was somewhat more limited than the effect seen in EEG, and this is consistent with the fact that EEG but not MEG is 'smeared' by the media between source and scalp

These findings suggest that this ERF effect is a functional homologue of the left-parietal ERP old/new effect - a claim that could not be made with confidence on the basis of previous findings. Tendolkar et al. (2000) acquired ERFs in a recognition memory task and identified a modulation in the magnetic record that had spatial and temporal properties comparable to those of the left-parietal ERP old/new effect (for related findings, see Friedman, 1990; Paller & Kutas, 1992; Wilding & Rugg, 1997; Curran, 2000; Friedman & Johnson, 2000). They proposed that this effect was the ERF homologue of the left-parietal ERP old/new effect. Their contrast, however, was restricted to ERFs elicited by old and new test items that attracted correct responses. In order to claim with confidence that the ERF effect is a functional homologue of an ERP effect, it is necessary to demonstrate that the effect is sensitive to experimental manipulations in the same way. This experiment provides such a demonstration.

Frontal ERF old/new effect

An early ERF old/new effect at left-fronto-temporal electrode locations in the 300-500 ms time window (see Figure 9.4) showed a graded positive-going response, with the old/new effect for non-targets being larger than that for targets. The time course of this effect suggests that it is a homologue of the mid-frontal ERP old/new effect, which has been identified as an ERP correlate of familiarity (Curran, 2000; Friedman & Johnson, 2000). The fact, however, that the effect is larger for non-targets than for targets does not correspond with the mid-frontal ERP old/new effect findings in Experiment 5, in which there was little differentiation between the old/new effects for correct responses to targets and non-targets. This insensitivity to target/non-target status has been observed in other experiments in this thesis (see experiments 2 and 3) as well as in published work (Herron & Rugg, 2003b; Dzulkifli & Wilding, 2005; Dzulkifli, Herron & Wilding, 2006).

An alternative, however, is that this MEG old/new effect is the functional homologue of the mid-frontal ERP old/new effect, and the graded response to non-targets and targets seen here is either: (i) a product of superior signal:noise ratio for MEG over EEG, or (ii) a consequence of the fact that the ERP old/new effects are contaminated with activity from other generators for which activity propagates to mid-frontal electrode locations, and which is sufficient to obscure differences between the magnitudes of the mid-frontal old/new effects for targets and for non-targets.

Some support for this account comes from the argument that non-targets should be on average more familiar than targets because of their shorter interval between first and second presentations. Data consistent with this claim comes from a study in which it was shown that the availability of familiarity declines over lags of between 8 and 32 intervening items (Yonelinas & Levy, 2002). This support is only indirect, however, and in further investigations of the correspondence between putative indices of familiarity in magnetic and electrical records of neural activity it will be important to use paradigms in which the mid-frontal ERP old/new effect has been shown to respond differently to an experiment manipulation of interest (e.g. Azimian-Faradani & Wilding, 2006; Woodruff, Hayama & Rugg, 2006).

Staresina and colleagues (see Introduction, this chapter) reported morphologically similar old/new effects to those reported here. These comprised old/new effects at anterior locations in the 300-500 ms epoch, and the effects did not differentiate reliably between studied items that attracted high or low confidence judgments and old judgments attracting incorrect (new) responses (Staresina et al., 2005). There were trends for the effect to be larger for high confidence judgments, and this would be consistent with a familiarity account of the effect. These data might also be considered to be broadly consistent with the view that this MEG effect is the functional homologue of the mid-frontal ERP old/new effect.

Importantly, a second ERF old/new effect was evident at fronto-temporal scalp locations, this one occurring in the 500-800 ms time window (see Figure 9.4) and comprising a greater relative positivity for targets and non-targets in comparison to new items, with targets also being more positive-going than non-targets. There is no comparable modulation evident in the ERP data, a point emphasised by comparing the scalp maps shown in Figure 9.6 with those of Figure 7.3 for Experiment 5 (page 228). The absence of a comparable modulation in the electrical record is intriguing, and the fact that this effect differentiates between targets, non-targets and new items, in a graded manner with targets being most positive-going, indicates that it is functionally dissociable from both the earlier frontal old/new effect (which showed a graded response but with non-targets being more positive-going), as well as the lateralised parietal effect (for which there was only an old/new effect for targets) with which it is co-temporal. It is possible that this effect could be an index of implicit memory, however this claim would gain greater credence if there were data available for unrecognised studied items (misses) which showed a greater relative positivity than new items, but was attenuated in comparison to the positivity for targets and non-targets. As such, with the available data and the fact that this effect has not been reported previously, future work that ascertains how this effect is modulated across paradigms with varying retrieval requirements than the task used here is required, before any specific functional significance can be assigned to this effect.

Concluding remarks

Three functionally dissociable effects were revealed in analyses of ERF old/new effects in an exclusion task that mapped closely onto an experiment in which EEG data was collected (see Chapter 7). One of these effects is likely to be a functional homologue of the left-parietal ERP old/new effect. This claim is supported by the similar time courses and sensitivities to experiment manipulations of the two effects. A second ERP old/new effect may be a functional homologue of mid-frontal ERP old/new effect, but the similarities between the two time courses of the two effects are not matched closely by equivalent sensitivities to the target/non-target manipulation in this experiment. Some reasons for this apparent difference in sensitivity were discussed, and ways to assess the correspondence between these two effects in subsequent experiments were outlined.

Finally, an ERF old/new effect with no apparent corresponding ERP correlate was evident at frontal electrodes between 500 and 800 ms. This effect was sensitive to the difference between all three item classes that attracted correct judgments, but functionally dissociable from the left-parietal ERF effect and the early frontal ERF effect. In combination, these data points emphasise that three functionally dissociable retrieval processes are revealed in exclusion tasks, and that in this context at least the information about retrieval processing that surface analysis of ERFs and ERPs provides is not mutually redundant. Whether this is true more generally in retrieval tasks, and in other cognitive domains, remains to be determined, and it is something that can only be established on a case by case basis. None the less, for studies of memory retrieval, these findings suggest that acquiring MEG in retrieval tasks will provide information complementary to that obtained with EEG, with obvious benefits for the resolution of cognitive accounts of memory retrieval. An obvious way in which to take this work forward is to acquire EEG and MEG conjointly in future experiments. This would exploit the properties of the established ERP functional correlates of recognition memory alongside the potentially greater sensitivity of the MEG to some experiment manipulations.

Figure 9.3. Grand averaged ERFs elicited by hits, correct rejections and repeated hits at inferior and mid-lateral ROIs. L= left, R = right, A= anterior, C= central, P= posterior, S = superior, M= mid-lateral, I = inferior, MD= midline.

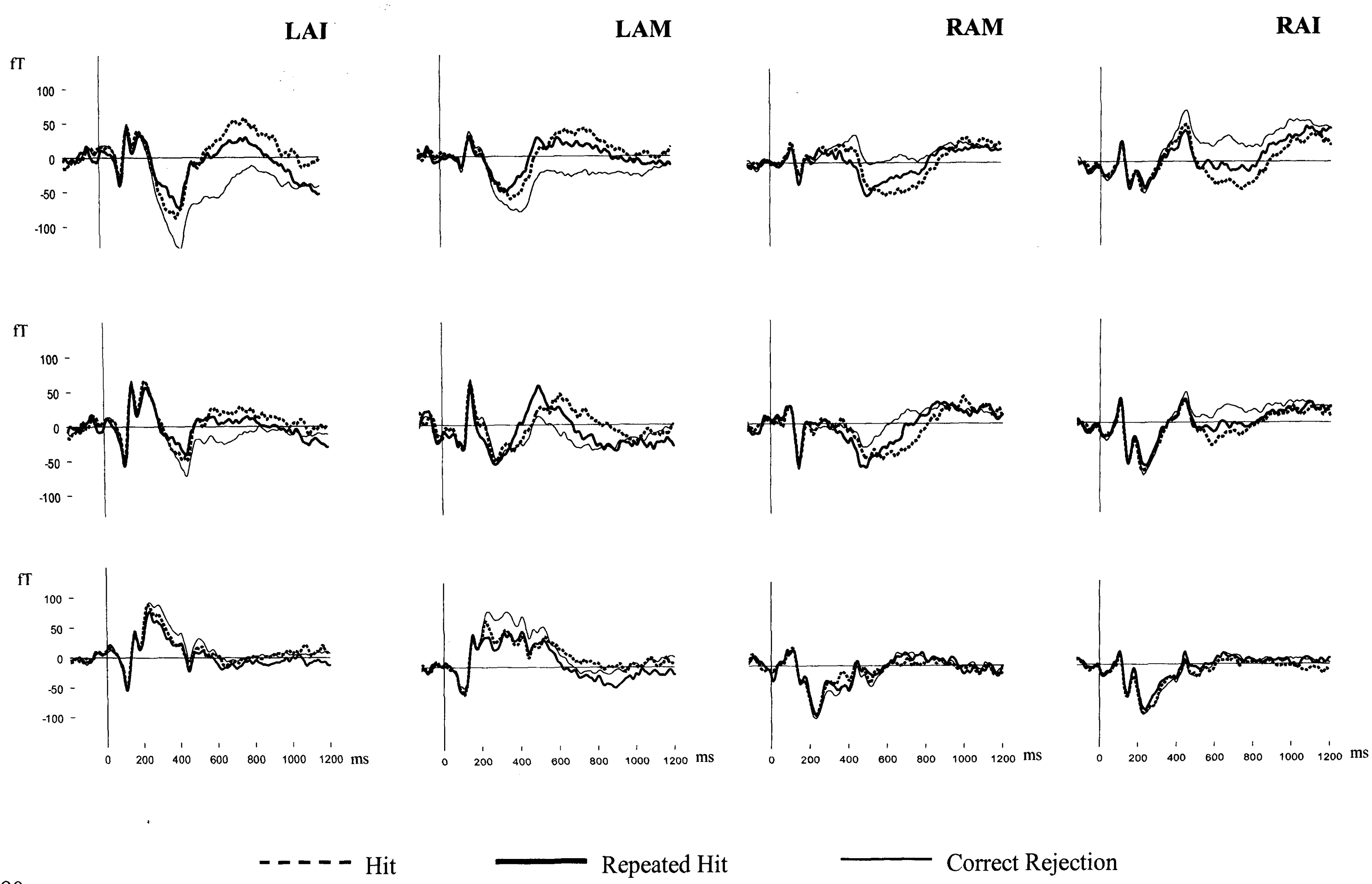
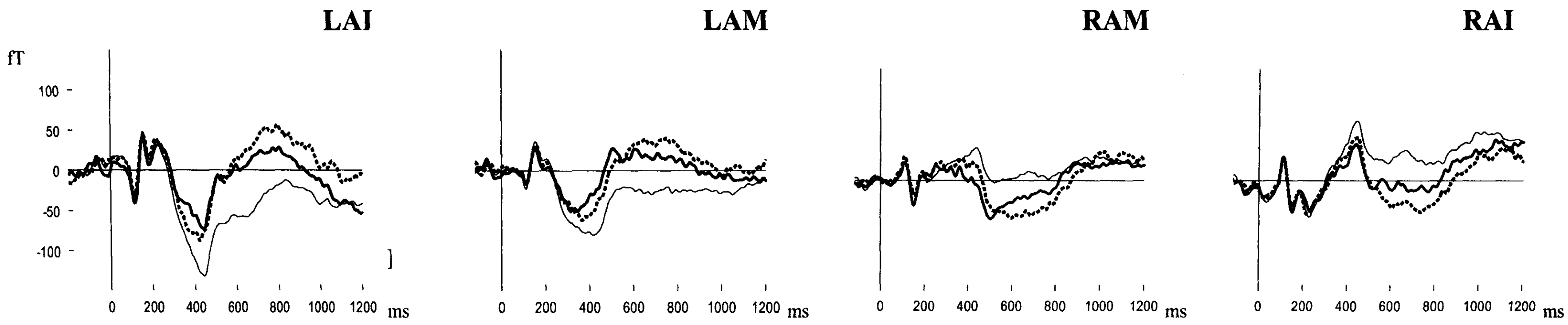


Figure 9.4. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at anterior inferior and mid-lateral ROIs. Nomenclature as for Figure 9.3.



- - - - - Hit
——— Repeated Hit
——— Correct Rejection

Figure 9.5. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at posterior superior and mid-lateral ROIs. Nomenclature as for Figure 9.3.

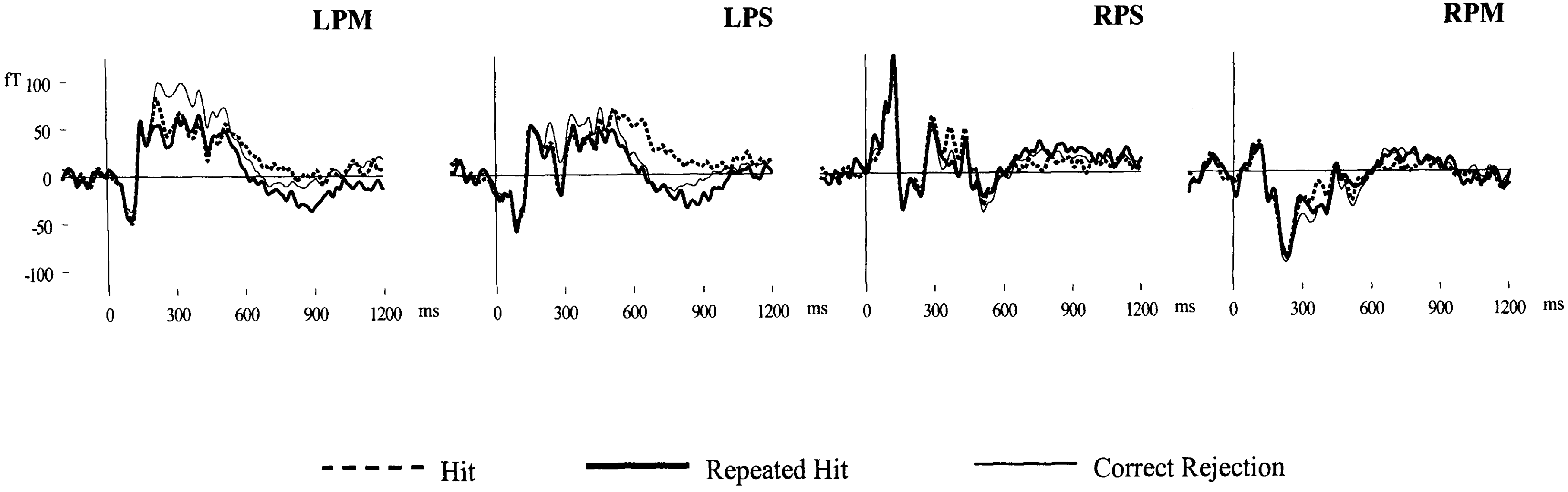
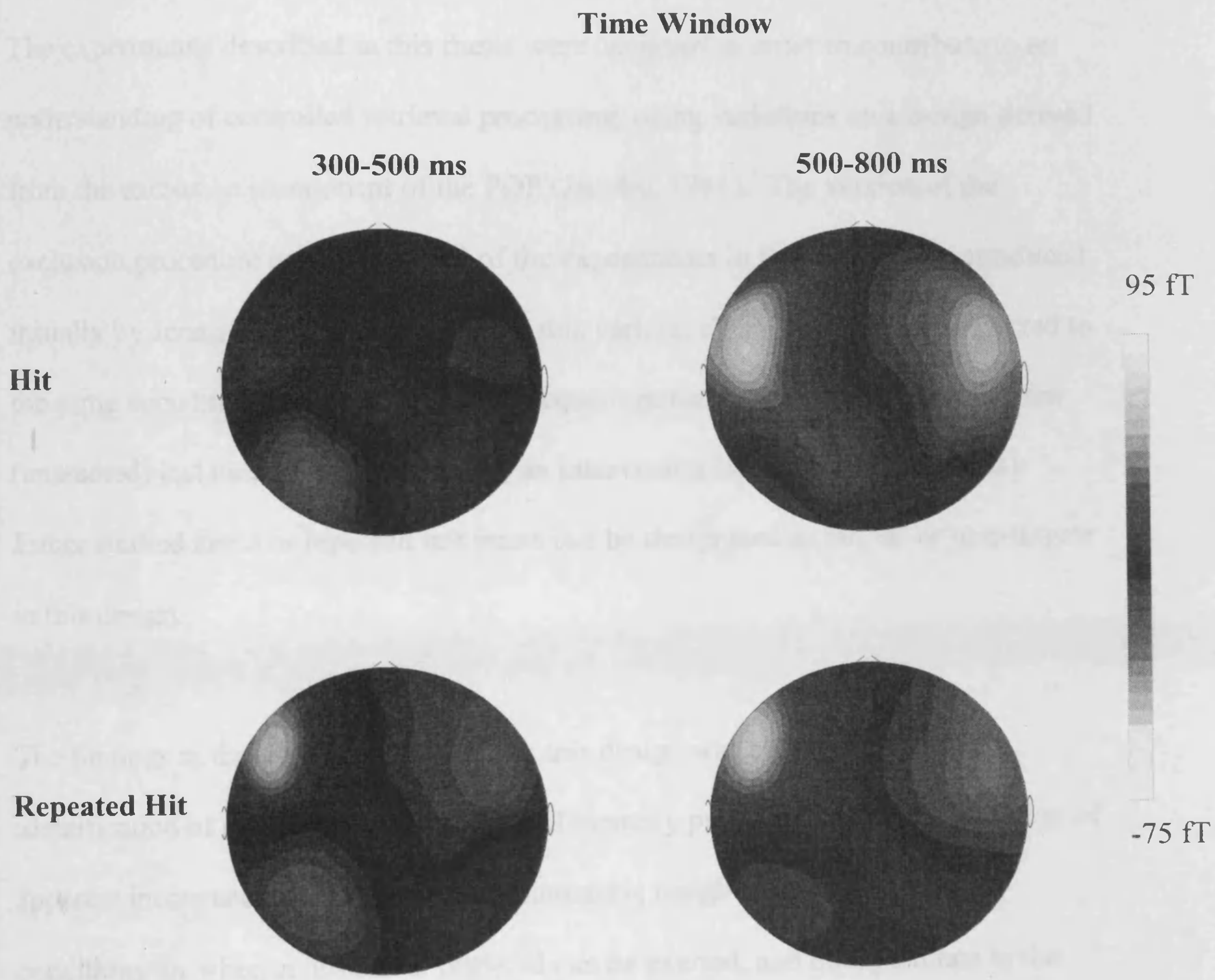


Figure 9.6. Scalp distributions of the ERF old/new effects for hits and repeated hits in Experiment 7. The data are shown for two post-stimulus epochs: 300-500 and 500-800 ms. The maps were computed from scores obtained by subtracting mean amplitudes from the ERFs evoked by correct rejections from hits and repeated hits. The amplitude differences (fT) between response categories can be interpreted relative to the colour bar on the right-hand side of the figure.



Chapter Ten

General Discussion

Introduction

The experiments described in this thesis were designed in order to contribute to an understanding of controlled retrieval processing, using variations on a design derived from the exclusion component of the PDP (Jacoby, 1991). The version of the exclusion procedure employed in all of the experiments in this thesis was introduced initially by Jennings & Jacoby (1997). In this variant, all study items are subjected to the same encoding operations. In the subsequent retrieval task, a proportion of new (unstudied) test items are repeated after an intervening lag (repeated test items). Either studied items or repeated test items can be designated as targets or non-targets in this design.

The findings in the experiments in which this design was employed included identification of multiple ERP correlates of memory processes, a partial resolution of apparent inconsistencies in the existing literature, insights into the boundary conditions for when control over retrieval can be exerted, and data germane to the question of the functional significance of the mid-frontal ERP old/new effect. The findings in the final experiment in this thesis also provide insights into the correspondences between the sensitivities of ERPs and ERFs to memory retrieval processes.

The critical aspects of the existing ERP data that motivated the designs employed in this series of ERP experiments were the ways in which parietal ERP old/new effects elicited by classes of items designated as targets and non-targets changed according to task demands (Dzulkifli et al., 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a, 2003b; Wilding et al., 2005). Experiments 1 and 2 were designed to establish the extent to which comparable patterns of selective attenuation of left-parietal ERP old/new effects could be obtained across tasks with somewhat different retrieval demands than a standard exclusion task (Jacoby, 1991) – the task-type employed in the majority of previous ERP exclusion studies. The only difference between experiments 1 and 2 was the encoding task used at study; a rhyming task was used in Experiment 1, whilst in Experiment 2, and the remaining experiments in this thesis, participants were required to read study words aloud.

The task employed in Experiment 3 was designed primarily to address questions regarding the disparity between the patterns of left-parietal ERP old/new effects for targets and non-targets in experiments 1 and 2 and previously published work in which the same paradigm was employed (Dywan et al., 1998, 2000, 2002). One explanation for the disparities across studies stemmed from the fact that, in experiments 1 and 2, the ratio of studied words to repeated test words was 2:1, contrasting with the 1:1 ratio in the studies of Dywan et al. Therefore, in Experiment 3, the probability of occurrence of studied and repeated test words was altered to a 1:1 ratio to replicate the ratio employed in the Dywan et al. studies. The reasoning behind this was to determine whether the disparities between studied and repeated test word ERP old/new effects across studies could be explained by this ratio difference.

Experiment 4 was a direct replication of Experiment 3 except for the fact that target/non-target designation was reversed at test, such that repeated test items were designated as targets. The reason for this manipulation was the fact that no direct indicator of the memorability of the repeated test items could be obtained when they were designated as non-targets, since correct responses to new items and non-targets are made on the same key in this variant of the exclusion task. The absence of such information made it difficult to interpret unequivocally any changes in the non-target ERP old/new effects as being due to the strategic control of recollection, since participants may have correctly classified a proportion of non-targets because these items were simply forgotten and misclassified as new words (Herron & Rugg, 2003a). Consequently, for the interpretation of the findings in terms of the control of recollective processes it was important that memory for non-targets was assessed directly.

In previous studies with similar levels of target accuracy to those in experiments 1-3 (Dzulkifli et al., 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a, 2003b; Wilding et al., 2005), a degree of attenuation of the non-target left-parietal ERP old/new effect was observed. This contrasts with the findings in Experiments 1-3 in this thesis, where no marked attenuation was evident. One possibility is that the nature of the paradigm employed in experiments 1-3 was such that the level of target accuracy required in order to observe this attenuation is higher than in other incarnations of the exclusion task. Experiment 5 was designed in order to assess this, via the use of shorter study and test list lengths than in the preceding studies.

Experiment 5 provided evidence that a degree of control of retrieval processing could be exerted in the repeated test version of the exclusion task, because the left-parietal ERP old/new effect was attenuated for non-targets relative to targets. Experiment 6 was designed to explore whether factors other than target accuracy could also encourage controlled retrieval processing. The experiment was a direct replication of Experiment 3 (where the findings suggested that such a strategy was not implemented) but with the addition of an enforced limit on the time period in which participants were asked to make a test response. The reasoning for this approach was that when the time available to make responses is shortened, participants might be forced into relying on recollection of information about targets only, irrespective of the likelihood of recovering such information, because this would be an economical way of employing cognitive resources to complete the task under time pressure.

The remainder of the discussion is broken down into four sections. The first two sections focus on the ERP findings, and how the findings in this thesis relate to previous work. The first section deals with the functional significance of the mid-frontal ERP old/new effect and other memory related effects that occur in the same epoch as the mid-frontal ERP old/new effect but which have a more posterior scalp distribution. The second section focuses on modulations of the left-parietal ERP old/new effect, and in keeping with the central focus on how these data points relate to issues concerning control of retrieval; this is the largest of the first three sections in the General Discussion. The third section will then address the MEG experiment findings. These sections each begin with a brief summary of the relevant principal findings from the experiments reported in this thesis. In the last section, summaries and conclusions are provided, along with a discussion of broader issues, and some suggestions for future work.

Mid-frontal ERP old/new effects

Summary of experimental findings

For all of the experiments presented in this thesis a set of directed analyses were conducted, which included factors of category and site (three levels: F3, Fz, F4), for the 300-500 ms time window. This analysis strategy was selected as it has been argued that, at anterior sites near the midline in this post-stimulus epoch, ERPs are sensitive to item familiarity (Curran, Tepe, & Piatt, 2006; Rugg et al., 1998).

In Experiment 1 correct judgments to targets and non-targets did not differ and the ERP mean amplitudes for both response categories were more positive-going than those elicited by correct rejections and incorrect responses to targets (misses). Misses were also reliably more positive-going than correct rejections. Experiment 2 showed a similar pattern of findings, except that there were no reliable differences between the magnitudes of the effects for targets, non-targets and misses.

The directed analyses in Experiment 3 showed that the ERPs elicited by targets as well as non-targets were more positive-going than those elicited by correct rejections. There were no significant effects for the contrasts between targets, non-targets and misses. The pattern of differences between the old/new effects for the three classes of items at these mid-frontal electrodes is similar to that for experiments 1 and 2.

For Experiment 4, in which targets were the repeated test words, the directed analyses demonstrated that targets and non-targets were both more positive-going than correct rejections at these mid-frontal electrode sites. Targets were also more positive-going than non-targets, with this greater relative positivity maximal at Fz. Due to the lack of sufficient trials following artefact rejection, there was no miss data available for inclusion in this experiment. Experiment 5 showed a similar pattern of findings to experiments 1, 2 and 3, with targets (in this case the studied words) as well as non-targets both being more positive-going than correct rejections. As for Experiment 4 there were insufficient miss trials for inclusion in analyses.

In Experiment 6 targets and non-targets were both more positive-going than correct rejections at these mid-frontal electrode sites. The contrast between misses and correct rejections revealed no significant effects. There were also no significant effects for the contrasts between targets and non-targets, targets and misses, and non-targets and misses.

Functional significance of the mid-frontal ERP old/new effect

<u>Mid-frontal ERP old/new effect as an index of familiarity</u>

Rugg et al. (1998) were the first to suggest that the mid-frontal ERP old/new effect indexes familiarity. Rugg et al. (1998) employed one shallow (orthographic) and one deep (semantic) encoding task, while at test participants were asked to make old/new recognition memory judgments. ERPs associated with hits were relatively more positive-going than those associated with correct rejections at anterior-superior sites. This anteriorly distributed effect was of equivalent size in both the shallow and deep conditions. However, the magnitude of the left-parietal ERP old/new effect was influenced by the depth of processing manipulation: the effect was larger for ERPs associated with hits in the deep than in the shallow encoding task. Rugg et al. suggested that the anterior modulation is an index of familiarity, a claim based upon; 1) the fact that this modulation preceded the putative index of recollection, 2) the ERP old/new effects associated with the deep and shallow conditions were of equivalent size, and 3) the effect was not present for misses. The results of Rugg et al. provide, however, equivocal evidence for the link between the mid-frontal ERP old/new effect and familiarity. This is because a number of studies have demonstrated that both recollection and familiarity are affected by depth of processing at encoding, though recollection is typically influenced more than familiarity (Gardiner, Java, & Richardson-Klavehn, 1996; Khoe, Kroll, Yonelinas, Dobbins, & Knight, 2000; Toth, 1996; Wagner, Gabrieli, & Verfaellie, 1997; Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998).

Despite this caveat, the findings in a number of subsequent studies have provided some empirical support for the link between this effect and the process of familiarity (Curran, 1999, 2000, 2004 – Experiment 1; Curran & Dien, 2003; Curran & Friedman, 2003; Curran, Tanaka, & Weiskopf, 2002; Duarte, Ranganath, Winward, Hayward, & Knight, 2004; Duzel, Vargha-Khadem, Heinze, & Mishkin, 2001; Finnigan, Humphreys, Dennis, & Geffen, 2002 - Experiment 2; Mecklinger, 2000; Nessler & Mecklinger, 2003; Nessler, Mecklinger, & Penney, 2001, 2005; Tendolkar et al., 1999). The vast majority of these relevant findings had the same pattern of statistical outcomes. These took the form of changes in the amplitude of the left-parietal ERP old/new effect, accompanied by the absence of changes in the mid-frontal ERP old/new effect (see e.g. Curran, 2000; Curran & Cleary, 2003; Nessler, Mecklinger, &

Penney, 2001). In a series of ERP studies, this pattern of effects has been obtained for different 'old/lure' combinations, where lures that are similar to test items evoked the mid-frontal ERP old/new effect, while copy cues (study items re-presented unchanged at test) elicited both left-parietal and mid-frontal ERP old/new effects (see e.g. Curran, 1999, 2000; Curran & Cleary, 2003; Nessler & Mecklinger, 2003; Nessler, Mecklinger, & Penney, 2001). Under the assumption that similar lures attract old responses on the basis of familiarity rather than recollection, these data points support the familiarity account of the mid-frontal ERP old/new effect (for additional review, see Chapter 3).

The findings in two recent ERP studies of recognition memory are also particularly important to the relevance of the mid-frontal ERP old/new effect as an index of familiarity as they suggest that the mid-frontal ERP old/new effect indexes the process of familiarity in a graded manner. First, Woodruff and colleagues (Woodruff, Hayama, & Rugg, 2006) showed that the mid-frontal ERP old/new effect increases in magnitude along with the level of confidence that accompanies a recognition memory decision. Second, the mid-frontal ERP old/new effect is sensitive to changes in criterion placement (Azimian-Faridani & Wilding, 2006, also see Curran, 2004; Bridson, Fraser, Herron & Wilding, 2006). Both of these factors have been associated with the process of familiarity to a greater degree than with recollection (see Yonelinas, 2002).

Additional data points relevant to the functional significance of the mid-frontal ERP old/new effect have come from the use of the same paradigm used in this thesis. Across three experiments, Bridson et al, (2006) showed that when participants were asked to respond on one key to studied words and on another to new as well as to repeated test words (experiments 1 & 2) at mid-frontal electrode locations in the 300-500 ms time window ERPs elicited by misses were reliably more positive-going than those elicited by correct rejections, however, when repeated test and studied words were assigned to the same key (Experiment 3) this was not the case. These findings support the link between this modulation of the electrical record and familiarity in so far as the designs of the experiments lead to the prediction that the average level of familiarity associated with misses should be higher in the first two experiments than in the third.

Mid-frontal ERP old/new effect as an index of conceptual priming

An alternative interpretation is that the mid-frontal ERP old/new effect indexes conceptual priming (Paller, Voss, & Boehm, 2007; Voss & Paller, 2006; 2007; Yovel & Paller, 2004), and the reason the mid-frontal ERP old/new effect varies according to response confidence is because the same processes that contribute to variations in the confidence with which responses are made are also those that introduce variations in the degree of conceptual priming.

One of the initial studies cited as challenging the link between the mid-frontal ERP old/new effect and familiarity is that of Olichney et al. (2000). During this study, participants (amnesic patients and controls) were required to decide whether study items were semantically congruent or incongruent (e.g. 'yes' for 'baby animal: cub'; 'no' for 'water sport: kitchen') and these cues were repeated up to three times during the task. The central maximum N400 was larger (more negative-going) for incongruent than congruent items, consistent with the view that the N400 is sensitive to the semantic correspondence between successive stimuli (Kutas, 1988). In addition, however, the N400 was less negative-going for repeated test items.

As this was true for patients and controls, Olichney et al. suggested that this repetition effect was an index of preserved implicit memory - conceptual priming. Yovel & Paller (2004, see also Voss & Paller, 2006) suggested that this account may also apply to the mid-frontal ERP old/new effect. They supported this proposal by arguing that, in verbal memory tasks, familiarity and conceptual priming are typically confounded. In addition, they argued that their failure to obtain reliable mid-frontal ERP old/new effects for unfamiliar faces (Yovel & Paller, 2005) supported this account because their behavioral data indicated that these items were familiar, but are presumably not associated with conceptual priming.

One problem with this interpretation of the data due to Olichney et al. (2000) is the fact that there is little in the paper to encourage the view that their N400 modulations share the anterior distribution associated with the mid-frontal ERP old/new effect. In addition, the data were not obtained in a direct memory task, and the use of repetitions of category cues might also have prompted participants to recover the appropriate test item before it was presented. If this was the case it is unclear what is being indexed in ERPs time-locked to the subsequent items.

These data aside, the null result for unfamiliar faces reported by Yovel & Paller (2004) challenges the view that the mid-frontal ERP old/new effect is a generic index of familiarity, although the perspective is complicated by the fact that mid-frontal ERP old/new effects have been reported for unfamiliar faces in some experimental conditions (Johansson, Mecklinger & Treese, 2004; Curran & Hancock, 2007). In addition, reliable mid-frontal ERP old/new effects have been observed for non-nameable figures (Curran & Cleary, 2003), which are presumably not susceptible to conceptual priming. The reason for these inconsistencies for faces remains unclear (for discussion see Donaldson & Curran, 2007), and there are numerous design differences across these experiments that may be influential, one notable one being disparities in the interval between presentations at study and again at test. The rates of decay for different stimulus types may also contribute to some of the differences in the existing literature.

If conceptual priming is indexed by the mid-frontal ERP old/new effect, it should be possible to observe changes in the magnitude of the mid-frontal ERP old/new effect when conceptual priming is varied but familiarity is unchanged. However, to date, only the opposite pattern has been shown: that is changes in the magnitude of mid-frontal ERP old/new effects when conceptual priming is likely to have been constant but familiarity varies (Ecker, Zimmer, & Groh-Bordin, 2007; in press; Groh-Bordin, Zimmer, & Ecker, 2006; Groh-Bordin, Zimmer & Mecklinger, 2005; Schloerscheidt & Rugg, 2004). The fact that the mid-frontal ERP old/new effect varies according to study-test overlap in some circumstances - for example when test modality or intrinsic versus extrinsic features of a stimulus are manipulated - presents a strong challenge to conceptual priming accounts of the mid-frontal effect (Rugg & Curran, 2007).

In summary the validity of a conceptual priming account is challenged by its inability to account for various data points, including; the variability in the magnitude of the mid-frontal ERP old/new effect with differing response criteria (Woodruff et al, 2006; see also Bridson et al, 2006), the occurrence of mid-frontal ERP old/new effects for false alarms and correctly recognized old items (Curran, 2000; Wolk et al, 2006), and the attenuation of the mid-frontal ERP old/new effect when old and new items are equated in familiarity strength (Woodruff et al, 2006). Furthermore, the mid-frontal ERP old/new effect demonstrates a positive across-participants correlation with familiarity-based recognition performance (Curran et al, 2006). As there is also evidence that the mid-frontal ERP old/new effect is not sensitive to format change between an item's initial and subsequent encounter (Schloerscheidt & Rugg, 2004; Groh-Bordin et al, 2006), it is most likely that a conceptual priming account for the mid-frontal ERP old/new effect is too limited, even if priming invariably contributes to familiarity-driven recognition (Rugg & Curran, 2007).

The experiments presented in this thesis were designed primarily in order to address issues concerning control of retrieval via assessments of modulations of left-parietal ERP old/new effects. As such they were not designed to contribute to the question of the functional significance of the mid-frontal ERP old/new effect. The data do, however, provide a form of evidence that has not been reported consistently before, and below the extent to which the data provide support for each of the familiarity or conceptual priming accounts of the mid-frontal ERP old/new effect is assessed.

Functional interpretations of the mid-frontal ERP old/new effect data

Across all six ERP experiments there were reliable mid-frontal old/new effects for targets and non-targets (see Figure 10.1). In the experiments in which miss data was available (experiments 1, 2, 3 and 6), the mean amplitudes for misses at mid-frontal electrode locations lay between that of the correctly identified old items (targets and non-targets) and correctly identified new items. The difference between misses and correct rejections was only reliable in experiments 1, 2 and 3, and across experiments, the pattern of statistically reliable differences between misses and old items attracting correct judgments was not entirely consistent. The very similar distribution of mean amplitudes across experiments that is shown in Figure 10.2 is quite striking, however.

Figure 10.1. Mean amplitudes of mid-frontal ERP old/new effects (amplitudes averaged across F3, Fz, and F4) for hits and repeated hits in the 300-500 ms time window for experiments 1-6.

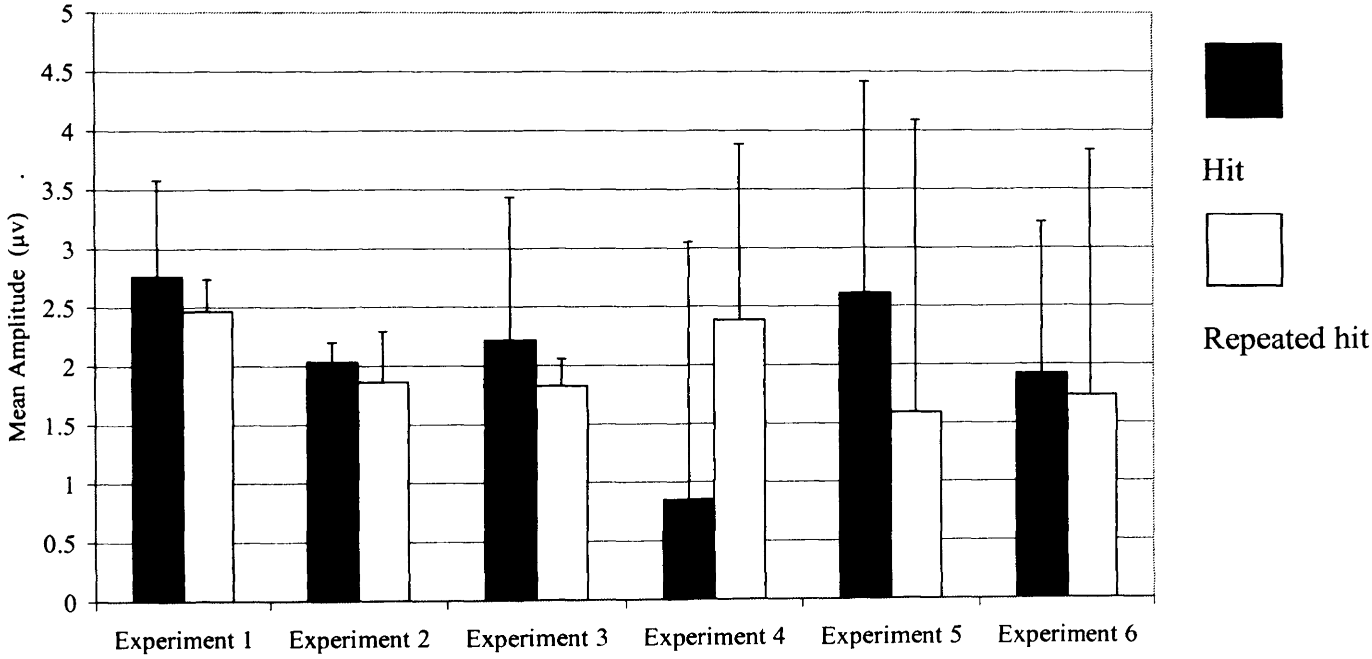
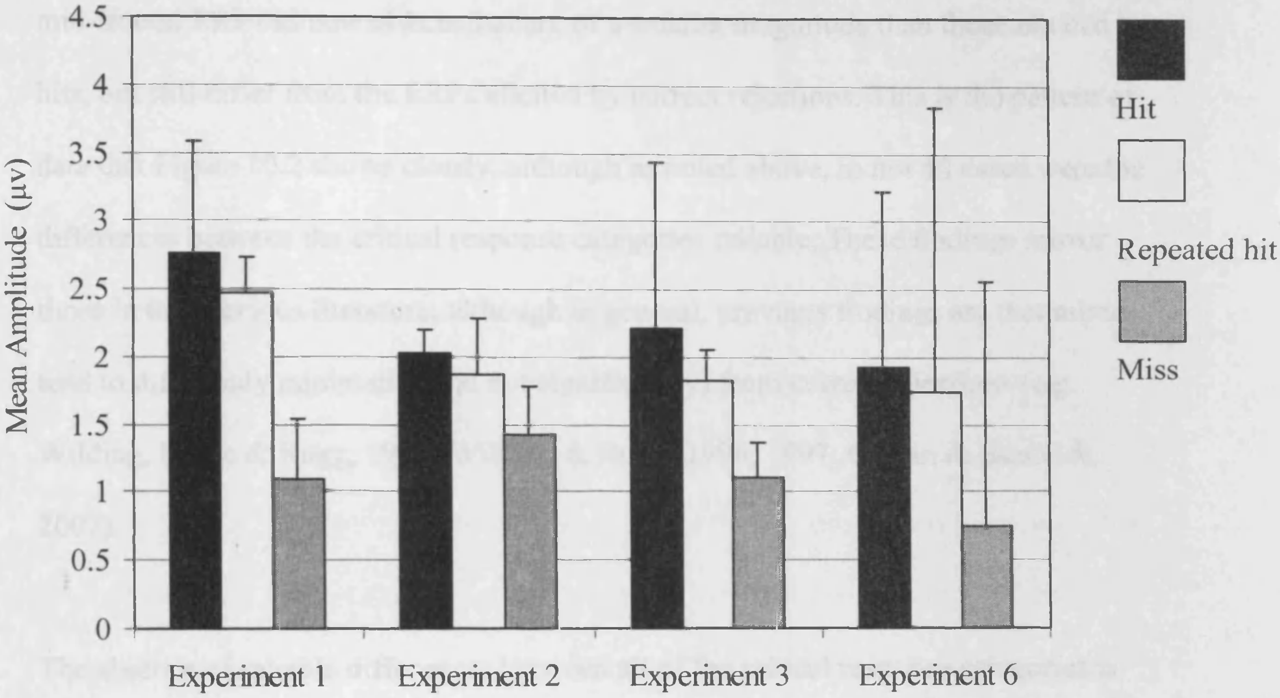


Figure 10.2. Mean amplitudes of mid-frontal ERP old/new effects (amplitudes averaged across F3, Fz, and F4) for hits, repeated hits and misses in the 300-500 ms time window for experiments 1, 2, 3, and 6.



As mentioned previously (see Chapter 1), most dual-process models of recognition memory assume that familiarity reflects the assessment of a continuous index of memory strength. In terms of the Signal Detection Model (SDM), individual items can be assumed to fall somewhere along a continuous familiarity axis (Yonelinas, 1994). New items fall toward the lower end of this continuum, due to their lower familiarity value relative to studied items, and the distributions of old and new items overlap. It is assumed that, in order to use familiarity as a basis for old/new discrimination, a criterion must be set. Only items that exceed the criterion will receive an old response. Misses and false alarms occur when old and new items, respectively, fail to reach or exceed the criterion. According to the SDM model, therefore, the levels of familiarity associated with misses should fall somewhere between the levels associated with hits and with correct rejections.

If the mid-frontal ERP old/new effect indexes familiarity, then misses should elicit mid-frontal ERP old/new effects that are of a smaller magnitude than those elicited by hits, but still differ from the ERPs elicited by correct rejections. This is the pattern of data that Figure 10.2 shows clearly, although as noted above, in not all cases were the differences between the critical response categories reliable. These findings mirror those in the previous literature; although in general, previous findings are that misses tend to differ only minimally (and not significantly) from correct rejections (e.g. Wilding, Doyle & Rugg, 1995; Wilding & Rugg, 1996, 1997; Curran & Hancock, 2007).

The absence of reliable differences between all of the critical response categories is perhaps unsurprising given the relatively small magnitude of the mid-frontal old/new effect (Curran, 2004; Azimian-Faridani & Wilding, 2006). So too is a greater similarity between misses and correct rejections rather than misses and hits in some studies: according to a SDM account differences in familiarity strength between hits and misses should on average be larger than the differences between misses and correct rejections because the latter two familiarity distributions should have more overlap (both falling below the new/old criterion).

Somewhat different considerations apply, however, for the task employed in the experiments in this thesis. First, because of the short repetition lag, the repeated test items are likely to be highly familiar, so in principle high levels of familiarity are a good cue for identifying a repeated item. Consider, however, studied items. If recollection and familiarity are independent bases for task judgments (Jacoby, 1998; Jacoby, Woloshyn, & Kelley, 1989), then some studied items will be familiar but not recollected. For these items, moderate to high levels of familiarity would not be a good basis for task judgments, assuming that many repeated test words are highly familiar because of the short lag between first and second presentations. As a result, familiar but not recollected studied words can attract incorrect responses despite relatively high levels of familiarity. This logic goes some way to explaining the magnitudes of the old/new effects elicited by misses in this series of experiments (see also Bridson et al., 2006).

In summary, the findings in the experiments in this thesis provide some evidence that the mid-frontal ERP old/new effect is a functional correlate of familiarity. Stronger support, however, would have accrued if there were consistent statistical demonstrations that the mean amplitudes associated with misses were reliably less positive-going than those associated with targets, and more positive-going than correct rejections. It is not straightforward, however, to estimate the degree to which the ERPs associated with these categories should converge, since incorrect target responses are made on the same key as new items and correct non-target responses, hence an unknown proportion of incorrect target responses are presumably 'forgotten' items that are associated with relatively low levels of familiarity.

How do the findings in this thesis speak to the conceptual priming account of the mid-frontal ERP old/new effect? If it is assumed that some experiment manipulations that influence familiarity also influence conceptual priming (Voss & Paller, 2007), then in the absence of knowing which manipulations will do this, there is no way to adjudicate between a conceptual priming and a familiarity account of the mid-frontal old/new effect. If conceptual priming is uncorrelated with familiarity, and if the mid-frontal effect indexes conceptual priming, there is no reason for the ERPs associated with misses to differ from those associated with studied and repeated test items. As no attempts were made to manipulate familiarity and conceptual priming in the experiments in this thesis, the data cannot support unequivocally one or other of these functional accounts.

Overall, however, the evidence linking the mid-frontal ERP old/new effect to familiarity is strong; and the findings in this thesis provide further supportive data. However, the cognitive operations reflected by this effect remain to be refined. There are, for example, grounds for thinking that the mid-frontal ERP old/new effect does not reflect familiarity directly. Tsivilis et al. (2001) had participants study visual objects superimposed onto background scenes. During test, old and new objects were superimposed on either studied or new backgrounds. Correctly classified old objects superimposed on studied backgrounds elicited a mid-frontal ERP old/new effect, whereas objects superimposed on a new background did not, although a behavioural study revealed no differences between the two conditions in estimates of familiarity. Tsivilis et al. proposed that the mid-frontal ERP old/new effect reflects processes downstream from those responsible for computing the familiarity of the different components in a single event, and that an earlier old/new effect (onsetting at approximately 120 ms post-stimulus) might be a more direct reflection of the accumulation of familiarity information, although this suggestion has not resulted in published follow-up investigations to date. A recent study by Ecker et al. (2007)

extended the findings of Tsivilis et al. (2001) by demonstrating that a test item on a novel background elicits a mid-frontal ERP old/new effect when attention is oriented to the item, but not when both item and background are attended to. Thus, the effect reflects attentionally mediated processing of multiple sources of information. In so far as conceptual priming is an implicit process, the sensitivity of the effect shown by Ecker et al. is arguably more consistent with a familiarity than a conceptual priming account.

Finally, it is worth noting that when reliable changes have been observed in the mid-frontal ERP old/new effects across at least two conditions (e.g. Azimian-Faridani & Wilding, 2006), they have occurred alongside relatively strong behavioural manipulations, which indicate that ERPs may not be as sensitive to fluctuations in familiarity as behavioural data (see Curran, 2004 for similar points). This observation is important, because it suggests that, despite the growing body of data linking the mid-frontal ERP old/new effect to familiarity, the utility of this index as a functional tool may be somewhat limited. This may be especially true for single-case/patient studies (although see Duzel et al., 2001), but also true in cases where paradigms do not permit clean separations between responses made on the basis of different processes, or when the design precludes acquisition of data on a sufficient number of trials to achieve excellent signal:noise.

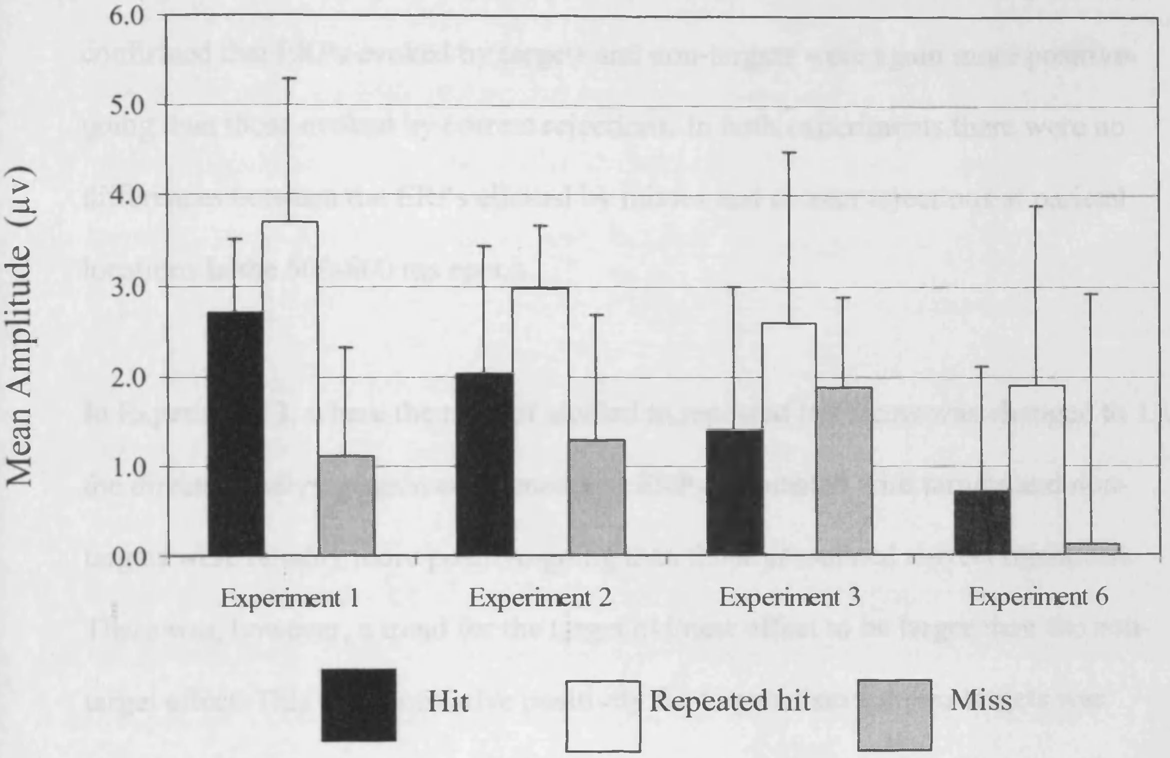
Parietal ERP old/new effects in the 300-500 ms time window

It has been proposed that two functionally distinct ERP old/new effects, with fronto-central and parietal maxima respectively, are evident in the 300-500 ms post-stimulus time-window (Azimian-Faridani & Wilding, 2006; Rugg et al., 1998). Rugg et al. (1998) linked the posterior effect with implicit memory, since in their study the effect differentiated only the old/new status of test items and not the accuracy of memory judgments.

The findings in Experiment 3 are somewhat consistent with this account as at posterior sites correct responses to targets and non-targets, as well as incorrect responses to targets, were reliably more positive-going than correct rejections (see Figure 10.3). Therefore, the ERPs at these posterior locations index the old/new status of test items but do not predict the accuracy of memory judgments. This pattern of data fulfils one criterion for being an index of implicit memory, but in this experiment, as in all prior studies to date where this has been demonstrated, the effect was not accompanied by a behavioural index of implicit memory such as a measure of priming (Azimian-Faridani & Wilding, 2006).

However, the data from the remaining experiments are not as straightforward to interpret in this manner, as the old/new effect for misses is smaller than for targets and non-targets (see Figure 10.3). If this early parietal modulation is a functional correlate of implicit memory processes it would be anticipated that the effect should be of equal magnitude for all items that are re-presented at test, or at least for correct and incorrect responses to targets, and that across a series of appropriately counter-balanced experiments the findings should be similar. As such the findings from the experiments in this thesis offer only weak support for the view that this effect is a correlate of implicit memory.

Figure 10.3. Mean amplitudes of ERP old/new effects (amplitudes averaged across P3, Pz, and P4) for hits, repeated hits and misses in the 300-500 ms time window for experiments 1, 2, 3, and 6.



Left-parietal ERP old/new effect

Summary of experimental findings

For one set of directed analyses, the analyses within each experiment were conducted over the 500-800 ms time window, and included factors of category, hemisphere, and site (four levels: P3, P4, P5, P6). This time window was selected as it captures the period during which the left-parietal ERP old/new effect is primarily evident (Friedman & Johnson, 2000; Rugg, Herron, & Morcom, 2002).

Experiment 1 established that in the 500-800 ms period, ERPs associated with targets and non-targets were relatively more positive-going than those associated with correct rejections. In Experiment 2, where the encoding task was changed to one in which the participants were required to read the study word aloud, the directed analysis confirmed that ERPs evoked by targets and non-targets were again more positive-going than those evoked by correct rejections. In both experiments there were no differences between the ERPs elicited by misses and correct rejections at parietal locations in the 500-800 ms epoch.

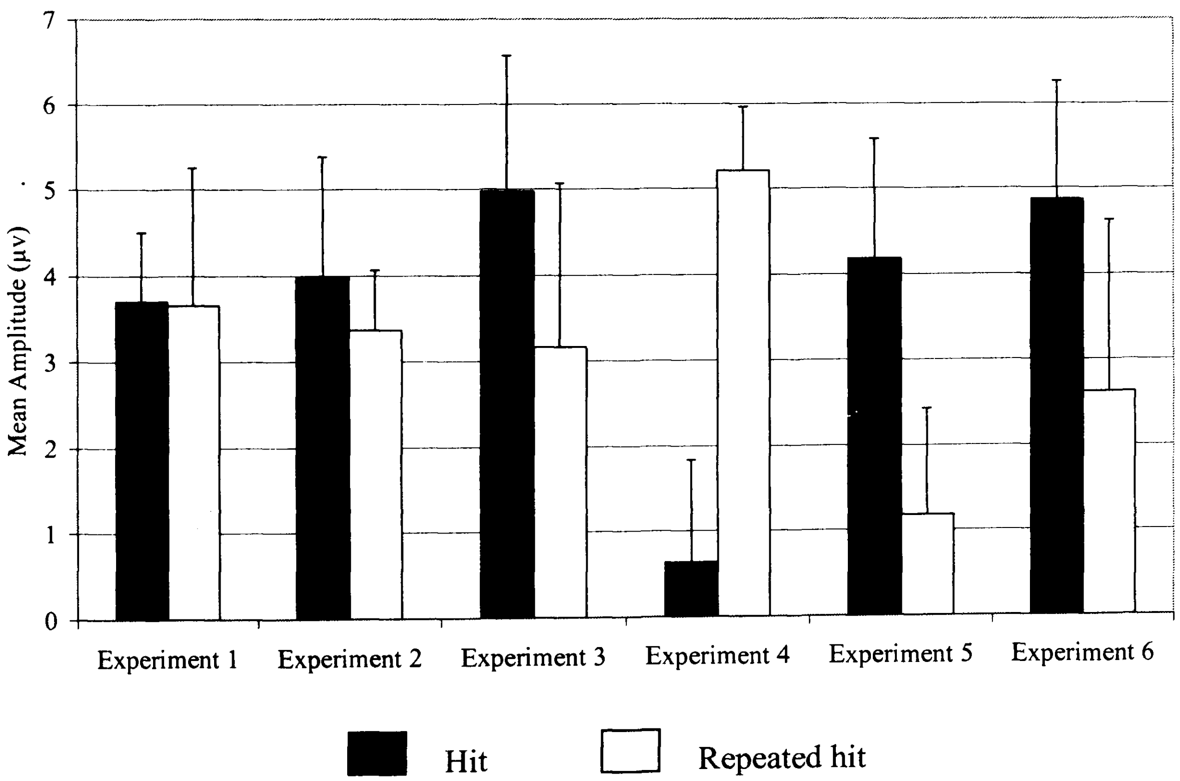
In Experiment 3, where the ratio of studied to repeated test items was changed to 1:1, the directed analyses again confirmed that ERPs associated with targets and non-targets were reliably more positive-going than those associated correct rejections. There was, however, a trend for the target old/new effect to be larger than the non-target effect. This greater relative positivity for targets than for non-targets was significant in Experiment 4, where the targets were the repeated test items, and where there was no reliable parietal old/new effect for non-targets (studied words).

The pattern of findings in Experiment 4 was replicated in Experiment 5. In this experiment studied items were designated as targets, and the levels of target accuracy were increased relative to the earlier studies. The ERPs elicited by targets were significantly more positive-going than those elicited by non-targets, and non-targets were more positive-going than correct rejections. The directed analyses in Experiment 6, where the response time at test was limited to 1 second, revealed the same pattern of parietal ERP old/new effects as for experiments 1, 2 and 3; targets and non-targets were both more positive-going than correct rejections and did not differ reliably from each other. See Figure 10.4 for an illustration of the magnitudes of the parietal ERP old/new effects for targets and non-targets in all six experiments.

Modulations of the left-parietal ERP old/new effect

Two of the initial motivations behind the studies presented in this thesis were to assess the generality of the findings of two study context exclusion tasks to a paradigm with somewhat different task demands, and the generality of the explanation offered initially by Herron & Rugg (2003b) for the attenuation of left-parietal ERP old/new effects in exclusion tasks under some circumstances but not under others.

Figure 10.4. Parietal ERP old/new effects (amplitudes averaged across P3, Pz, and P4) for hits and repeated hits in the 500-800 ms time window for experiments 1-6.



The ERP findings that are most relevant to the work in this thesis are those relating to the left-parietal ERP old/new effects elicited by correct judgments to targets and to non-targets in exclusion task studies. In a number of recent studies, the magnitude of the left-parietal ERP old/new effects has been markedly larger for targets than for non-targets (e.g. Czernochowski, Mecklinger, Johansson, & Brinkmann, 2005; Dzulkifli, Herron, & Wilding, 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a, 2003b; Hornberger, Morcom, & Rugg, 2004). If it is the case that the left-parietal ERP old/new effect indexes recollection, then these data suggest that participants relied upon recollection of information about targets to complete the task to a markedly greater degree than on information about non-targets (Herron & Rugg, 2003a, 2003b).

Turning to the data in this thesis, parietal ERP old/new effects were reliable for targets in all 6 ERP experiments, and for non-targets in experiments 1, 2 3, 5 and 6. The non-target left-parietal ERP old/new effect was significantly attenuated in magnitude in comparison to that for targets in experiments 4 and 5. Targets were denoted as studied words in experiments 1, 2, 3, 5 and 6, and as repeated test words in Experiment 4.

This example of differential attenuation of non-target parietal old/new effects across experiments replicates key prior findings (Dzulkifli et al., 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a, 2003b; Wilding et al., 2005). Consistent with these, the differential attenuation of the ERP old/new effects for non-targets occurred across a set of experiments in which the likelihood of a correct target judgment was lower in some than in others. As in previous cases, the greater attenuation of non-target old/new effects relative to the respective target effects occurred in the experiment in which the likelihood of a correct target judgment was higher. As in Experiment 5, target accuracy was higher than in all other comparable studies (Experiment 4 is a special case because repeated test items were designated as targets, so the direct contrast across experiments is weaker. None the less, the parietal old/new effects were larger for targets than for non-targets (studied items), and levels of target accuracy were high).

These findings are therefore consistent with the view that participants adopt strategies in exclusion tasks whereby the extent to which recollection of information of targets is likely determines the extent to which recollection of information about non-targets will be prioritised (Herron & Rugg, 2003b). Importantly, the findings generalise those obtained in previous experiments to circumstances under which one class of 'old' test items comprises items repeated during the exclusion test phases.

However, in the previous exclusion task studies where new items were not repeated, some degree of attenuation of non-target old/new effects has been reported with levels of target accuracy comparable to those reported in experiments 1, 2, 3 and 6, which resulted in no significant attenuation of the left-parietal ERP old/new effect for non-targets here (cf. Dzulkifli et al., 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a, 2003b; Wilding et al., 2005). It may be the case that the reason for the findings here is due to the difficulty in controlling recollection of the repeated test items, with the findings in earlier studies reflecting relatively lower degrees of difficulty for the non-target categories employed in those experiments.

Therefore, under the experimental circumstances of the paradigm employed in this thesis, the levels of target accuracy necessary to observe attenuation of left-parietal old/new effects – and therefore to license claims about selective recollection of task relevant information – need to be higher than those at which attenuation is observed in standard exclusion task paradigms. The finding in Experiment 5 that increasing target accuracy (from a mean of 0.66 across experiments 1, 2 and 3 to 0.79 in Experiment 5) led to a significant difference in the magnitude of the left-parietal ERP old/new effects for targets and non-targets, suggests that there is some factor of the experimental paradigm and its associated cognitive demands that requires target accuracy to be even higher in order to enable participants to prioritise the recollection of target information over that of non-target information. These data suggest that the likelihood of recollecting information about targets is not the only factor influencing the strategy adopted by participants in exclusion tasks, in keeping with the findings of Herron & Wilding (2005).

What other factors could be influencing the strategy participants use to complete this incarnation of the exclusion task? One possibility, as outlined above, is that it is simply the fact that control of recollection for items presented very recently is somewhat more difficult than exerting control over recollection when longer periods intervene between presentation and re-presentation of critical stimuli. A more general consideration, however, is that the results in this thesis are due at least in part to the availability and use of different processes to support task judgments.

In considering the variant of the exclusion task used here it is entirely possible that to correctly exclude non-target items one does not need to use recollection of either target or non-target information. Instead, the relative levels of familiarity for each item class can be used to complete the task. The repeated test items, by virtue of the short lag between presentations, are presumably associated with high levels of item familiarity (Yonelinas & Levy, 2002), whereas studied items would be associated with lower levels, under the assumption that familiarity declines appreciably more during the period between presentations of studied items than during the period between presentations of repeated test items.

Can a "familiarity only" account accommodate the findings in this thesis? One piece of relevant data comes from Experiment 5, in which there was attenuation of the non-target left-parietal ERP old/new effect in comparison to the target effect, an aspect of the electrical record linked with recollection and not with familiarity. The results of Experiment 5 suggest that recollection was used strategically to prioritise task-relevant information in order to complete the task. The key difference between Experiment 5 and the remaining experiments in the thesis, however, was the use of shorter study and test blocks (utilised in order to increase target accuracy levels), which could have resulted in a greater degree of similarity in the relative levels of familiarity for target and non-target items than in the other experiments. That is, the temporal difference between the re-presentation of each class of item was reduced, and as a result relative familiarity levels of targets and non-targets may have become less distinct, hence the usefulness of familiarity for task judgments was reduced far enough that participants relied primarily on recollection of target information in order to distinguish between targets and non-targets. According to this argument, therefore, a "familiarity only" account does not hold for Experiment 5, but the lack of any difference between the left-parietal ERP old/new effects for targets and for non-targets in the remaining experiments does not preclude an interpretation of their findings in terms of a reliance on different levels of familiarity.

If familiarity is the sole basis for task responses within this incarnation of the exclusion task then the patterns of data for the putative electrophysiological index of familiarity (the mid-frontal ERP old/new effect) become relevant. One argument would be that, if differences in familiarity are employed solely in order to complete some study/repeated test exclusion tasks, then correct responses to repeated test items (repeated hits) should elicit larger old/new effects than correct responses to studied items. Similarly, the mid-frontal effects for correct responses to studied words should be smaller than those for incorrect responses to studied words. This is not the case across any of the relevant ERP experiments reported in this thesis (see Figure 10.2).

One caveat to interpreting this pattern of mid-frontal ERP old/new effects, however, is the response requirements of the task. As correct rejections, repeated hits and studied misses are all associated with responses made on the same key it is impossible to determine which proportion of, for example, misses reflect studied items that are genuinely forgotten, and which proportion are due to their misinterpretation as repeated test items. Because of this, the averaged mid-frontal ERP old/new effects for repeated hits and studied misses are presumably some combination of forgotten and misinterpreted items. If the two kinds of trials contributing to the averaged waveforms are associated with different levels of familiarity, then it makes interpretation of similarities or differences between mid-frontal old/new effects for these categories somewhat difficult.

Perhaps the critical ERP data points are from Experiment 4, where repeated test items were designated as targets. According to the “familiarity only” interpretation above, in this case, the mid-frontal old/new effect for correct responses to repeated test items should be larger than that for studied items. The fact that it is not is important, because any attenuation of non-target effects in this experiment should actually be encouraging a difference between the magnitudes of these effects to emerge.

It is not possible from the data within this thesis alone to determine specifically the degree to which recollection or familiarity are used to complete the variant of the exclusion task used in experiments 1, 2, 3 and 6, and of course any explanation in terms of familiarity only needs also to accommodate the presence of robust parietal old/new effects for correct responses to studied as well as repeated test items (see Discussions in Chapters 5, 6 and 7). It is also worth emphasising that when target accuracy is increased recollection is more likely to be used (as in Experiment 5), and these data points argue strongly for the deployment of recollection in at least some circumstances.

These observations have particular relevance to which version of this task to use when inferences about the use of recollection are to be made. As the findings suggest that different strategies are employed dependent on task difficulty (as indexed by response accuracy), it is important to note that in populations who complete the same incarnation of the task, but who have different levels of response accuracy, it becomes difficult to make confident claims about task performance in regards to a deficit in a particular process.

This is a key issue should this task be employed in pursuit of defining memory changes across different populations in whom process-specific memory impairments may be present. However, by equating performance across different lags for different populations, it should in principle be possible to ascertain whether the selective control of retrieval exerted by one population can also be exerted, under comparable circumstances, by another.

This highlights one of the particular strengths of the paradigm employed here; that the use of varying lags in different populations provides a means of contrasting measures of neural activity across lags at which response accuracy is equated. Furthermore, it is precisely for this reason that Jennings & Jacoby (1997) argued that this task was well-suited to assessments of changes in memory processing according to age. There is also the added benefit that concerns over differences across groups in following task instructions can be ruled out by demonstrating high and comparable levels of response accuracy across groups at short lags (Jennings & Jacoby, 1997).

On another note, a number of the findings reported in this thesis do not concur with some of the assumptions underlying the PDP (for details, see Chapter 1, pages 45-50), suggesting that under some circumstances the PDP would not accurately estimate the contributions of familiarity and recollection to performance. One such assumption is that correctly classified non-targets are excluded on the basis of recollection (Jacoby, 1991). Electrophysiological support for this interpretation would, therefore, comprise reliable parietal ERP old/new effects associated with correct judgments to non-targets (Herron & Rugg, 2003b), and these are evident in experiments 1, 2, 3, 4 and 6. The ERP data reported in Experiment 5 however, suggests that, at least when response accuracy for targets is high, the assumption that recollection is the basis for non-target judgments is questionable, which in turn calls into question the accuracy of recollection and familiarity estimates derived from the process-dissociation procedure.

The present findings therefore highlight the fragility of the boundary conditions surrounding the use of the exclusion task to assess recollection, as participants may make differential use of non-target information depending upon the accessibility and distinctiveness of target information. The exclusion task employed here differed from the classical exclusion task only in two ways; non-targets were presented in the test phase rather than in the study phase, and only targets were encoded using a study task, whereas non-targets received only incidental encoding from an initial new response on their first presentation at test. It therefore appears that the boundary conditions of the PDP can be violated either by presenting the targets and non-targets with a considerable temporal gap, or by rendering targets sufficiently distinct from non-targets.

Functional significance of the left-parietal ERP old/new effect

The left-parietal ERP old/new effect is one of the most established correlates in the ERP memory literature. Numerous studies have shown that the left-parietal ERP old/new effect is sensitive to manipulations that are thought to affect recollection.

For example, as mentioned in Chapter 3, the effect is larger for correct than incorrect source judgments (Curran, 2000; Wilding, 2000; Wilding & Rugg, 1996), and for 'remember' than 'know' responses (Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997; Smith, 1993; Trott, Friedman, Ritter, Fabiani, & Snodgrass, 1999), for correctly recognised old words than for pseudowords (Curran, 1999), for deeply than for shallowly encoded items (Rugg et al., 1998; Rugg, Allan, & Birch, 2000), and for intact word-pairs than for rearranged pairs (Donaldson & Rugg, 1998). This wealth of convergent evidence strongly suggests that the parietal old/new effect is a correlate of recollection. So strong is the link between recollection and the parietal old/new effect, it has been argued that the detection of a parietal old/new effect for a particular response category indicates that this response category is associated with recollection (Paller, Kutas, & McIsaac, 1995). This assumption is made when interpreting the work in this thesis, with the specific assumption being that the differences between the magnitudes of left-parietal ERP old/new effects in different experiment conditions can license inferences about the degree to which recollection is engaged.

In more detail, the experiments presented in this thesis were designed to investigate strategic recollection, using modulations of the left-parietal ERP old/new effect as one means of accomplishing this. If the left-parietal ERP old/new effect indexes recollection, then contrasts between the size of the effect across targets and non-targets in exclusion tasks can in principle provide data relevant to this issue, and allows for inferences to be made about the degree to which recollection can be strategically prioritised for task relevant information under appropriate circumstances.

As mentioned above the experiments in this report were designed on the assumption that the left-parietal ERP old/new effect is an index of recollection. How are the findings consistent with this functional interpretation? To answer this question it is necessary to consider the response requirements of the task. Jacoby (1991) has argued that, in the exclusion task, participants rely upon recollection of targets as well as recollection of non-targets in order to make task judgments. This assumption is required if one wishes to estimate the contributions that recollection and familiarity make to recognition memory performance using the computational approach provided by Jacoby and colleagues (the Process Dissociation Procedure (PDP): Jacoby, 1991; Jacoby, 1998). If this assumption is correct, then both targets and non-targets attracting correct judgments should be associated with left-parietal ERP old/new effects, if this aspect of the electrical record is linked to the process of recollection (Friedman & Johnson, 2000; Rugg & Allan, 2000; Wilding & Sharpe, 2003). The findings of reliable left-parietal ERP old/new effects for targets and non-targets in all of the experiments within this thesis can therefore be accommodated within the functional interpretation of the left-parietal ERP old/new effect as an index of recollection.

However, recent findings employing the exclusion task suggest that the functional significance of the left-parietal ERP old/new effect may be more complex (Dywan, Segalowitz & Webster, 1998). Employing the exclusion task, some ERP studies (Dywan, Segalowitz & Arsenault, 2002; Dywan et al., 1998, Dywan et al., 2001; Herron & Rugg 2003a; 2003b) have shown that correctly rejected non-targets may sometimes fail to elicit a left-parietal ERP old/new effect. Furthermore within the experiments presented in this thesis the left-parietal ERP old/new effect for non-targets was significantly attenuated relative to targets in experiments 4 and 5. Considering this effect is held to reflect processes of recollection, the findings in this thesis license discussions about a more specific functional account of the left-parietal ERP old/new effect.

The pattern of results pertaining to non-target parietal ERP old/new effects arguably leads to two other possible conclusions for the functional significance of the left-parietal ERP old/new effect. The first of these is that the left-parietal old/new effect is not an obligatory correlate of recollection, but rather that it reflects additional processing contingent on recollection (Dywan et al., 2002; Dywan et al., 1998; Dywan et al., 2001). That is the effect is a consequence of attending selectively to the outputs of retrieval. Dywan et al (1998) suggested that the absence of this effect for non-targets in younger but not older participants completing the task used in this thesis reflects the younger participants greater ability to inhibit attending to retrieved non-target information (see also Dywan et al., 2002; 2001).

Herron & Rugg (2003a) reported similar findings across two experiments involving a depth of processing manipulation. At test, left-parietal ERP old/new effects were elicited for correctly identified non-targets in Experiment 2 in which the encoding task for targets was shallow. The authors initially proposed that non-target information was, in fact, retrieved in both experiments, but was only attended to in Experiment 2 (Herron & Rugg, 2003a). This attentional hypothesis would state that the left-parietal ERP old/new effect reflects the attentional and/or control processes that act upon recollected information as opposed to the recollected information itself.

It could alternatively be concluded that the attenuation of the left-parietal ERP old/new effect for correctly classified non-targets in experiments 4 and 5 reflects processes underlying the retrieval of partial or less specified aspects of source information (Johnson et al., 1993). This interpretation would be predicted on the basis of previous reports of successful source attributions based on the retrieval of partial source information (Donaldson et al., 1998) as well as the findings that the left-parietal old/new effect may index the amount of information retrieved from episodic memory in a graded rather than "all-or-none" fashion (Vilberg, Moosavi & Rugg, 2006; Wilding, 2000). This information recovery account is distinguishable from the attentional account by its implication that the information retrieved itself can be controlled, rather than supposing that, across the products of retrieval, attention is controlled and orientated to particular outputs.

Support for the information recovery account comes from a study by Vilberg, Moosavi & Rugg (2006) in which a modified remember/know paradigm was used in conjunction with a study task that required an association to be formed between two pictures. On each test trial, participants were presented with one of the two pictures that had been presented on a study trial, or an unstudied picture. The response options allowed them to signal that they could recollect the picture that had been associated with the test item at study (R2), that they could recollect a detail or details of the study episode other than the associate (R1), that no details could be recollected although the test item was highly familiar or, that the test item was new. The rationale for this procedure rests on the assumption that whereas an R2 judgment depends on retrieval of enough information to facilitate the retrieval of the test item's pairmate, an R1 response can be made on the basis of only partial retrieval of the encoding episode. The left parietal old/new effect was sensitive to the amount of information recollected, demonstrated through greater amplitude when elicited by test items associated with full relative to partial recollection (also see Wilding, 2000). These findings support the proposal that the left parietal ERP old/new effect is sensitive to the amount of information recovered from episodic memory.

With regards to the findings from the experiments presented in this thesis; according to the attentional account target and non-target information may have been recollected in all six experiments, but at test in experiments 4 and 5 participants attended to and employed target information only to complete the task. The information recovery account would interpret the same findings as evidence that in experiments 4 and 5 less non-target information was recollected than in the remaining experiments. The left-parietal ERP old/new data in this set of experiments can feasibly be interpreted by either of the hypotheses, and the data therefore, lends no more credence to one hypothesis than the other. Similar ideas to those expressed here are included in considerations of mechanisms of selective retrieval processing, and these are discussed below.

Mechanisms underlying selective retrieval processing

In one influential review chapter, Anderson & Bjork (1994) discussed several types of mechanism that can permit selective retrieval. The first is target bias, which refers to processes that operate on the critical memory representations themselves. Memory representations associated with the target category may be activated, making them more accessible than the representations for other memory contents. Selective accessibility of memory representation could also occur if memory representations associated with non-targets were inhibited. It is possible that activation and/or inhibition of memory representations can support selective retrieval processing. One consequence of adopting a specific retrieval strategy might be the continuous activation and/or suppression of memory representations for as long as is necessary, although these processes could also in principle be initiated on a trial-by-trial basis.

A second process that might be responsible for selective control of recollection is cue bias, which refers to the way in which specific units or aspects of a retrieval cue are more likely to interact with memory representations because of the way that the cues are processed. Thus this mechanism also provides a means for the implementation of selective retrieval. The notion of cue bias is somewhat comparable to Burgess and Shallice's (1996) notions of cue specification, as well as the concept of focusing in the CMF (Schacter et al., 1998). Anderson & Bjork (1994) argued that cue bias could either take the form of 'meaning bias' or 'context bias'. The context bias hypothesis states that recollection will fail when the contextual representation used to conduct the memory search does not match the contextual representation that was present at encoding. Therefore, if participants in the present experiments employed a contextual representation during the memory search that only matched the contextual representation formed during the encoding of targets, non-targets would be rendered irretrievable. This account also has parallels with the principles of transfer appropriate processing (Morris, Bransford, & Franks, 1977) and encoding specificity (Tulving & Thomson, 1973), which state that the extent of retrieval success depends upon the degree of overlap between processes engaged at encoding and processes engaged at retrieval. The present findings can be interpreted within this kind of a framework by proposing that participants selectively probed memory for target information by recapitulating processing operations carried out during study phase in the test phase.

A third account – the attention bias account - is also possible. According to this view, selective recollection does not come about because of processes that operate during the interaction between retrieval cues and memory representations. Rather, it occurs because only some of the products of retrieval are attended to. Anderson & Bjork (1994) argued that this attentional suppression can be applied to any representation which is perceived to interfere with performance. This account therefore locates selective retrieval processing at a post-retrieval locus, and so the concept of attention bias shares some similarities with the notions of monitoring and evaluation (Burgess & Shallice, 1996). This hypothesis is also consistent with other evidence suggesting that the parietal old/new effect is sensitive to the 'task relevance' of retrieved information. For example, the magnitude of the parietal old/new effect is typically larger in direct tests of recognition memory than in indirect tests such as semantic classification when episodic retrieval is incidental to the task (Duzel et al., 1999; Paller, Kutas, & McIsaac, 1995; Rugg & Wilding, 2000). Rugg & Wilding (2000) observed that these findings may reflect not so much the failure to retrieve study information in indirect tasks, as the failure to allocate processing resources to the information once retrieved (cf. Rugg, Fletcher, Frith, Frackowiak, & Dolan, 1997).

One or more of these classes of mechanism might be responsible for the selective control of recollection. Thus, correspondingly, neural correlates of retrieval may reflect any of these types of control operation. One approach to distinguishing between these could be to compare complementary data across ERP and fMRI studies using the same experimental paradigm to investigate both the anatomy and time course of brain activity associated with strategic and control processes in episodic memory retrieval.

Exploring which brain regions are involved in the retrieval of task-relevant information could help differentiate between each of the above hypotheses. For example, if an fMRI experiment, with the same paradigm employed in this thesis showed changes in relative levels of neuronal activation for targets and non-targets in regions implicated in the retrieval of memory contents (for example the medial temporal lobe (MTL) and in particular the hippocampus) this would be consistent with a selective retrieval and not a selective attention account. Conversely, if a selective attention mechanism was responsible one would anticipate changes in neural activity in regions implicated in the orientation and maintenance of attentional processes, such as the pre-frontal cortex (PFC).

The neural basis of ERP old/new effects

In Chapter 2 it was emphasised that it is difficult to make inferences about the neural basis of scalp-recorded ERPs unless converging information from other brain imaging modalities as well as data from patients with selective brain damage is available. It is also important to note that none of the functional conclusions drawn in this thesis depend upon claims about the specific brain regions that are responsible for old/new effects.

There are no strong conclusions that can be drawn about the neural basis of the left-parietal ERP old/new effect; although the data from patient studies suggests that the effect depends upon the medial temporal lobes being intact (Smith & Halgren, 1989; Duzel et al., 2001; Rugg, Roberts, Potter, Pickles, & Nagy, 1991; Tendolkar et al., 1999). The effect is unlikely to be a direct reflection of hippocampal or medial temporal lobe activity, however (Johnson, 1989; Rugg, 1995; Stapleton, Halgren & Moreno, 1987), and it has been suggested recently that left-parietal cortex is the likely brain region that generates this effect (Henson, Shallice, & Dolan, 1999). This account is based principally on the finding that this region has been activated in several fMRI studies of episodic retrieval (e.g. Wheeler et al., 1997; Henson et al., 1999), and in particular the findings of direct functional parallels between left-parietal cortex activation and left-parietal ERP old/new effects (Yonelinas, Otten, Shaw & Rugg, 2005; Spencer, Vila Abad & Donchin, 2000; Herron, Henson & Rugg, 2004; Vilberg, Moosavi & Rugg, 2006; Vilberg & Rugg, 2007; Herron, Quayle & Rugg, 2003).

The relatively focal anterior distribution of the mid-frontal ERP old/new effect suggests that tissue located close to the F3, Fz and F4 electrodes is responsible for the effect. This locates the generators in frontal and most likely pre-frontal cortex. Consistent with this account, Yonelinas et al. (2005) identified regions of left prefrontal cortex as cortical regions likely to index familiarity as they were regions in which activity was correlated positively with the confidence associated with judgments based upon familiarity. The absence of a markedly lateralised distribution of the mid-frontal effect is also not an impediment in this regard, because the locations at which scalp recorded EEG will be largest are influenced by the orientations of cellular configurations, which vary according to structural factors.

It is also worth noting, however, that cells in the medial temporal lobe are responsive to stimulus repetition (Zhu, Brown, & Aggleton, 1995), and that they do so within 200 ms of the presentation of a repeated stimulus. The disparity between the time courses of these cellular responses and the mid-frontal ERP old/new effect argues that this effect is a downstream index of a raw familiarity signal, and suggests that the effect is a consequence of fronto-temporal interactions signalling the familiarity of a stimulus. However, familiarity-sensitive neuronal responses have also been identified in a variety of prefrontal regions in primates (Xiang & Brown, 2004), and have onset latencies of approximately 250 ms, which is more in keeping with the time-course of the mid-frontal ERP effect. These findings suggest that the mid-frontal effect originates from one or more regions of the prefrontal cortex. A more precise anatomical characterisation than this is not possible at the present time.

MEG experiment findings

Three functionally dissociable effects were revealed in analyses of ERF old/new effects in an exclusion task that mapped closely onto Experiment 5. One of these effects is likely to be a functional homologue of the left-parietal ERP old/new effect. This claim is supported by the similar time courses and sensitivities to experiment manipulations of the two effects. A second ERP old/new effect was identified which may be a functional homologue of the mid-frontal ERP old/new effect, but the similarities between the two time courses of the two effects were not matched closely by equivalent sensitivities to the target/non-target manipulation in the MEG experiment. Finally, an ERF old/new effect with no apparent corresponding ERP correlate was evident at frontal electrodes between 500 and 800 ms. This effect was sensitive to the difference between all three item classes, but the greater relative positivity was for targets, in contrast with the graded pattern of effects for the early frontal ERF effect in which the relative greater positivity was for non-targets, and for the left-parietal ERF effect in which there was only an old/new effect for targets.

In combination, these data points emphasise that three functionally dissociable retrieval processes are revealed in exclusion tasks by MEG, and that in this context at least the information about retrieval processing that surface analysis of ERFs and ERPs provides is not mutually redundant. Whether this is true more generally in retrieval tasks, and in other cognitive domains, remains to be determined, and it is something that can only be established on a case by case basis. None the less, for studies of memory retrieval, these findings suggest that acquiring MEG in retrieval tasks will provide information complementary to that obtained with EEG, with obvious benefits for the resolution of cognitive accounts of memory retrieval. An obvious way in which to take this work forward is to acquire EEG and MEG conjointly in future experiments.

Concluding remarks

The electrophysiological correlate of recollection is the left-parietal old/new effect, (Rugg, 1995) and the effect was observed for correctly classified target items in all six experiments but was significantly attenuated for non-target items in experiments 4 and 5. This suggests that recollection of information associated with non-targets occurred markedly less often than recollection of information associated with targets in these two experiments. The accuracy of task judgments was also superior in experiments 4 and 5 than in experiments 1, 2, 3 and 6. This differential attenuation of non-target parietal ERP old/new effects across experiments replicates previous exclusion task findings (Dzulkifli et al., 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003a, 2003b; Wilding et al., 2005), with the attenuation of the non-target ERP old/new effect taking place in the experiment in which the likelihood of a correct target judgment was highest. These findings are therefore consistent with the view that participants adopt strategies in exclusion tasks whereby the extent to which recollection of information of targets is likely determines the extent to which recollection of information about non-targets will be prioritised (Herron & Rugg, 2003b).

One important question which the work in this thesis attempted to answer was whether target accuracy is the sole factor influencing the nature of the retrieval strategy adopted by participants in the exclusion task. In the studies of Wilding & Sharpe (2004), a non-target left-parietal old/new effect was observed even when the accuracy of target judgments was high (> .70). In Wilding & Rugg (1997), target recognition accuracy was low (.58) and they reported a left-parietal old/new effect for non-target items, whereas in the study of Dywan et al. (1998) a left-parietal old/new effect was observed for targets only, although target accuracy was relatively poor (.58). These data suggest that target accuracy is not the only factor influencing the strategy adopted by participants.

One other factor that may influence the adoption of a specific strategy is the correspondence between targets and non-targets. In studies where target accuracy has been relatively high yet ERP old/new effects for non-targets have been obtained, targets and non-targets have been associated with what can be regarded as relatively similar kinds of information. For example, in the studies of Wilding and colleagues

(Wilding & Rugg, 1997; Wilding & Sharpe, 2004), the target/non-target distinction was gender of study voice (male/female). In the study of Cycowicz, Friedman and Snodgrass (2001) the distinction was colour (red/green). It may be the case that for certain kinds of information – perhaps perceptual information bound to a stimulus – there is less opportunity to adopt a specific strategy that results in the selective processing of information associated with targets only. According to this account, therefore, the reduced effects for non-targets comes about because the encoding operations associated with targets and non-targets were sufficiently distinct to support a strategy of processing targets relatively selectively. It remains to be seen whether this as well as other factors also influence the likelihood of the adoption of a strategy of prioritising recollection of information about targets only.

These findings concerning the boundary conditions under which recollection of some forms of information is prioritised at the expense of others – either strategically or as a necessary consequence of task demands - are important for at least three reasons. First, with respect to the process-dissociation procedure, a core assumption is that, in the exclusion task component of the procedure, non-target judgments are made upon the basis of recollection (Jacoby, 1991, 1998).

The findings reported within this thesis did not concur with this prediction, as it appears that non-targets were not excluded on the basis of the recollection of associated source information in experiments 4 and 5, but rather through the failure to recollect source information associated with targets, this interpretation being contingent on the functional interpretation of the left-parietal ERP old/new effect as a correlate of the degree to which recollection is engaged. This finding either implies that some non-targets were not recollected at all, or that recollected information was not employed in the exclusion of these items.

This naturally has implications for the employment of this task in different populations, notably older participants, which Jennings & Jacoby (1997) have identified explicitly as one group for whom this would make a useful task to employ in order to identify deficits in recollection. Whist the task remains a practical tool for investigating memory impairment with age, due to the ability to vary the intervening lag of the repeated test items, it may be more useful in the discussion of questions regarding the understanding of how and when control over recollection changes with age, rather than for making claims about changes in the availability of recollection.

Investigation of the boundary conditions under which selective recollection occurs is a means of determining the mechanisms that are responsible for the recovery and use of some forms of information at the expense of others. Herron & Rugg (2003a) favoured the view that the reason for selective recollection of task-relevant information is the engagement of cue-specification processes, whereby internal representations generated by external cues are more likely to interact with some kinds of trace information than with others. Another possibility, however, is that the mechanism for selective recollection occurs further downstream, at the stage of attending to task-relevant outputs of retrieval processes (Dywan et al., 2002; Dzulkifli et al., 2006). This remains an account that encompasses selective recollection, in so far as the definition of recollection incorporates the recovery and use of information in service of task demands (Herron & Rugg, 2003b; Jacoby & Kelley, 1992), and can also explain the majority of the relevant data described here.

It may be the case that processes acting at these two stages are responsible for selective recollection of task-relevant information under different sets of circumstances, or that processes operating at both stages are typically involved (Dzulkifli et al., 2006). While the work described here does not speak directly to the accuracy of one or other of these possibilities, in combination with other findings, it points to the fact that experiments incorporating electrophysiological measures of neural activity are likely to be useful in further elucidating these issues.

The focus of the work presented in this thesis is in line with recent developments in brain imaging studies of episodic memory that have seen a shift towards consideration of control processes that are important for modulating what is retrieved from memory (Fletcher & Henson, 2001; Rugg & Henson, 2001). The work also helps to extend current understanding of the ways in which retrieval of information from episodic memory may be controlled. This is important, as memory impairments in aging (Logan, Sanders, Snyder, Morris & Buckner, 2002), in Alzheimer's disease (Grady, McIntosh, Beig, Keightley, Burian & Black, 2003) and following frontal brain damage (Stuss et al., 1994) may be due to the failure to engage such control processes.

Future research directions

A number of interesting avenues for further investigation arise from the main findings described in this thesis. Many of the interpretations discussed above rely on the ability to use ERP data to make inferences about behaviour. Although this is in line with the convergent operations approach adopted in neuroimaging, it is often possible to explain patterns of imaging data in more than one way. Further work is therefore required to examine the arguments made within this thesis in greater detail, and to test the hypotheses arising from these interpretations.

In particular, considerations over whether the probability of successfully retrieving target information influences the strategic retrieval of target information warrant further investigation. That is, will participants abandon a target-specific strategy if it is not reinforced by the frequent successful retrieval of target information? The density of targets re-presented at test could be varied within experimental blocks (high density = 80%, equal density = 50%, low density = 20%). The critical comparison would then be between the magnitudes of the left-parietal ERP old/new effect for targets and non-targets in each of the three conditions.

Also, the retrieval instructions employed within the task - "respond on one key to items from the study phase, and on another key to new items and any new items which repeat" may elicit different patterns of neural activity than retrieval instruction which stress the conceptual/perceptual/temporal differences between targets and non-targets, such as "respond on one key to items you saw in the first phase and on another key to items you have seen only within this second phase". An experiment, in which instructions were varied, would permit an assessment both of the episodic control processes that vary according to task requirements and also of the impact these control processes have on known correlates of retrieval success.

The highest priority avenue of research arising from this thesis is arguably the future use of the incarnation of the exclusion task used here with different populations. The findings in this thesis indicate that under certain conditions healthy young adults are able to selectively retrieve task-relevant contextual information while inhibiting the recollection of less relevant information. One of the implications of the findings to date is that, under some circumstances, healthy young adults can exert considerable control over whether or not information is recollected. Moreover this restriction of recollection to task-relevant information can be observed in two imaging techniques. This in turn suggests that ERPs (and ERFs) acquired in episodic retrieval tasks may be useful functional tools for determining; (i) the conditions under which this selectivity can be achieved and (ii) the ways in which control of retrieval varies according to subject variables such as age, from childhood all the way through to older age.

Perhaps the most obvious future application of the paradigm used in this thesis would be in the areas of aging, and memory impairment, as this particular paradigm has some advantages over the exclusion procedure in which targets and non-targets are both presented in a prior study-phase (Jennings & Jacoby, 1997). One advantage is that the use of very short repetition lags at test permits an assessment of whether different groups are able to understand task instructions equally well (Jennings & Jacoby, 1997). The short repetition lag makes the task possible for older adults and patients with mild memory impairment. Furthermore, by equating performance across different lags for different groups of individuals, it should in principle be possible to ascertain whether the selective control of retrieval exerted by healthy young adults can also be exerted, under comparable circumstances, by patient or older populations. The use of varying lags in different populations provides a means of contrasting measures of neural activity across lags at which response accuracy is equated. At the same time, however, as highlighting the utility of acquiring ERPs alongside behavioural measures in appropriately titrated exclusion paradigms as a means of exploring changes in retrieval control according to age, this research is a precursor to establishing how such control operations vary according to variables including disease state and pharmacological interventions. In this sense, an important contribution of the work in this thesis is the provision of baseline data that will provide the springboard for subsequent research in more applied contexts.

References

Aggleton, J. P., & Shaw, C. (1996). Amnesia and recognition memory: a reanalysis of psychometric data. *Neuropsychologia, 34*, 51-62.

Aggleton, J. P., Vann, S. D., Oswald, C. J., & Good, M. (2000). Identifying cortical inputs to the rat hippocampus that subserve allocentric spatial processes: a simple problem with a complex answer. *Hippocampus, 10*, 466-474.

Aggleton, J.P., Vann, S.D., Denby, C., Dix, S., Mayes, A.R., Roberts, N., et al. (2005). Sparing of the familiarity component of recognition memory in a patient with hippocampal pathology. *Neuropsychologia, 43*, 1810-1823.

Allison, T., Wood, C. C., & McCarthy, G. (1986). The central nervous system. In M. G. H. Coles, S. W. Porges & E. Donchin (Eds.), *Psychophysiology: Systems, Processes and Application.* (pp. 5-25). New York: Guilford Press.

Anderson, M.C. & Bjork, R.A. (1994). Mechanisms of nhibition in long term memor. In D. Dagebach & T.H. Carr (Eds), *Inhibitory processes in attention, memory, and language* (pp. 265-325). San Diego,California: Academic Press.

Atkinson, R. C., & Juola, J. F. (1973). Factors influencing speed and accuracy of word recognition. In S. Kornblum (Ed.), *Attention and Performance IV* (pp. 583-612). New York: Academic Press.

Atkinson, R. C., & Juola, J. F. (1974). Search and decision processes in recognition memory. In D. H. Krantz, R. C. Atkinson & P. Suppes (Eds.), *Contemporary Developments in Mathematical Psychology* (pp. 243-293). San Francisco: W.H. Freeman.

Atkinson, R. C., & Shiffrin, R. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation.* London: Academic Press.

Awh, E., Jonides, J., Smith, E. E., Schumacher, E. H., Koeppe, R. A., & Katz, S. (1996). Dissociation of storage and rehearsal in verbal working memory: evidence from positron emission tomography. *Psychological Science, 7*, 25-31.

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.

Baddeley, A. D. (1990). *Human Memory: Theory and practice.* London: Erlbaum.

Baddeley, A. D. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences, 4*, 417-423.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. A. Bower (Ed.), *Recent Advances in Learning and Motivation* (Vol. 8, pp. 47-90). New York: Academic Press.

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

Barrett, S. E., & Rugg, M. D. (1990). Event-related potentials and the phonological matching of pictures. *Psychophysiology, 30*, 327-339.

Barth, D.S. and Di, S. (1990). The electrophysiological basis of epileptiform magnetic fields in neocortex. *Brain Research, 530,* 35–39.

Barth, D.S. and Sutherling, W. (1988). Current source-density and neuromagnetic analysis of the direct cortical response in rat cortex. *Brain Research, 450,* 280–294.

Barth, D.S., Sutherling, W., Broffman, J. & Beatty, J. (1986). Magnetic localization of a dipolar current source implanted in a sphere and a human cranium. *Electroencephalography and Clinical Neurophysiology. 63,* 260–273

Becker, J. T., MacAndrew, D. K., & Fiez, J. A. (1999). A comment on the functional localization of the phonological storage subsystem of working memory. *Brain and Cognition, 41*, 27-38.

Bentin, S., McCarthy, G., & Wood, C. C. (1985). Event-related potentials, lexical decision, and semantic priming. *Electroencephalography and Clinical Neurophysiology, 60*, 343-355.

Blaxton, T., & Theodore, W. H. (1997). The role of the temporal lobes in recognising visuospatial materials: Remembering versus knowing. *Brain and Cognition, 35*, 5-25.

Blumhardt, L.D., Barrett, G., Halliday, A.M. & Kriss, A (1977): The asymmetrical visual evoked potential to pattern reversal in one half field and its significance for the analysis of visual field effects. *British Journal of Ophthalmology,* 61, 454-61.

Bornstein, B. H., & LeCompte, D. C. (1995). A comparison of item and source forgetting. *Psychonomic Bulletin & Review*, 2, 254-259.

Bowles, N. & Glanzer, M. (1983). An analysis of interference in recognition memory. *Memory and Cognition., 11,* 315.

Bridson, N.C., Fraser, C.S., Herron, J.E. & Wilding, E.L. (2006). Electrophysiological correlates of familiarity in recognition memory and exclusion tasks. *Brain Research*, 1114, 149-160.

Buckner, R. L., & Koutstaal, W. (1998). Functional neuroimaging studies of encoding, priming, and explicit memory retrieval. *Proceedings of the national Academy of Sciences USA, 95*, 891-898.

Buckner, R. L., Petersen, S. E., Ojemann, J. G., Miezin, F. M., Squire, L. R., & Raichle, M. E. (1995). Functional anatomical studies of explicit and implicit memory retrieval tasks. *Journal of Neuroscience, 15*, 12-29.

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

Cansino, S., Maquet, P., Dolan, R. J., & Rugg, M. D. (2002). Brain activity underlying encoding and retrieval of source memory. *Cerebral Cortex, 12*, 1048-1056.

Caton, R. (1875). The electrical currents of the brain. *British Medical Journal, 2,* 278.

Churchland, P. S. (1986). *Neurophilosophy: toward a unified science of the mind-brain.* Cambridge, MA.: MIT Press.

Clark, S.E., & Gronlund, S.D. (1996). Global matching models of recognition memory: how the models match the data. *Psychonomic Bulletin and Review, 3*, 37-60.

Cohen, D. (1968) Magnetoencephalography: evidence of magnetic fields produced by α-rhythm currents. *Science, 23,* 784-6.

Cohen, D. (1972) Magnetoencephalography: Detection of brain's electric activity with a superconducting magnetometer. *Science,* 175, 664-6.

Cohen, D. and Hosaka, H. (1976). Magnetic field produced by a current dipole. *Journal of Electrocardiology,* 9, 409–417.

Coles, M. G. H., Gratton, G., & Fabiani, M. (1990). Event-related brain potentials. In J. T. Cacciopo & L. G. Tassinary (Eds.), *Principles of psychophysiology:*

physical, social and inferential elements (pp. 413-455). Cambridge: Cambridge University Press.

Coles, M. G. H., & Rugg, M.D. (1995). Event-related brain potentials: an introduction. In M. D. Rugg, Coles, M.G.H. (Ed.), *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 J. of Experimental Psychology,* 33A, 497–505.

Cooper, R., Osselton, J. W., & Shaw, J. C. (1980). *EEG Technology*. London: Butterworths.

Corkin, S. (1968). Acquisition of motor skill after bilateral medial temporal lobe excision. *Neuropsychologia, 6*, 255-265.

Courchesne, E., Kilman, B.A., Galambos, R. & Lincoln, A.J. (1984). Autism: processing of novel auditory information assessed by event-related potentials. *Electroencephalogr Clin Neurophysiol*, 59, 238–248

Cowan, N. (2005). *Working memory capacity*. New York, NY: Psychology Press.

Cowan, N. & Stadler, M. A. (1996). Estimating unconscious processes: Implications of a general class of models. *Journal of Experimental Psychology: General, 125,* 195-200.

Craik, F. I. M. (2002). Levels of processing: past, present and future? *Memory, 10,* 305-318.

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behaviour, 11,* 671-684.

Cuffin, B.N. & Cohen, D. (1979). Comparison of the magnetoencephalogram and electroencephalogram. *Electroencephalography and Clinical Neurophysiology. 47,* 131–146.

Curran, T. (1999). The electrophysiology of incidental and intentional retrieval: ERP old/new effects in lexical decision and recognition memory. *Neuropsychologia, 37*, 771-785.

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., & Cleary, A. M. (2003). Using ERPs to dissociate familiarity from recollection in picture recognition. *Cognitive Brain Research, 15*, 191-205.

Curran, T., & Dien, J. (2003). Differentiating amodal familiarity from modality-specific memory processes: an ERP study. *Psychophysiology, 40*, 979-988.

Curran, T., & Friedman, W. J. (2004). ERP old/new effects at different retention intervals in recency discrimination tasks. *Cognitive Brain Research, 18*, 107-120.

Curran, T., & Hancock, J. (2007). The FN400 indexes familiarity-based recognition of faces.*NeuroImage, 36,* 464-471.

Curran, T., Schacter, D. L., Johnson, M., & Spinks, R. (2001). Brain potentials reflect behavioral differences in true and false recognition. *Journal of Cognitive Neuroscience., 13,* 201-216.

Curran, T., Schacter, D. L., Norman, K. A., & Galluccio, L. (1997). False recognition after a right frontal lobe infarction: memory for general and specific information. *Neuropsychologia, 35*, 1035-1049.

Curran, T., Tanaka, J. W., & Weiskopf, D. M. (2002). An electrophysiological comparison of visual categorization and recognition memory. *Cognitive, Affective, & Behavioral Neuroscience, 2*, 1-18.

Curran, T., Tepe, K. L., & Piatt, C. (2006). ERP explorations of dual processes in recognition memory. In H. D. Zimmer, A. Mecklinger & U. Lindenberger (Eds.), *Binding in human memory: A neurocognitive approach* (pp. 139-179). Oxford: Oxford University Press.

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.

Czernochowski, D., Mecklinger, A., Johansson, M., & Brinkmann, M. (2005). Age-related differences in familiarity and recollection: ERP evidence from a recognition memory study in children and young adults. *Cognitive, Affective and Behavioural Neuroscience, 5*, 417-433.

Davachi, L., Mitchell, J. P., & Wagner, A. D. (2003). Multiple routes to memory: Distinct medial temporal lobe processes build item and source memories. *Proceedings of the National Academy of Sciences, USA, 100*, 2157-2162.

D'Esposito, M., Aguirre, G. K., Zarahn, E., Ballard, D., Shin, R. K., & Lease, J. (1998). Functional MRI studies of spatial and nonspatial working memory. *Brain Research: Cognitive Brain Research, 7*, 1-13.

D'Esposito, M., Detre, J. A., Alsop, D. C., Shin, R. K., Atlas, S., & Grossman, M. (1995). The neural basis of the central executive system of working memory. *Nature, 378*, 279-281.

Dhond, R.P., Witzel, T, Dale, A.M. & Halgren, E. (2005). Spatiotemporal brain maps of delayed word repetition and recognition. *Neuroimage, 28,* 293-304.

Dobbins, I. G., Foley, H., Schacter, D. L., & Wagner, A. D. (2002). Executive control during episodic retrieval: Multiple prefrontal processes subserve source memory. *Neuron, 35*, 989-996.

Dodson, C. S. & Johnson, M. (1996). Some problems with the process-dissociation approach to memory. *Journal of Experimental Psychology: General, 125,* 181-194.

Donaldson, D. I., Allan, K., & Wilding, E. L. (2002). Fractionating retrieval from episodic memory using event-related potentials. In A. E. Parker, E. L. Wilding & T. J. Bussey (Eds.), *The cognitive neuroscience of memory: Episodic encoding and retrieval* (pp. 39-58). Hove: Psychology Press.

Donaldson, D.I., & Curran, T. (2007). Letter to the editor. *NeuroImage, 36,* 488-489.

Donaldson, D. I. & Rugg, M. (1998). Recognition memory for new associations: electrophysiological evidence for the role of recollection. *Neuropsychologia, 37,* 396.

Donaldson, W. (1996). The role of decision processes in remembering and knowing. *Memory and Cognition., 24,* 523-533.

Donchin, E. (1981). Presidential address, 1980 surprise! ... surprise? *Psychophysiology, 18,* 493–513.

Donchin, E., & Coles, M. G. H. (1988). Is the P300 component a manifestation of context updating? *Behavioral and Brain Sciences, 11*, 357-374.

Donchin, E., Ritter, W. & McCallum, W.C. (1978). Cognitive psychophysiology: The endogenous components of the ERP. In: E. Callaway, P. Tueting and S. Koslow, Editors, *Event-related brain potentials in man.* (pp. 349-441). Academic Press, New York.

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.

Duncan-Johnson, C. C., & Donchin, E. (1977). On quantifying surprise: The variation of event-related potentials with subjective probability. *Psychophysiology, 14*, 456-467.

Duzel, E., Cabeza, R., Picton, T. W., Yonelinas, A. P., Scheich, H., Heinze, H. J. & Tulving, E. (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. & Tulving, E. (2001). Comparing electrophysiological and hemodynamic measures of neural activation during memory retrieval. *Human Brain Mapping, 13*, 104-123.

Duzel, E., Richardson-Klavehn, A., Neufang, M., Schott, B.H., Scholz, M. & Heinze, H-J. (2005). Early, partly anticipatory, neural oscillations during identification set the stage for priming. *Neuroimage, 25,* 690-700.

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.

Duzel. E., Habib, R., Schott. B., Schoenfeld, A., Lobaugh, N., McIntosh, A.R., Scholz, M. & Heinze, H.J. (2003). A multivariate, spatiotemporal analysis of electromagnetic time-frequency data of recognition memory. *Neuroimage, 18, 184-197.*

Dywan, J., Segalowitz, S. J., & Arsenault, A. (2002). Electrophysiological response during source memory decisions in older and younger adults. *Brain and Cognition, 49*, 322-340.

Dywan, J., Segalowitz, S. J., & Webster, L. (1998). Source monitoring: ERP evidence for greater reactivity to non-target information in older adults. *Brain and Cognition, 36*, 390-430.

Dywan, J., Segalowitz, S. J., Webster, L., Hendry, K., & Harding, J. (2001). Event-related potential evidence for age-related differences in attentional allocation during a source monitoring task. *Developmental Neuropsychology, 19*, 99-120.

Dzulkifli, M. A., & Wilding, E. L. (2005). Electrophysiological indices of strategic episodic retrieval processing. *Neuropsychologia, 43*, 1152-1162.

Dzulkifli, M. A., Herron, J. E., & Wilding, E. L. (2006). Memory retrieval processing: Neural indices of processes supporting selective episodic retrieval. *Neuropsychologia, 44*, 1120-1130.

Ebbinghaus, H. (1913). *Memory, a contribution to experimental psychology*. New York: Teacher's College, Columbia University (Reprinted Bristol: Thoemmes Press, 1999).

Ecker, U.K H., Zimmer, H.D., & Groh-Bordin, C. (2007). Color and context: An ERP study on intrinsic and extrinsic feature binding in episodic memory. *Memory and Cognition, 35,* 1483-1501.
Ecker, U.K.H., Zimmer, H.D., & Groh-Bordin, C. (in press). The influence of object and background colour manipulations on the electrophysiological indices of recognition memory. *Brain Research.*
Eldridge, L.L., Knowlton, B.J., Furmanski, C.S., Bookheimer, S.Y., & Engel, S.A. (2000). Remembering episodes: a selective role for the hippocampus during retrieval. *Nature, 3*(11), 1149-1069.
Exner, C., Weniger, G., & Irle, E. (2001). Implicit and explicit memory after focal thalamic lesions. *Neurology, 57,* 2054-2063.
Eysenck, M.W. (1979). Depth, elaboration, and distinctiveness. In L. S. Cermak & F. I. M. Craik (Eds.), *Levels of processing in human memory.* Hillsdale, NJ: Lawrence Erlbaum Associates Inc.
Eysenck, M. W., & Eysenck, M. C. (1980). Effects of processing depth, distinctiveness, and word frequency on retention. *British Journal of Psychology, 71,* 263-274.
Fiez, J.A. (2001). Bridging the gap between neuroimaging and neuro- psychology: using working memory as a case-study. *Journal of Clinical and Experimental Neuropsychology, 23,* 19-31.
Finnigan, S., Humphreys, M.S., Dennis, S. & Geffen, G. (2002). ERP 'old/new' effects: Memory strength and decision confidence. *Neuropsychologia, 40*:2288-2304.
Fletcher, P.C. & Henson, R.N.A. (2001). Frontal lobes and human memory: Insights from functional neuroimaging. *Brain, 124,* 849-881.
Ford, J.M., Roth, W.T., Mohs, R.C., Hopkins III, W.F., & Kopell, B.S. (1979). Event-related potentials recorded from young and old adults during a memory retrieval task. *Electroencephalography and Clinical Neurophysiology, 47,* 450-459
Fox, N.C., Warrington, E.K., Seiffer, A.L., Agnew, S.K., & Rossor, M.N. (1998). Presymptomatic cognitive deficits in individuals at risk of familial Alzheimer's disease: a longitudinal prospective study. *Brain, 121,* 1631–1639.
Friedman, D. (1990). Cognitive event-related potential components during continuous recognition memory for pictures. *Psychophysiology, 27,* 136-148.
Friedman, D. (1990). ERPs during continuous recognition memory for words. *Biological Psychology, 30,* 61-87.
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.
Gabrieli, J.D.E., Fleischman, D.A., Keane, M.M., Reminger, S.L., & Morrell, F. (1995). Double dissociation between memory systems underlying explicit and implicit memory in the human brain. *Psychological Science, 6,* 76-82.
Gainotti, G., Cappa, A., Perri, R., & Silveri, M. C. (1994). Disorders of verbal and pictorial memory in right and left brain-damaged patients. *International Journal of Neuroscience, 78,* 9-20.
Gardiner, J. M. & Conway, M. A. (1999). Level of awareness and varieties of experience. In B.Challis & B. M. Velichkovsky (Eds.), *Stratification in cognition and consciousness. Advances in consciousness research.* (pp. 237-254). Amsterdam: John Benjamins Publishing Company.

Gardiner, J. M. (1988). Functional aspects of recollective experience. *Memory and Cognition, 16*, 309-313.
Gardiner, J. M., & Java, R. I. (1990). Recollective experience in word and non-word recognition. *Memory and Cognition, 18*, 23-30.
Gardiner, J. M., & Java, R. I. (1991). Forgetting in recognition memory with and without recollective experience. *Memory and Cognition, 19*, 617-623.
Gardiner, J. M., & Java, R. I. (1993). Recognising and remembering. In A. Collins, M. A. Conway, S. E. Gathercole & P. E. Morris (Eds.), *Theories of Memory* (pp. 163-188). Hillsdale, New Jersey: Erlbaum.
Gardiner, J. M., Java, R. I., & Richardson-Klavehn, A. (1996). How level of processing really influences awareness in recognition memory. *Canadian Journal of Experimental Psychology, 50*, 114-122.
Gardiner, J.M., & Parkin, A.J. (1990). Attention and recollective experience in recognition memory. *Memory and Cognition, 18*, 579-583.
Gardiner, J. M. & Ramponi, C. (1998). Experiences of Remembering, Knowing and Guessing. *Consciousness and Cognition, 7*, 1-26.
Gardiner, J.M., Richardson-Klavehn, A., & Ramponi, C. (1997). On reporting recollective experiences and 'direct access to memory systems. *Psychological Science, 8*, 391-394.
Gardiner, J.M., Richardson-Klavehn, A., & Ramponi, C. (1998). Limitations of the signal detection model of the Remember-Know paradigm: a reply to Hirshman. *Consciousness and Cognition, 7*, 285-288.
Gathercole, S. E. (1994). Neuropsychology and working memory: A review. *Neuropsychology, 8*, 494-505.
Geselowitz, D.B. (1970). On the magnetic field generated outside an inhomogeneous volume conductor by internal current sources. *IEEE Transactions on Magnetics*, 6, 346–347.
Gillund, G., & Shiffrin, R. M. (1984). A retrieval model for both recognition and recall. *Psychological Review, 91*, 1-67.
Glanzer, M., Adams, J. K., Iverson, G. J., & Kim, K. (1993). The regularities of recognition memory. *Psychological Review, 100*, 546-567.
Glanzer, M., Kim, K., Hilford, A., & Adams, J.K. (1999). Slope of the received operating characteristics in recognition memory. *Journal of Experimental Psychology: Learning, Memory and Cognition, 25*, 500-513.
Grady, C.L., McIntosh, A.R., Beig, S, Keightley, M.L., Burian, H., & Black, S.E. (2003). Evidence from functional neuroimaging of a compensatory prefrontal network in Alzheimer's disease. *Journal of Neuroscience*, 23, 986-993.
Graf, P., & Schacter, D. L. (1985). Implicit and explicit memory for new associations in normal and amnesic participants. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11*, 501-518.
Graf, P., Mandler, G., & Haden, P. E. (1982). Simulating amnesic symptoms in normals. *Science, 218*, 1243-1244.
Graf, P., Squire, L. R., & Mandler, G. (1984). The information that amnesics do not forget. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*, 164-178.
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.

Gregg, V. H., & Gardiner, J. H. (1994). Recognition memory and awareness: A large effect of study-test modalities on 'Know' responses following a highly perceptual orienting task. *European Journal of Cognitive Psychology, 6*, 131-147.

Groh-Bordin, C., Zimmer, H.D., & Ecker, U.H. (2006). Has the butcher on the bus dyed his hair? When colour changes modulate ERP correlates of familiarity and recollection. *NeuroImage, 32*, 1879-1890.

Groh-Bordin, C., Zimmer, H. D., & Mecklinger, A. (2005). Feature binding in perceptual priming and in episodic object recognition: Evidence from event-related brain potentials. *Cognitive Brain Research, 24*, 556-567.

Gruppuso, V., Lindsay, D. S., & Colleen, M. (1997). The process-dissociation procedure and similarity: defining and estimating recollection and familiarity in recognition memory. *Journal of Experimental Psychology: Learning, Memory and Cognition, 23,* 259-278.

Grynszpan, F. & Geselowitz, D.B. (1973). Model studies for the magnetocardiogram. *Biophysical Journal, 13,* 911–925.

Guillem, F., Bicu, M. & Debruille, J.B. (2001) Dissociating memory processes involved in direct and indirect tests with ERPs to unfamiliar faces. *Cognitive Brain Research,* 11, 113-125.

Hämäläinen, M. & Sarvas, J. (1989). Realistic conductivity geometry model of the human head for interpretation of neuromagnetic data. *IEEE Transactions on Biomedical Engineering, 36,* 165–171.

Hari, R., Joutsiniemi, S,-L. & Sarvas, J. (1988). Spatial resolution of neuromagnetic records: theoretical calculations in a spherical model. *Electroencephalography and Clinical Neurophysiology, 71,* 64–72.

Henson, R. N. A., Cansino, S., Herron, J. E., Robb, W. G. K., & Rugg, M. D. (2003). A familliarity signal in human anterior medial temporal cortex? *Hippocampus, 13*, 301-304.

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., 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.

Herron, J.E., Henson, R.N. & Rugg, M.D. (2004). Probability effects on the neural correlates of retrieval success: an fMRI study. *Neuroimage,* 21, 302-310.

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.

Herron, J. E., & Rugg, M. D. (2003a). Retrieval orientation and the control of recollection. *Journal of Cognitive Neuroscience, 15*, 843-854.

Herron, J. E., & Rugg, M. D. (2003b). Strategic influences on recollection in the exclusion task: Electrophysiological evidence. *Psychonomic Bulletin and Review, 10*, 703-710.

Herron, J. E., & Wilding, E. L. (2004). An electrophysiological dissociation of retrieval orientation and retrieval mode. *Neuroimage, 22*, 1554-1562.

Herron, J.E., & Wilding, E.L. (2005). An electrophysiological investigation of factors facilitating strategic recollection, *Journal of Cognitive Neuroscience*, 17, 1–11.
Hicks, J. L. & Marsh, R. L. (1999). Remember-know judgments can depend on how memory is tested. *Psychonomic Bulletin and Review, 6,* 117-122.
Hillebrand, A. & Barnes, G.R. (2001). On the detection probability of cortical activity from the human brain using magnetoencephalography (MEG). *Neuroimage, 13,* S150.
Hillyard, S. A., Hink, R. F., Schwent, V. L., & Picton, T. W. (1973). Electrical signs of selective attention in the human brain. *Science, 182*, 51-60.
Hintzman, D. L. (1984). MINERVA 2: A simulation model of human memory. *Behavior Research Methods, Instruments, & Computers 16*, 96-101.
Hintzman, D. L. (1986). "Schema abstraction" in a multiple-trace memory model *Psychological Review, 93*, 411-428.
Hintzman, D.L. (1988). Judgments of frequency and recognition memory in a multiple-trace memory model. *Psychological Review, 95*, 528-551.
Hintzman, D. L., & Curran, T. (1995). When encoding fails: instructions, feedback, and registration without learning. *Memory and Cognition, 23*, 213-226.
Hintzman, D. L., Caulton, D. A., & Levitin, D. (1998). Retrieval dynamics in recognition and list discrimination: further evidence of separate processes of familiarity and recall. *Memory and Cognition., 26*, 449-462.
Hintzman, D. L., Curran, T., & Oppy, B. (1992). Effects of similarity and repetition on memory: registration without learning? *Journal of Experimental Psychology: Learning, Memory and Cognition, 18*, 667-680.
Hintzman, D.L., & Curran, T. (1994). Retrieval Dynamics of Recognition and Frequency Judgments: Evidence for Separate Processes of Familiarity and Recall. *Journal of Memory and Language, 33*, 1-18.
Hirshman, E., Fisher, J., Henthorn, T., Arndt, J., & Passannante, A. (2002). Midazolam amnesia and dual-process models of the word-frequency mirror effect *Journal of Memory and Language, 47*, 499–516.
Hirshman, E. & Master, S. (1997). Modeling the conscious correlates of recognition memory: reflections on the remember-know paradigm. *Memory and Cognition, 25,* 345-351.
Hitch, G. J., & Baddeley, A. D. (1976). Verbal reasoning and working memory. *Quarterly Journal of Experimental Psychology, 28*, 603-621.
Hornberger, M., Morcom, A. M., & Rugg, M. D. (2004). Neural correlates of retrieval orientation: Effects of study-test similarity. *Journal of Cognitive Neuroscience, 16*, 1196-1210.
Horst, R. L., Johnson, J. R., & Donchin, E. (1980). Event-related brain potentials and subjetive probability in a learning task. *Memory and Cognition, 8*, 476-488.
Humphreys, M. S., Bain, J. D., & Pike, R. (1989). Different ways to cue a coherent memory system: A theory for episodic, semantic, and procedural tasks. *Psychological Review, 96*, 208-233.
Inoue, C. & Bellezza, F. S. (1998). The detection model of recognition using know and remember judgments. *Memory and Cognition, 299.*
Jacoby, L. L. (1984). Incidental vs. intentional retrieval: Remembering and awareness as separate issues. In L. R. Squire & N. Butters (Eds.), *The Neuropsychology of memory*. New York, NY: Guildford Press.
Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language, 30*, 513-541.

Jacoby, L. L. (1998). Invariance in automatic influences of memory: Toward a user's guide for the process-dissociation procedure. *Journal of Experimental Psychology: Learning, Memory and Cognition, 24*, 3-26.

Jacoby, L. L., & Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General, 3*, 306-340.

Jacoby, L. L., & Kelley, C. (1992). Unconscious influences of memory: Dissociations and automaticity. In A. D. Milner & M. D. Rugg (Eds.), *The Neuropsychology of Consciousness* (pp. 201-233). London: Academic Press.

Jacoby, L. L., Toth, J. P., & Yonelinas, A. P. (1993). Separating conscious and unconscious influences of memory: Measuring recollection. *Journal of Experimental Psychology: General, 122*, 139-154.

Jacoby, L.L, Woloshyn, V., & Kelley, C. (1997) Becoming famous without being recognized: Unconscious influences of memory produced by dividing attention. *Journal of Experimental Psychology: General*, 118, 115–125.

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

Jennings, J. M., & Jacoby, L. L. (1997). An opposition procedure for detecting age-related deficits in recollection: Telling effects of repetition. *Psychology and Aging,* 12, 352-361.

Johansson, M., Mecklinger, A., & Treese, A. (2004). Recognition memory for emotional and neutral faces: An event-related potential study *Journal of Cognitive Neuroscience, 16*, 1840-1853.

John, E. R., Ruchkin, D. S., & Vidal, J. J. (1978). Measurement of event-related potentials. In E. Callaway, P. Tueting & S. H. Koslow (Eds.), *Event-Related Brain Potentials in Man* (pp. 93-151). New York: Academic Press.

Johnson, J.D., & Rugg, M.D. (2006). Modulation of the electrophysiological correlates of retrieval cue processing by the specificity of task demands. *Brain Research, 1071*, 153-164.

Johnson, M. K., Foley, M. A., Suengas, A. G., & Raye, C. L. (1988). Phenomenal characteristics of memories for perceived and imagined autobiographical events. *Journal of Experimental Psychology: General, 117*, 371-376.

Johnson, M. K. & Hasher, L. (1987). Human learning and memory. *Annual Review of Psychology, 38*, 631-668.

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

Johnson, M. K., Raye, C. L., Foley, H. J., & Foley, M. A. (1981). Cognitive operations and decision bias in reality monitoring. *American Journal of Psychology, 94*, 37-64.

Johnson-Jr, R., Kreiter, K., Russo, B., & Zhu, J. (1998). A spatio-temporal analysis of recognition-related event-related brain potentials. *International Journal of Psychophysiology, 29*, 83-104.

Jones, G. V. (1987). Independence and exclusivity among psychological processes: Implications for the structure of recall. *Psychological Review, 94*, 229-235.

Jonides, J., Schumacher, E. H., Smith, E. E., Koeppe, R. A., Awh, E., Reuter-Lorenz, P. A., et al. (1998). The role of parietal cortex in verbal working memory. *Journal of Neuroscience, 18*, 5026-5034.

Joordens, S. & Merikle, P. M. (1993). Independence or redundancy? two models of conscious and unconscious influences. *Journal of Experimental Psychology: General, 122,* 462-467.

Joyce, C. A., Paller, K. A., Schwartz, T. J., & Kutas, M. (1999). An electrophysiological analysis of modality-specific aspects of word repetition. *Psychophysiology, 36*, 655-665.

Juola, J. F., Fischler, I., Wood, C. T., & Atkinson, R. C. (1971). Recognition time for information stored in long-term memory. *Perception and Psychophysics, 10*, 8-14.

Kapur, S., Craik, F. I. M., Jones, C., Brown, G. M., Houle, S., & Tulving, E. (1995). Functional role of the prefrontal cortex in retrieval of memories: a PET study. *Neuroreport, 6*, 1880-1884.

Kaufman, L., Okada, Y.C., Brenner, D. & Williamson, S.J. (1981).. On the relationship between somatic evoked fields and potentials. *International Journal of Neuroscience 15*, 223–239

Keane, M. M., Gabrieli, J. D. E., Mapstone, H. C., Johnson, K. A., & Corkin, S. (1995). Double dissociation of memory capacities after bilateral occipital-lobe or medial temporal lobe lesions. *Brain, 118*, 1129-1148.

Kelley, R., & Wixted, J. T. (2001) On the nature of associative information in recognition memory. *Journal of Experimental Psychology-Learning, Memory, and Cognition, 27*, 701-722.

Kemner, C., van der Gaag, R.J., Verbaten, M., van Engeland, H. (1999). ERP differences among subtypes of. pervasive developmental disorders. Biological Psychiatry, 46, 781-789.

Khoe, W., Kroll, N. E., Yonelinas, A. P., Dobbins, I. G., & Knight, R. T. (2000). The contribution of recollection and familiarity to yes-no and forced-choice recognition tests in healthy participants and amnesics. *Neuropsychologia, 38*, 1333-1341.

Kintsch, W. (1970). Models for free recall and recognition. In D.A.Norman (Ed.), *Models of human memory*. New York: Academic Press.

Knight, R.T. (1984). Decreased response to novel stimuli after prefrontal lesions in man. *Electroencephalography and Clinical Neurophysiology, 59*, 9–20.

Knowlton, B. (1998). The relationship between remembering and knowing: a cognitive neuroscience perspective. *Acta Psychologica, 98*, 253-265.

Knowlton, B. J., & Squire, L. R. (1995). Remembering and knowing: Two different expressions of declarative memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 699-710.

Kapur, S., Craik, F.I.M., Jones, C., Brown, G.M., Houle, S. & Tulving, E. (1995). Functional role of the prefrontal cortex in retrieval of memories: a PET study. *Neuroreport* 6, 1880-1884.

Kopelman, M. D. (1989). Remote and autobiographical memory, temporal context memory and frontal atrophy in Korsakoff and Alzheimer patients. *Neuropsychologia, 27*, 437-460.

Kopelman, M.D., & Stanhope, N. (1998). Recall and recognition memory in patients with focal frontal, temporal lobe and diencephalic lesions. *Neuropsychologia, 36*, 785-795.

Koriat, A. and Goldsmith, M. (1996). Monitoring and control operations in the strategic regulation of memory accuracy. *Psychological Review, 103*, 490-517.

Kutas, M. (1998). Review of event-related potential studies of memory. In M.S. Gazzaniga (Ed.), *Perspectives in Memory Research* (pp. 182-217). Cambridge, USA: MIT Press.

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.

Kutas, M., & Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Science, 4*, 463-470.

Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: brain potentials reflect semantic incongruity. *Science, 207*, 203-205.

Kutas, M., McCarthy, G., & Donchin, E. (1987). Augmenting mental chronometry: The P300 as a measure evaluation time. *Brain Research, 202*, 95-115.

Lazzara, M.M., Yonelinas, A.P. & Ober, B.A.(2001). Conceptual implicit memory performance in Alzheimer's disease. *Neuropsychology, 15*, 483-91.

Leahy, R.M., Mosher, J.C., Spencer, M.E., Huang, M.X. & Lewine, J.D. (1998). A study of dipole localization accuracy for MEG and EEG using a human skull phantom. *Electroencephalography and Clinical. Neurophysiology, 107,* 159–173.

Lee, D., Simos, P., Sawrie, S., Martin, R.C. & Knowlton, R.C. (2005). Dynamic brain activation patterns for face recognition: a magnetoencephalography study. *Brain Topography, 18,* 19-26.

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.

Logan, J.M., Sanders, A.L., Snyder, A.Z., Morris, J.C. & Buckner, R.L. (2002). Under-recruitment and nonselective recruitment: dissociable neural mechanisms associated with aging, *Neuron*,33 ,827–840.

Lopez, L., Chan, C.Y., Okada, Y.C. & Nicholson, C. (1991). Multimodal characterization of population responses evoked by applied electric field in vitro: Extracellular potential, magnetic evoked field, transmembrane potential and current-source density analysis. J*ournal of Neuroscience, 1,* 1998–2010.

Luck, S.J. (2005). *An introduction to the event-related potential technique.* MIT press, Cambridge, MA.

Lütkenhöner, B.(1996). Current dipole localization with an ideal magnetometer system. *IEEE Transactions in Biomedical Engineering, 43,* 1049–1061.

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

Mandler, G. (1991). Your face looks familiar but I can't remember your name: A review of dual process theory. In W. E. Hockley & S. Lewandowsky (Eds.), *Relating Theory and Data: Essays on Human Memory in Honor of Bennet B. Murdock* (pp. 207-225). Hillsdale, NJ: Erlbaum.

Mandler, G. & Boeck, W. J. (1974). Retrieval processes in recognition. *Memory and Cognition, 2*, 613-615.

Mandler, G., Goodman, G. O., & Wilkes-Gibbs, D. L. (1982). The word-frequency paradox in recognition. *Memory and Cognition, 10*, 33-42.

Mandler, G., Pearlstone, Z., & Koopsman, H. S. (1969). Effects of organisation and semantic ability on recall and recognition. *Journal of Verbal Learning and Verbal Behaviour., 8,* 410-423.

Manns, J.R., Hopkins, R.O., Reed, J.R., Kitchener, E.G., & Squire, L. (2003). Recognition memory and the human hippocampus. *Neuron, 38*, 127-133.

Mayes, A.R., Holdstock, J.S., Isaac, C.L., Montaldi, D., Grigor, J., Gummer, A., Cariga, P., Downes, J.J., Tsivilis, D., Gaffan, D., & Norman, K.A. (2004). Associative recognition in a patient with selective hippocampal lesions and relatively normal item recognition. *Hippocampus, 14*, 763-784.

Mayes, A.R., Isaac, C.L., Downes, J.J., Holdstock, J.S., Hunkin, N.M., Montaldi, D., MacDonald C., Cezayirli E., & Roberts J.N. (2001). Memory for single items, word pairs, and temporal order in a patient with selective hippocampal lesions. *Cognitive Neuropsychology, 18*, 97-123.

McClelland, J. L., McNaughton, B. L., & O'Reilly, R. C. (1995). Why there are complementary learning systems in the hippocampus and neocortex: Insights from the successes and failures of connectionist models of learning and memory. *Psychological Review, 102*(3), 419-457.

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

Meijs, J.W.H., Bosch, F.G.C., Peters, M.J. & Lopes da Silva, F.H. (1987). On the magnetic field distribution generated by a dipolar current source situated in a realistically shaped compartment model of the head. *Electroencephalography and Clinical. Neurophysiology, 66*, 286–298.

Morcom, A. M., & Rugg, M. D. (2001). Getting ready to remember: The neural correlates of task set during recognition memory. *Neuroreport, 13*, 149-152.

Morris, C. D., Bransford, J. D., & Franks, J. J. (1977). Levels of processing versus transfer appropriate processing. *Journal of Verbal Learning and Verbal Behaviour, 16*, 519-533.

Moscovitch, D.A. & McAndrews, M.P. (2002). Material-specific deficits in "remembering" in patients with unilateral temporal lobe epilepsy and excisions. *Neuropsychologia, 40*, 1335-1342.

Murdock, B. B. (1982). A theory for the storage and retrieval of item and associative information. *Psychological Review, 89*, 609-626.

Murdock, B. B. (1983). A distributed memory model for serial-order information. *Psychological Review, 90*, 316-338.

Murdock, B. B. (1993). TODAM2: A model for storage and retrieval of item, associative, and serial-order information. *Psychological Review, 100*, 183-203.

Murdock, B.B., & Dufty, P.O. (1972). Strength theory and recognition memory. *Journal of Experimental Psychology: General, 94*, 284-290.

Murnane, K. & Shiffrin, R.M. (1991). Word repetitions in sentence recognition, *Memory and Cognition, 19*: 119–130.

Nakasato, N., Levesque, M.F., Barth, D.S., Baumgartner, C., Rogers, R.L. & Sutherling, W.W. (1994). Comparisons of MEG, EEG, and ECoG source localization in neocortical partial epilepsy in humans. *Electroencephalography and Clinical. Neurophysiology, 171*, 171–178.

Nessler, D., & Mecklinger, A. (2003). ERP correlates of true and false recognition after different retention delays: stimulus- and response-related processes. *Psychophysiology, 40*, 146-159.

Nessler, D., Mecklinger, A., & Penney, T. B. (2001). Event related brain potentials and illusory memories: the effects of differential encoding. *Cognitive Brain Research, 10*, 283-301.

Nessler, D., Mecklinger, A., & Penney, T. B. (2005). Perceptual fluency, semantic familiarity and recognition-related familiarity: an electrophysiological exploration. *Cognitive Brain Research, 22*, 265-288.

Neville, H.J., Kutas, M., Chesney, G., & Schmidt, A.L. (1986). Event-related brain potentials during initial encoding and recognition memory of congruous and incongruous words. *Journal of Memory and Language, 25*, 75-92.

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

Nunn, J. A., Graydon, F. J., Polkey, C. E., & Morris, R. G. (1999). Differential spatial memory impairment after right temporal

Nyberg, L., Tulving, E., Habib, R., Nilsson, L. G., Kapur, S., Houle, S., et al. (1995). Functional brain maps of retrieval mode and recovery of episodic information. *Neuroreport, 7*, 249-252.

Oberauer, K. (2002). Access to information in working memory: Exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory and Cognition, 28*, 411-421.

Ogawa, S., Lee, T. M., Kay, A. R., & Tank, D. W. (1990). Brain magnetic-resonance-imaging with contrast dependent on blood oxygenation. *Proceedings of the National Academy of Sciences.* 9868-9872.

Okada, Y.C. (1989) Recent developments on the physiological basis of magnetoencephalography. In: S.J. Williamson, M. Hoke, G. Stroink and M. Kotani (Eds.), Biomagnetism. Plenum (pp. 273–278), New York.

Okada, Y.C. and Nicholson, C.(1988). Magnetic evoked field associated with transcortical currents in turtle cerebellum. *Biophysics. Journal, 53,* 723–731.

Okada, Y.C., Wu, J. and Kyuhou, S. (1997). Genesis of MEG signals in a mammalian CNS structure. *Electroencephalography and Clinical. Neurophysiology, 103,* 474–485.

Olichney, J. M., Petten, C. V., Paller, K. A., Salmon, D. P., Iragui, V. J., & Kutas, M. (2000). Word repetition in amnesia: Electrophysiological measures of impaired and spared memory. *Brain, 123*, 1948-1963.

Otten, L. J., & Rugg, M. D. (2001). Electrophysiological correlates of memory encoding are task-dependent. *Cognitive Brain Research, 12*, 11-18.

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., Hutson, C. A., Miller, B. B., & Boehm, S. G. (2003). Neural manifestations of memory with and without awareness. *Neuron, 38*, 507-516.

Paller, K. A., Kutas, M., & McIsaac, H. K. (1995). Monitoring conscious recollection via the electrical activity of the brain. *Psychological Science, 6*, 107-111.

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

Paulesu, E., Frith, C. D., & Frackowiak, R. S. (1993). The neural correlates of the verbal component of working memory. *Nature, 362*, 342-345.

Phillips, C. L. M. (2001). *Source estimation in EEG: combining anatomical and functional constraints.*, University of Liege, Belgium.

Picton, D. W., & Stuss, D. T. (1980). The component structure of the human event-related potentials. In H. H. Kornhuber & L. Deecke (Eds.), *Progress in Brain Research* (Vol. 54, pp. 17-49). Amsterdam: Elsevier/North Holland Biomedical Press.

Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, S. A., et al. (2000). Guidelines for using human event-related potentials to study cognition: recording standards and publication criteria. *Psychophysiology, 37*, 127-152.

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. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical Neurophysiology,* 118, 2128-2148.

Posner, M. I. & Keele, S. W. (1970). Retention of abstract ideas. *Journal of Experimental Psychology, 83,* 304-308.

Rajaram, S. (1993). Remembering and knowing: Two means of access to the personal past. *Memory and Cognition, 21*, 89-102.

Rajaram, S., & Neely, J. H. (1992). Dissociative masked repetition priming and word frequency effects in lexical decision and episodic recognition tasks. *Journal of Memory and Language,* 31**,** 152–182.

Ranganath, C., & Blumenfeld, R.S. (2005). Doubts about double dissociations between short- and long-term memory. *Trends in Cognitive Science, 9*, 374-380.

Ranganath, C., Yonelinas, A. P., Cohen, M. X., Dy, C. J., Tom, S. M., & D'Esposito, M. (2004). Dissociable correlates of recollection and familiarity within the medial temporal lobes. *Neuropsychologia, 42*, 2-13.

Ratcliff, R., Van Zandt, T., & McKoon, G. (1995). Process dissociation, single-process theories, and recognition memory. *Journal of Experimental Psychology: General, 124*, 352-374.

Rhodes, S.M., & Donaldson, D.I. (2008). Association and not semantic relationships elicit the N400 effect: Electrophysiological evidence from an explicit language comprehension task . *Psychophysiology,* 45, 50–59.

Richardson-Klavehn, A., Gardiner, J.M., & Java, R.I. (1994). Involuntary conscious memory and the method of opposition. *Memory, 2*, 1-29.

Rosch, E. (1978). *"Principles of Categorization."* In Rosch, E, & Lloyd, B.B. *Cognition and Categorization.* (p27-48).Hillsdale, NJ: Lawrence Erlbaum.

Rosch, E. (1999). *"Principles of Categorization."* In E. Margolis & S. Laurence (Eds.), *Concepts: Core Readings* (pp. 189-206). Cambridge, MA: MIT Press.

Rotello, C.M., MacMillan, N.A., & Reeder, J.A. (2004). Sum-difference theory of remembering and knowing: A two-dimensional signal detection model. *Psychological Review, 111*, 588 – 616.

Rugg, M. D. (1985). The effects of semantic priming and word repetition on event-related potentials. *Psychophysiology, 22*, 642-647.

Rugg, M.D. (1995). ERP studies of memory. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of Mind* (pp. 132-170). New York: Oxford University Press.

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

Rugg, M. D. (2001). Functional neuroimaging in cognitive neuroscience. In M. W. Brown & P. Hagoort (Eds.), *The Neurocognition of Language* (pp. 15-36). New York: Oxford University Press.

Rugg, M. D., & Allan, K. (2000). Event-related potential studies of memory. In E. Tulving & F. I. M. Craik (Eds.), *The Oxford handbook of memory* (pp. 521-537). Oxford: Oxford University Press.

Rugg, M. D., & Barrett, S. E. (1987). Event-related potentials and the interaction between orthographic and phonological information in a rhyme-judgment task. *Brain and Language, 32*, 336-336.

Rugg, M., Brovedani, P., & Doyle, M. C. (1992). Modulation of event-related potentials (ERPs) by word repetition in a task with inconsistent mapping between repetition and response. *Electroencephalography and Clinical Neurophysiology, 84,* 521-531.

Rugg, M. D., Cox, C. J. C., Doyle, M. C., & Wells, T. (1995). Event-related potentials and the recollection of low and high frequency words. *Neuropsychologia, 33*, 471-484.

Rugg, M. D., & Curran, T. (2007). Event-related potentials and recognition memory. *Trends in Cognitive Sciences, 11*, 251-257.

Rugg, M. D., & Doyle, M. C. (1992). Event-related potentials and recognition memory for low- and high-frequency words. *Journal of Cognitive Neuroscience, 4*, 69-79.

Rugg, M. & Doyle, M. C. (1994). Event-related potentials and stimulus repetition in indirect and direct tests of memory. In H.Heinze, T. Munte, & G. R. Mangun (Eds.), *Cognitive Electrophysiology* (pp. 124-148). Boston, Cambridge, MA: Birkhauser.

Rugg, M., Fletcher, P. C., Frith, C. D., Frackowiak, R. S. J., & Dolan.R.J. (1996). Differential response of the prefrontal cortex in successful and unsuccessful memory retrieval. *Brain, 119,* 2073-2083.

Rugg, M. & Henson, R. N. A. (2001). Episodic memory retrieval: an (event-related) functional neuroimaging perspective. In A.Parker, E. L. Wilding, & T. Bussey (Eds.), *The cognitive neuroscience of memory encoding and retrieval.* London: Psychology Press.

Rugg, M. D., Herron, J., & Morcom, A. (2002). Electrophysiological studies of retrieval processing. In L. R. Squire & D. L. Schacter (Eds.), *Neuropsychology of Memory* (3rd ed., pp. 154-165). New York: Guilford Publications.

Rugg, M. D., Mark, R. E., Gilchrist, J., & Roberts, S. C. (1997). ERP repetition effects in direct and indirect tasks; effects of age and inter-item lag. *Psychophysiology, 34*, 572-586.

Rugg, M. D., Mark, R. E., Walla, P., Schloerscheidt, A., Birch, C. S., & Allan, K. (1998). Dissociation of the neural correlates of implicit and explicit memory. *Nature, 392*, 595-598.

Rugg, M. D., & Nagy, M. E. (1989). Event-related potentials and recognition memory for words. *Electroencephalography and Clinical Neurophysiology, 72*, 395-406.

Rugg, M.D., Roberts, R.C., Potter, D.D. Pickles,C.D., & Nagy M.E. (1991). Event-related potentials related to recognition memory: effects of unilateral temporal lobectomy and temporal lobe epilepsy. *Brain* 114, 2313-2332.

Rugg, M. D., Walla, P., Schloerscheidt, A. M., Fletcher, P. C., Frith, C. D., & Dolan, R. J. (1998). Neural correlates of depth of processing effects on recollection: evidence from brain potentials and positron emission tomography. *Experimental Brain Research, 123*, 18-23.

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

Sangal, R.B. & Sangal, J.M. (2004). Rating scales for inattention and sleepiness are correlated in adults with symptoms of sleep disordered breathing syndrome, but not in adults with symptoms of attention-deficit/hyperactivity disorder, *Sleep Medicine, 5*, 133-135.

Sanquist, T. F., Rohrbaugh, J. W., Syndulko, K., & Lindsley, D. B. (1980). Electrocortical signs of levels of processing: Perceptual analysis and recognition memory. *Psychophysiology, 17*, 568-576.
Sarvas, J. (1987). Basic mathematical and electromagnetic concepts of the biomagnetic inverse problem. *Physics in Medicine and Biology, 32,* 11–22.
Schacter, D. L. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 501-518.
Schacter, D. L., Norman, K. A., & Koutstaal, W. (1998). The cognitive neuroscience of constructive memory. *Annual Review of Psychology, 49*, 289-318.
Schacter, D. L., Verfaellie, M., & Anes, M. D. (1997). Illusory memories in amnesic patients: conceptual and perceptual false recognition. *Neuropsychology, 11*, 331-342.
Schacter, D. L., Verfaellie, M., & Pradere, D. (1996). Neuropsychology of memory illusions - false recall and recognition in amnesic patients. *Journal of Memory and Language, 35*, 319-334.
Scherg, M. (1990). Fundamentals of dipole source potential analysis. In: F. Grandori, M. Hoke and G.L. Romani (Eds.), *Auditory Evoked Magnetic Fields and Electric Potentials. Advances in Audiology, Vol 6.* (pp. 40-69). Karger, Basel.
Schloerscheidt, A. M., & Rugg, M. D. (2004). The impact of change in stimulus format on the electrophysiological indices of recognition. *Neuropsychologia, 42*, 451-466.
Schott, B., Henson, R. N., Richardson-Klavehn, A., Becker, C., Thoma, V., Heinze, H. J., et al. (2005). Redefining implicit and explicit memory: the functional neuroanatomy of priming, remembering, and control of retrieval. *Proceedings of the National Academy of Sciences, 102*, 1257-1262.
Schott, B., Richardson-Klavehn, A., Heinze, H. J., & Duzel, E. (2002). Perceptual priming versus explicit memory: Dissociable neural correlates at encoding. *Journal of Cognitive Neuroscience, 14*, 578-592.
Scoville, W. B., & Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions. *Journal of Neurology, Neurosurgery, and Psychiatry, 20*, 11-21.
Sekiguchi, T., Koyama, S. & Kakigi, R. (2000). The effect of word repetition on evoked magnetic responses in the human brain. *Japanese Psychological research, 42,* 3-14.
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). *Die mneme als erhaltendes prinzip im wechsel des organishchen gesechehens*. Berlin: William Engelman.
Semon, R. S. (1914). *The Mneme*: 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.
Shallice, T., & Warrington, E. K. (1970). Independent functioning of verbal memory stores: A neuropsychological study. *Quarterly Journal of Experimental Psychology, 22*, 261-273.
Shiffrin, R.M. & Steyvers, M. (1997). A model for recognition memory: REM—retrieving effectively from memory. *Psychonomic Bulletin & Review* 4: 145–166.

Shimamura, A.P., & Squire, L.R. (1987). A neuropsychological study of fact memory and source amnesia. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 464-473.

Smith, E. E., & Jonides, J. (1995). Working memory in humans: neuro-psychological evidence. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences*. Cambridge, MA: The MIT Press.

Smith, E. E., & Jonides, J. (1999). Storage and executive processes in the frontal lobes. *Science, 283*, 1657-1661.

Smith, E. E., Jonides, J., & Koeppe, R. A. (1996). Dissociating verbal and spatial working memory using PET. *Cerebral Cortex, 6*, 11-20.

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

Smith, M. E., & Guster, K. (1993). Decomposition of recognition memory event-related potentials yields target, repetition, and retrieval effects. *Electroencephalography and Clinical Neurophysiology, 86*, 335-343.

Smith, M. E., & Halgren, E. (1989). Dissociation of recognition memory components following temporal lobe lesions. *Journal of Experimental Psychology: Learning, Memory and Cognition, 15*, 50-60.

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

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

Squire, L. R. (1987). *Memory and Brain*. New York: Oxford University Press.

Squire, L. R. (1992). Memory and the hippocampus: a synthesis from findings with rats, monkeys, and humans. *Psychological Review, 99*, 195-231.

Squire, L. R. (2004). Memory systems of the brain: a brief history and current perspective. *Neurobiology of Learning and Memory, 82*, 171-177.

Squire, L. R., & Knowlton, B. J. (1995). Learning about categories in the absence of memory. *Proceedings of the National Academy of Sciences, USA, 92*, 12470-12474.

Squire, L.R., Wixted, J.T, & Clark, R.E. (2007). Recognition memory and the medial temporal lobe: a new perspective. *Nature, 8,* 872-883.

Squire, L. R., & Zola-Morgan, S. (1988). Memory: Brain systems and behavior. *Trends in Neuroscience, 11*, 170-175.

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

Squires, N. K., Squires, K. C., & Hillyard, S. A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Neurophysiology, 38*, 387-401.

Stapleton, J.M., Halgren, E., & Moreno, K.A. (1987). Endogenous potentials after anterior temporal lobectomy. *Neuropsychologia,* 25: 549-557.

Staresina, B.P., Bauer,H, Deecke, L. & Walla, P. (2005). Magnetoencephalographic correlates of different levels in subjective recognition memory. *Neuroimage, 27*, 83-94.

Stuss, D.T., Eskes, G.A. & Foster, J.K. (1994). Experimental neuropsychological studies of frontal lobe functions. In: Boller, F. and Grafman, J. eds.

Handbook of Neuropsychology, Volume 10. (pp. 149-183). New York: Elsevier.
Sutherling, W.W., Crandall, P.H., Darcey, T.M., Becker, D.P., Levesque, M.F. & Barth, D.S. (1988). The magnetic and electrical fields agree with intracranial localizations of somatosensory cortex. *Neurology, 38,* 1705–1714.
Sutherling, W.W., Nakasato, N., Muresan, L., Vinet, L., Baumgartner, C. & Barth, D.(1991) Comparison of EEG, ECoG, MRI and seven versus 31 channels of MEG for noninvasive localization of the somatosensory response. In: M. Hoke, S.N. Erné, Y.C. Okada and G.L. Romani (Eds.), Biomagnetism: Clinical Aspects (pp. 233–236). Excerpta Medica, Amsterdam.
Sutton, S., Braren, M., & Zubin, J. (1965). Evoked potential correlates of stimulus uncertainty. Science, 150, 1187-1188.
Swets, J. A. (1986). Indiced of discrimination or diagnostic accuracy: their ROCs and implied models. *Psychological Bulletin, 99,* 100-117.
Swick, D., & Knight, R. T. (1997). Event-related potentials differentiate the effect of aging on word and nonword repetition in explicit and implicit memory tasks. *Journal of Experimental Psychology: Learning, Memory and Cognition, 23,* 123-142.
Tallon-Baudry C., Bertrand, O. & Pernier, J. (1999). A ring-shaped distribution of dipoles as a source model of induced gamma-band activity. *Clinical Neurology, 110,* 660–665.
Tendolkar, I., Rugg, M.D., Fell, J., Vogt, H., Scholz, M., Hinrichs, H. & Heinze, H-J. (2000). A magnetoencephalographic study of brain activity related to recognition memory in healthy young human participants. *Neuroscience Letters, 280*, 69-72.
Tendolkar, I., Schoenfeld, A., Golz, G., Fernandez, G., Kuhl, K., Ferszt, R. & Heinze, H-J. (1999). Neural correlates of recognition memory with and without recollection in patients with Alzheimer's disease and healthy controls. *Neuroscience Letters, 263*, 45-48.
Toth, J. P. (1996). Conceptual automaticity in recognition memory: Levels of processing effects on familiarity. *Canadian Journal of Experimental Psychology, 50*, 123-128.
Toth, J.P., Reingold, E.M. & Jacoby, L.L. (1994). Tpward a redefinition of implicit memory: Process dissociations following elaborative processing and self-generation. *Journal of Experimental Psychology: Learning, Memory and Cognition, 20,*290-303.
Trott, C. T., Friedman, D., Ritter.D., Fabiani, M., & Snodgrass, J. G. (1999). Episodic priming and memory for temporal source: event-related potentials reval age-related differences in prefrontal functioning. *Psychology and Ageing, 14,* 390-413.
Tsivilis, D., Otten, L., & Rugg, M. D. (2001). Context effects on the neural correlates of recognition memory: an electrophysiological study. *Neuron, 31*, 497-505.
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. (1976). Ecphoric processes in recall and recognition. In J.Brown (Ed.), *Recall and recognition.* London: Wiley.
Tulving, E. (1983). *Elements of Episodic Memory.* Oxford: Oxford University Press.
Tulving, E. (1985a). How many memory systems are there? *American Psychologist, 40*, 385-398.
Tulving, E. (1985b). Memory and consciousness. *Canadian Psychologist, 26*, 1-12.

Tulving, E. (1993). What is episodic memory? *Current Perspectives in Psychological Science, 2,* 67-70.
Tulving, E., & Craik, F. I. M. (2000). *The Oxford handbook of memory*. New York: Oxford University Press.
Tulving, E., Kapur, S., Markowitsch, H. J., Craik, F. I., Habib, R., & Houle, S. (1994). Neuroanatomical correlates of retrieval in episodic memory: auditory sentence recognition [see comments]. *Proc Natl Acad Sci U S A, 91*, 2012-2015.
Tulving, E. & Markowitsch, H. J. (1998). Episodic and declarative memory: role of the hippocampus. *Hippocampus, 8,* 198-204.
Tulving, E., & Schacter, D. L. (1990). Priming and human memory systems. *Science, 247*, 301-306.
Tulving, E. & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review, 80,* 352–373.
Vallar, G., & Shallice, T. (1990). *Neuropsychological Impairment.* New York: Cambridge University Press.
Van der Linden, M., Coyette, F., & Seron, X. (1992). Selective impairment of the 'central executive' component of working memory: a single case study. *Cognitive Neuropsychology, 9*, 301-326.
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.
Vargha-Khadem, F., Gadian, D. G., Watkins, K. E., Connelly, A., Van Paesschen, W., & Mishkin, M. (1997). Differential effects of early hippocampal pathology on episodic and semantic memory. *Science, 277*, 376-380.
Verfaellie, M., Giovanello, K.S., & Keane, M.M. (2001). Recognition memory in amnesia: effects of relaxing response criteria. *Cognitive, Affective and Behavioural Neuroscience, 1*, 3-9.
Verfaellie, M., & Treadwell, J. R. (1993). Status of recognition memory in amnesia. *Neuropsychology, 7*, 5-13.
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.
Vilberg K.L., Rugg M.D. (2007). Dissociation of the neural correlates of recognition memory according to familiarity, recollection, and amount of recollected information. Neuropsychologia, 45(10), 2216-2225.
Voss, J. L., & Paller, K. A. (2006). Fluent conceptual processing and explicit memory for faces are electrophysiologically distinct. *The Journal of Neuroscience, 26*, 926-933.
Voss, J. L., & Paller, K. A. (2007). Neural correlates of conceptual implicit memory and their contamination of putative neural correlates of explicit memory. *Learning and Memory, 14*, 259-267.
Wagner, A. D., Gabrieli.J.D., & Verfaellie, M. (1997). Dissociations between familiarity processes in explicit recognition and implicit perceptual processing. *Journal of Experimental Psychology: Learning, Memory and Cognition, 23*, 305-323.
Wagner, A. D., Koutstaal, W., & Schachter, D. L. (1999). When encoding yields remembering: insights from event-related neuroimaging. *Philosophical Transactions of the Royal Society (London), 354*, 1307-1324.

Wagner, A. D., Paré-Blagoev, J. E., Clark, J., & Poldrack, R. A. (2001). Recovering Meaning: Left Prefrontal Cortex Guides Controlled Semantic Retrieval. *Neuron, 31*, 329-338.
Walla, P., Endl. W., Lindinger, G., Lalouschek, W., Deecke, L. & Lang, W. (1999). Early occipito-parietal activity in a word recognition task: an EEG and MEG study. *Clinical Neurophysiology, 110*: 1378-1387.
Walla, P., Hufnagl, B., Lindinger, G., Imhof, H., Deecke, L. & Lang,W. (2001). Left temporal and temporoparietal brain activity depends on depth of word encoding: a magnetoencephalographic study in healthy young participants. *Neuroimage, 13*, 402-409.
Warrington, E. K., & Weiskrantz, L. (1970). Amnesic syndrome: Consolidation or retrieval? *Nature, 228*, 628-630.
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. (2000). In what way does the parietal ERP old/new effect index recollection? *International Journal of Psychophysiology, 35*, 81-87.
Wilding, E. L., Doyle, M. C., & Rugg, M. D. (1995). Recognition memory with and without retrieval of study 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., & Rugg, M. (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. (1997). An event-related potential study of memory for spoken and heard words. *Neuropsychologia, 35*, 1185-1195.
Wilding, E. L., & Sharpe, H.L. (2003). Episodic memory encoding and retrieval: Recent insights from event-related potentials. In A. Zani & A. Mado-Proverbio (Eds.), *The cognitive electrophysiology of mind and brain* (pp. 169-196). San Diego: Academic Press.
Wilding, E. L., & Sharpe, H. L. (2004). The influence of response-time demands on electrophysiological correlates of successful episodic retrieval. *Cognitive Brain Research, 18*, 185-195.
Willingham, D. B. (1997). Systems of memory in the human brain. *Neuron, 18*, 5-8.
Wirsén, A., Stenberg, G., Rosen, I, & Ingvar, D.H. (1992). Quantified EEG and cortical evoked responses in patients with chronic traumatic frontal lesions. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section, 84,* 127-138.
Wixted, J.T. (2007). Dual-process theory and signal detection theory of recognition memory. *Psychological Review, 114,* 152-176.
Wolk, D.A., Schacter, D.L., Berman, A.R., Holcomb, P.J., Daffner, K.R. & Budson, A.E. (2004). An electrophysiological investigation of the relationship between conceptual fluency and familiarity, *Neuroscience Letters*, 369, 150–155.
Wolk, D. A., Schacter, D. L., Lygizos, M., Mandu Sen, N., Holcomb, P. J., Daffner, K. R., et al. (2006). ERP correlates of recognition memory: Effects of retention interval and false alarms. *Brain Research, 1096*, 148-162.

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.
Wood, C.C. (1987). Generators of event-related potentials. In A. M. Halliday, S. M. Butler & R. Paul (Eds.), *A Textbook of Clinical Neurophysiology* (pp. 535-567). New York: Wiley.
Wood, C.C., Cohen, D., Cuffin, B.N., Yarita, M. & Allison, T. (1985). Electrical sources in the human somatosensory cortex: identification by combined magnetic and electric potential recordings. *Science, 227,* 1051–1053.
Wood, J.N. & Grafman, J. (2003). Human prefrontal cortex: processing and representational perspectives. *Neuroscience,* 4, 139-147.
Wood, C.C. & McCarthy, G. (1984). Principal component analysis of event-related potentials: simulation studies demonstrate misallocation of variance across components. *Electroencephalography and Clinical Neurophysiology,* 59, 249–260.
Wood, S.M., Potts, G.F., Hall, J.F., Ulanday, J.B., Netsiri, C. (2006). Event-related potentials to auditory and visual selective attention in schizophrenia. *International Journal of Psychophysiology,* 60, 67-75.
Woodruff, C.C., Hayama, H., & Rugg, M.D. (2006). Electrophysiological dissociation of the neural correlates of recollection and familiarity. *Brain Research, 1100,* 125-135.
Xiang, J.Z., & Brown, M.W. (2004). Neuronal responses related to long-term recognition memory process in the prefrontal cortex. *Neuron, 42,* 817-829.
Yamaguchi ,S. & Knight, R.T. (1990). Gating of somatosensory input by human prefrontal cortex. Brain Research, 521, 281–8.
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. (1997). Recognition memory for item and associative information: the contribution of recollection and familiarity. *Memory and Cognition, 25*, 747-763.
Yonelinas, A. P. (1999). Recognition memory ROCs and the dual-process signal-detection model comment on Glanzer, Kim, Hilford, and Adams (1999). *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*, 514-521.
Yonelinas, A. P. (2001a). The 3 Cs of recognition memory: consciousness, control, and confidence. *Journal of Experimental Psychology: General, 130*(3), 361-379.
Yonelinas, A. P. (2001b). 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., Dobbins, I., Szymanski, M.D., Dhaliwal, H.S., & King, L. (1996). Signal-detection, threshold, and dual-process models of recognition memory: ROCs and conscious recollection. *Consciousness and Cognition, 5*, 418-441.
Yonelinas, A. P., Hopfinger, J. B., Buonocore, M. H., Kroll, N. E. A., & Baynes, K. (2001). Hippocampal, parahippocampal and occipital-temporal contributions to associative and item recognition memory: an fMRI study. *Neuroreport, 12*, 359-363.

Yonelinas, A. P. & Jacoby, L. L. (1994). Dissociations of processes in recognition memory: Effects of interference and of response speed. *Canadian Journal of Experimental Psychology, 48*, 516-534.

Yonelinas, A. P. & Jacoby, L. L. (1995). The relation between remembering and knowing as bases for recognition: effects of size congruency. *Journal of Memory and Language, 34,* 622-643.

Yonelinas, A. P. & Jacoby, L. L. (1996). Noncriterial recollection; familiarity as automatic, irrelevant recollection. *Consciousness and Cognition, 5,* 131-141.

Yonelinas, A. P., Kroll, N. E., Dobbins, I., Lazzara, M., & Knight, R. T. (1998). Recollection and familiarity deficits in amnesia: Convergence of remember-know, process dissociation, and receiver operating characteristic data. *Neuropsychology, 12*, 323-339.

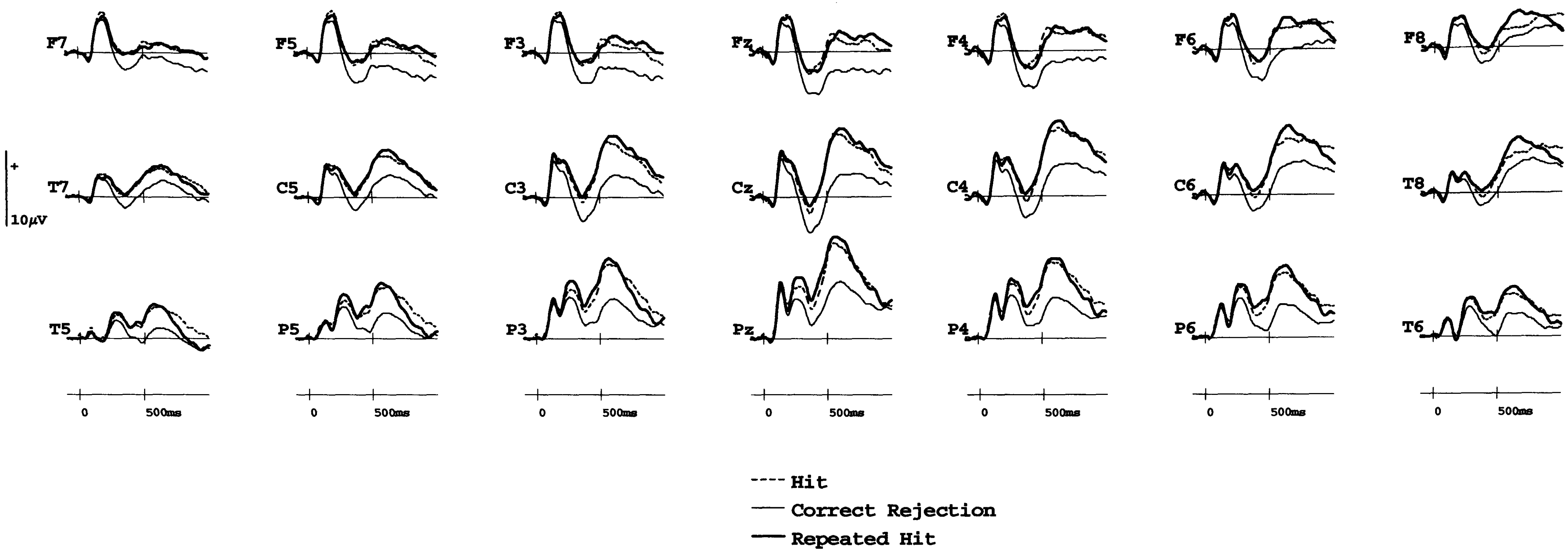
Yonelinas, A.P. & Levy, B.J. (2002). Dissociating familiarity from recollection in human recognition memory: different rates of forgetting over short retention intervals, *Psychonomic Bulletin and. Review, 9,* 575–582.

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.

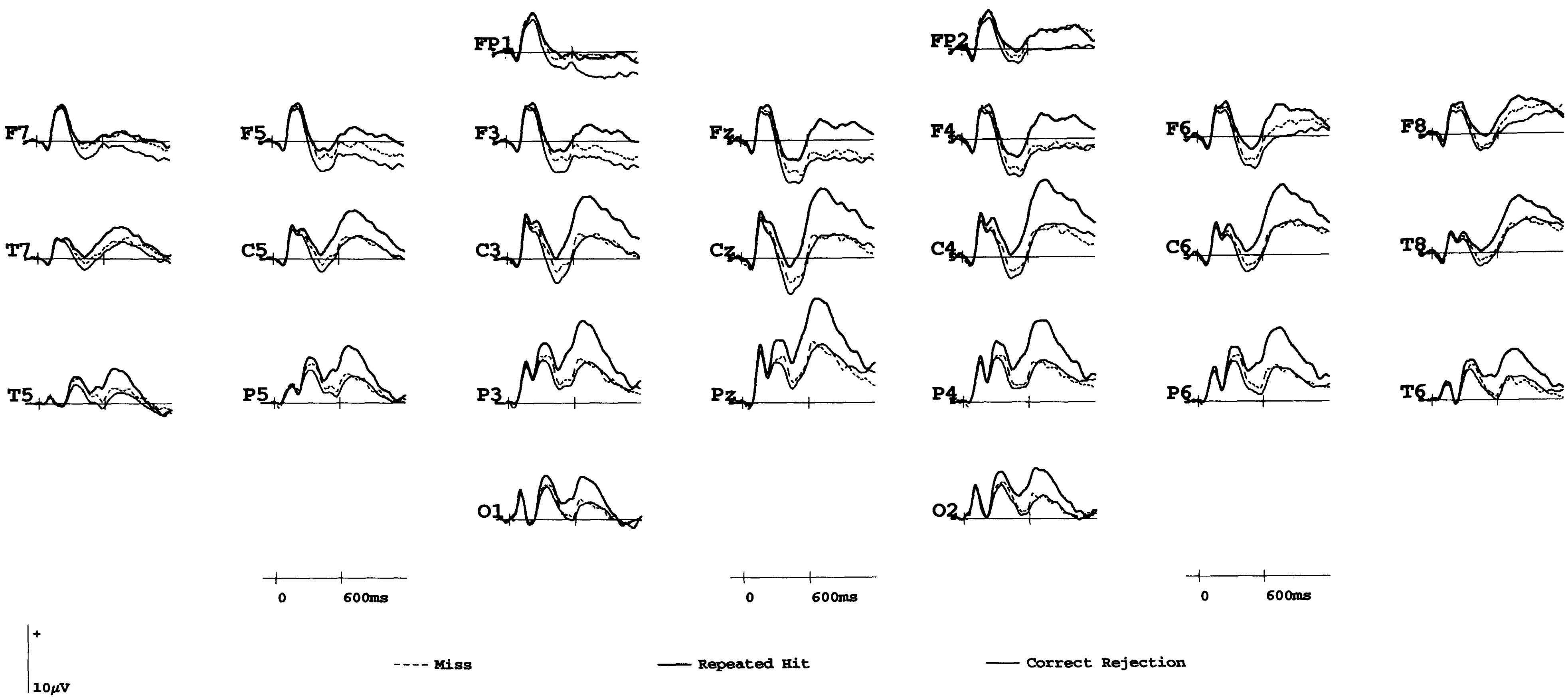
Yovel, G., & Paller, K. A. (2004). The neural basis of the butcher-on-the-bus phenomenon: when a face seems familiar but is not remembered. *Neuroimage, 21*, 789-800.

Appendices

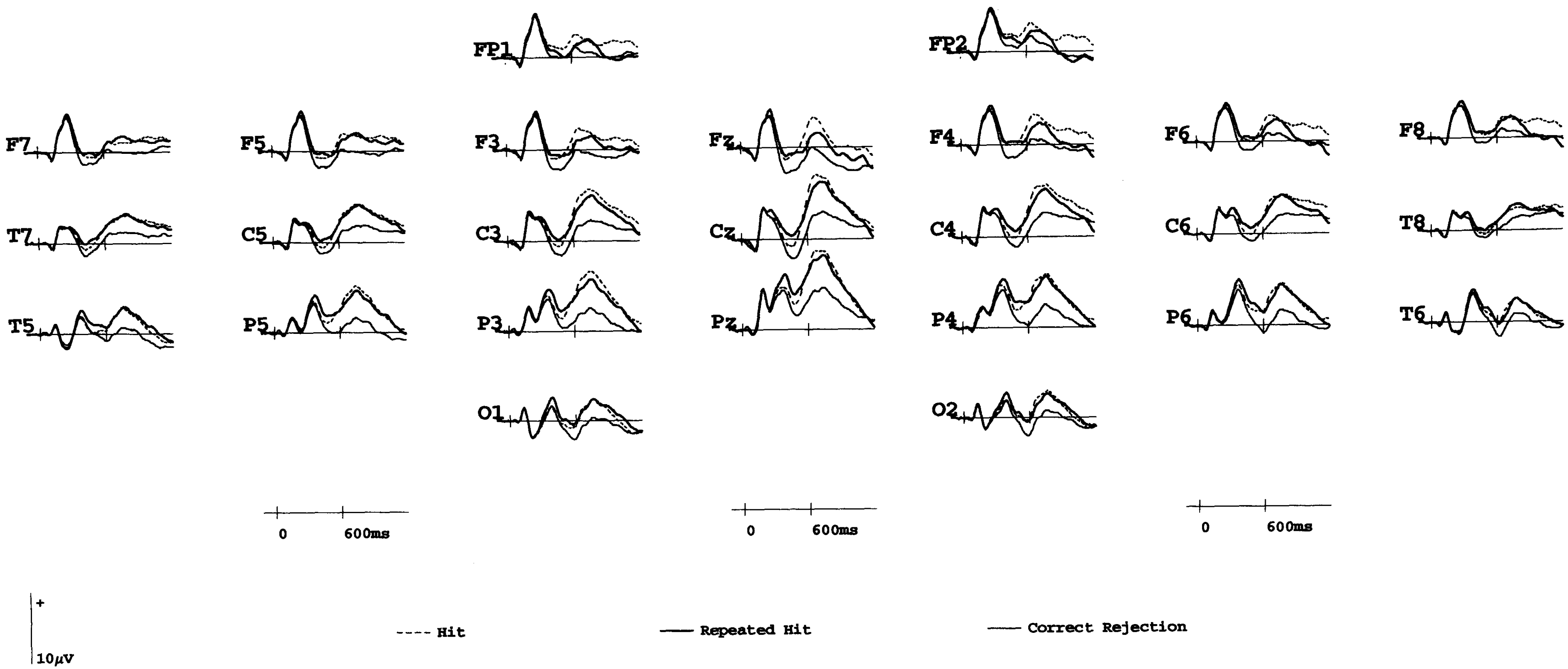
Appendix 1. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at sites FP1/2, F7/8, F5/6, F3/4, T7/8, C5/6, C3/4, T5/6, P5/6, P3/4, Fz, Cz and Pz in Experiment 1.



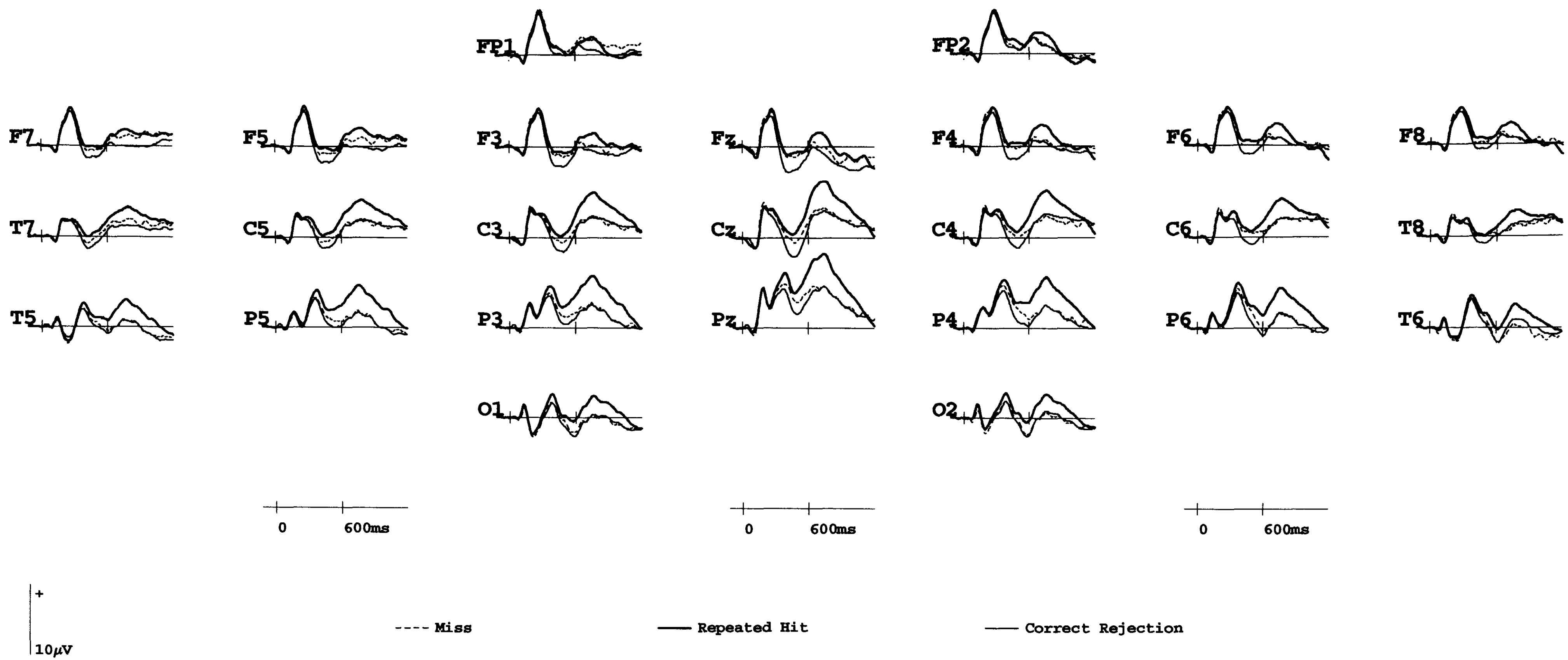
Appendix 2. Grand averaged ERPs elicited by misses, repeated hits and correct rejections at sites FP1/2, F7/8, F5/6, F3/4, T7/8, C5/6, C3/4, T5/6, P5/6, P3/4, Fz, Cz and Pz in Experiment 1.



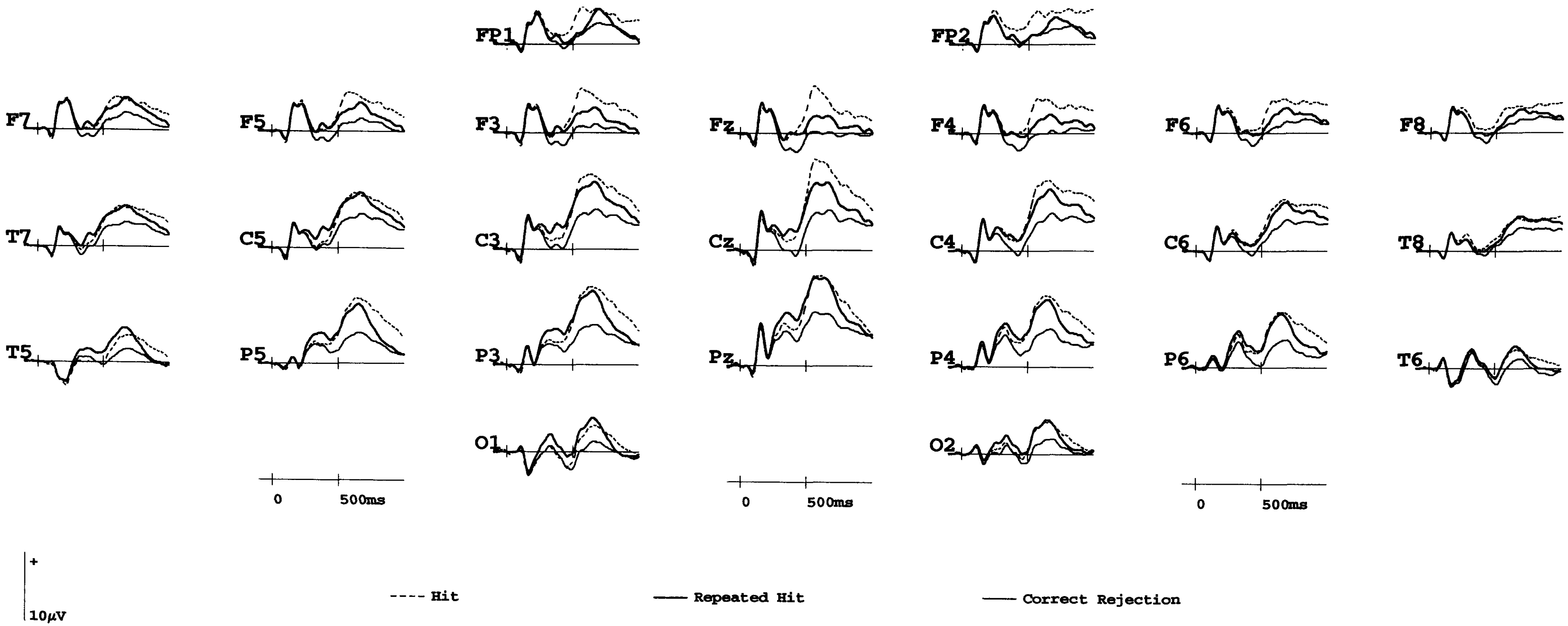
Appendix 3. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at sites FP1/2, F7/8, F5/6, F3/4, T7/8, C5/6, C3/4, T5/6, P5/6, P3/4, Fz, Cz and Pz in Experiment 2.



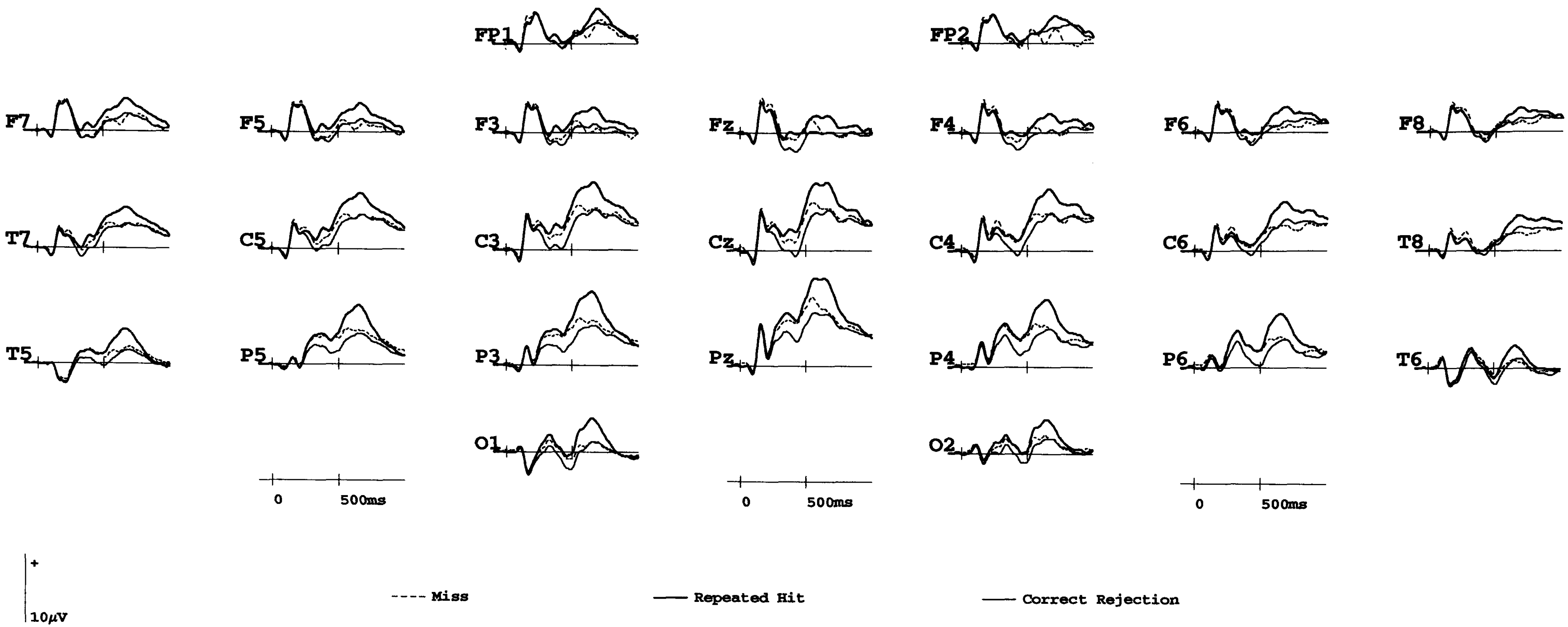
Appendix 4. Grand averaged ERPs elicited by misses, repeated hits and correct rejections at sites FP1/2, F7/8, F5/6, F3/4, T7/8, C5/6, C3/4, T5/6, P5/6, P3/4, Fz, Cz and Pz in Experiment 2.



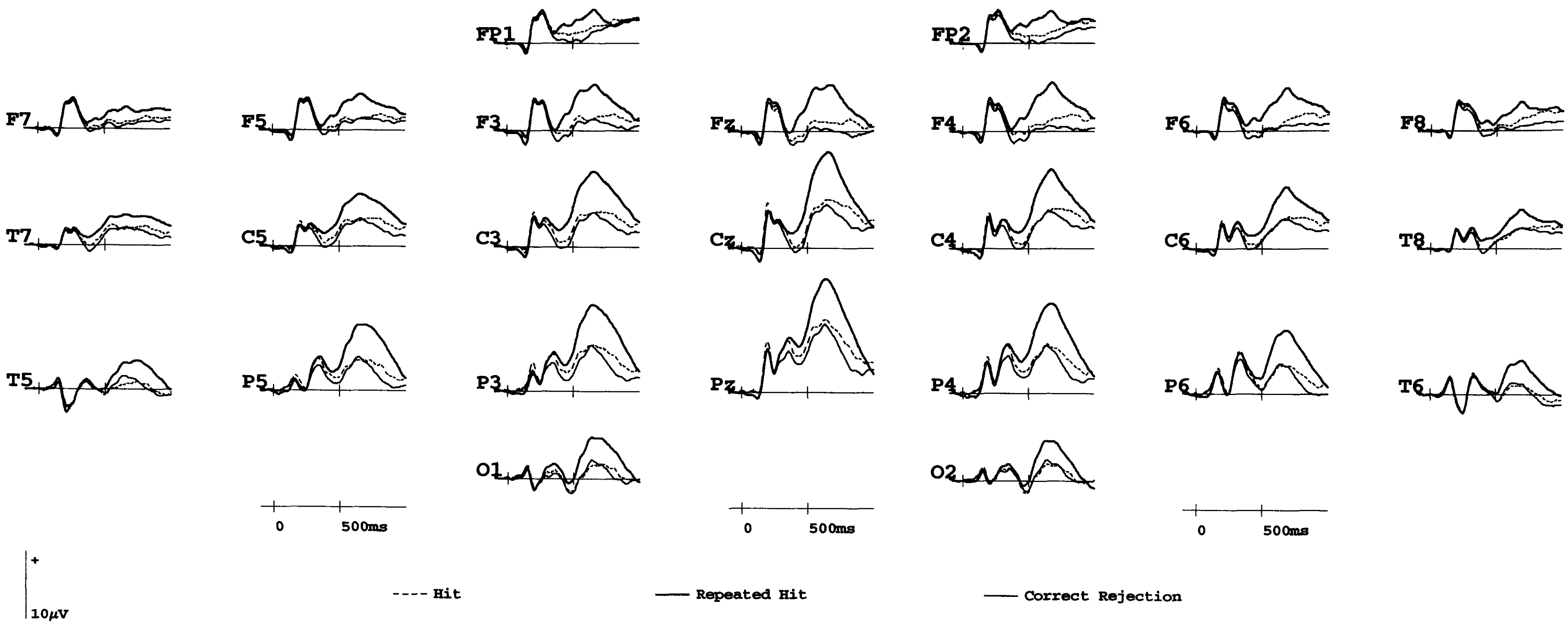
Appendix 5. Grand averaged ERPs elicited by hits, repeated hits and correct rejections at sites FP1/2, F7/8, F5/6, F3/4, T7/8, C5/6, C3/4, T5/6, P5/6, P3/4, Fz, Cz and Pz in Experiment 3.



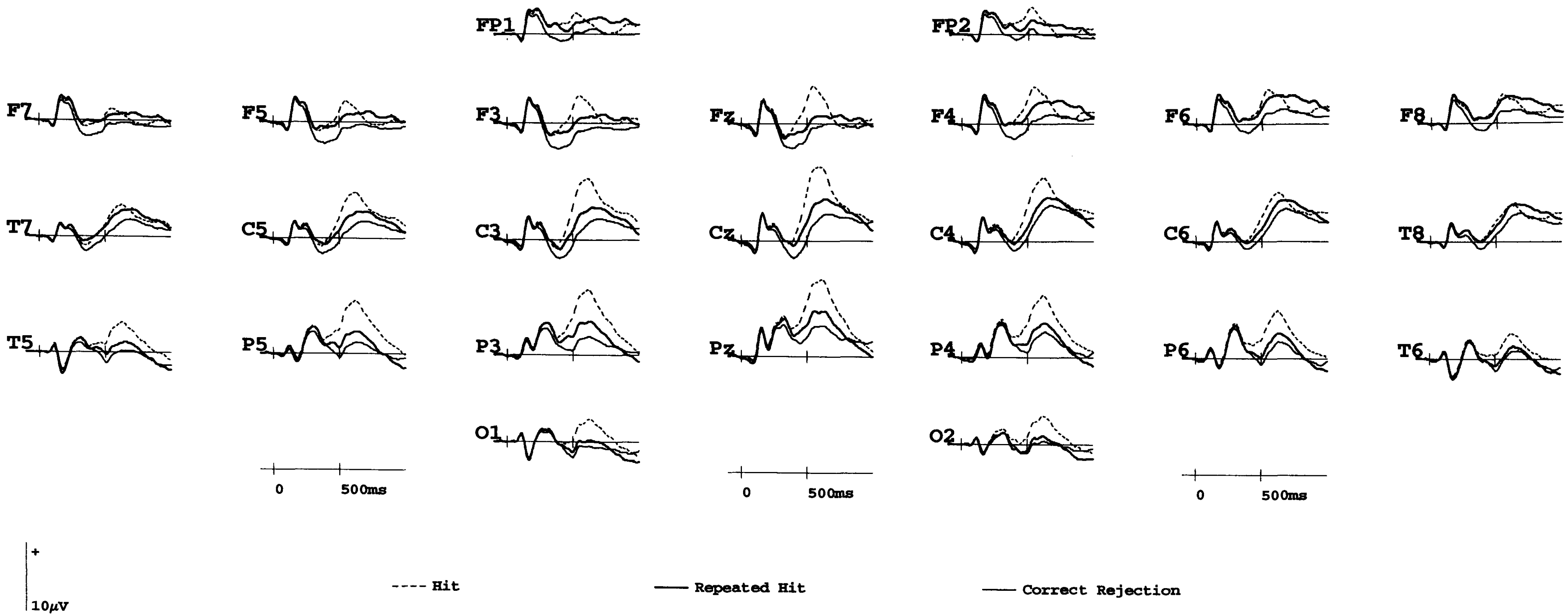
Appendix 6. Grand averaged ERPs elicited by misses, repeated hits and correct rejections at sites FP1/2, F7/8, F5/6, F3/4, T7/8, C5/6, C3/4, T5/6, P5/6, P3/4, Fz, Cz and Pz in Experiment 3.



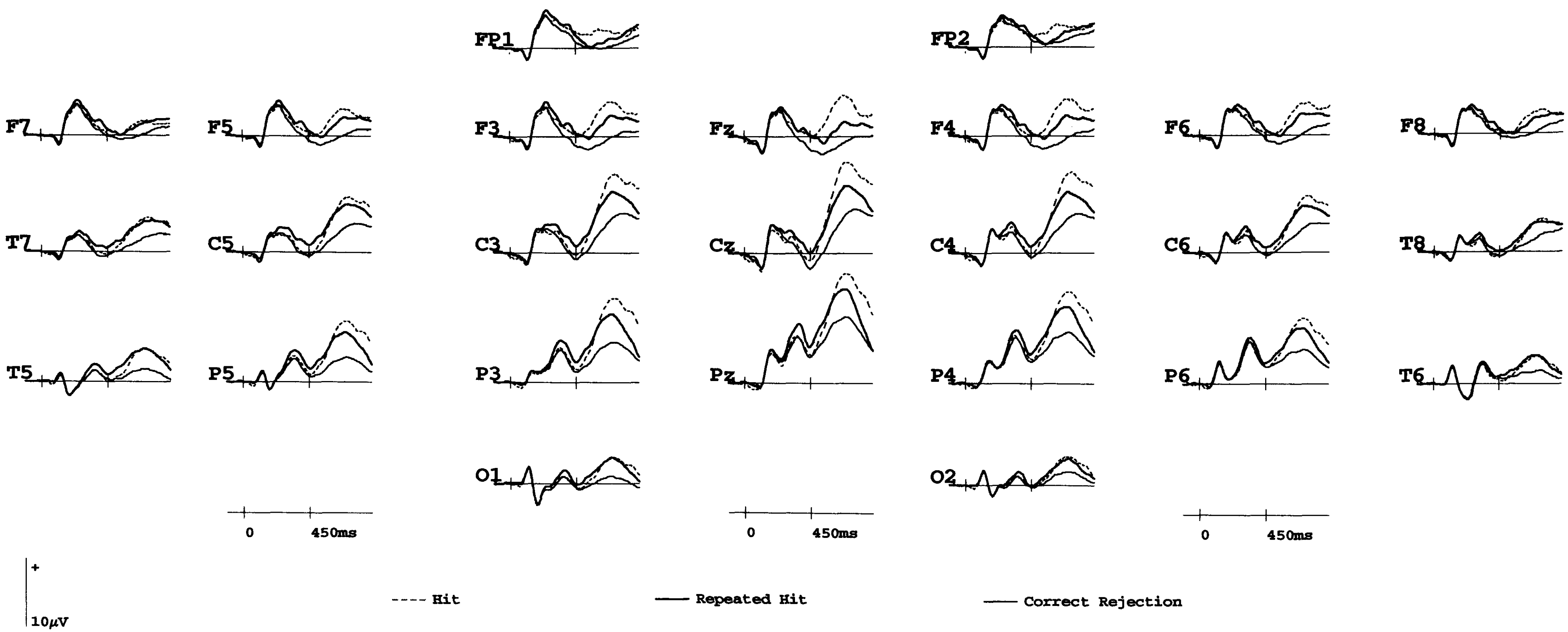
Appendix 7. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at sites FP1/2, F7/8, F5/6, F3/4, T7/8, C5/6, C3/4, T5/6, P5/6, P3/4, Fz, Cz and Pz in Experiment 4.



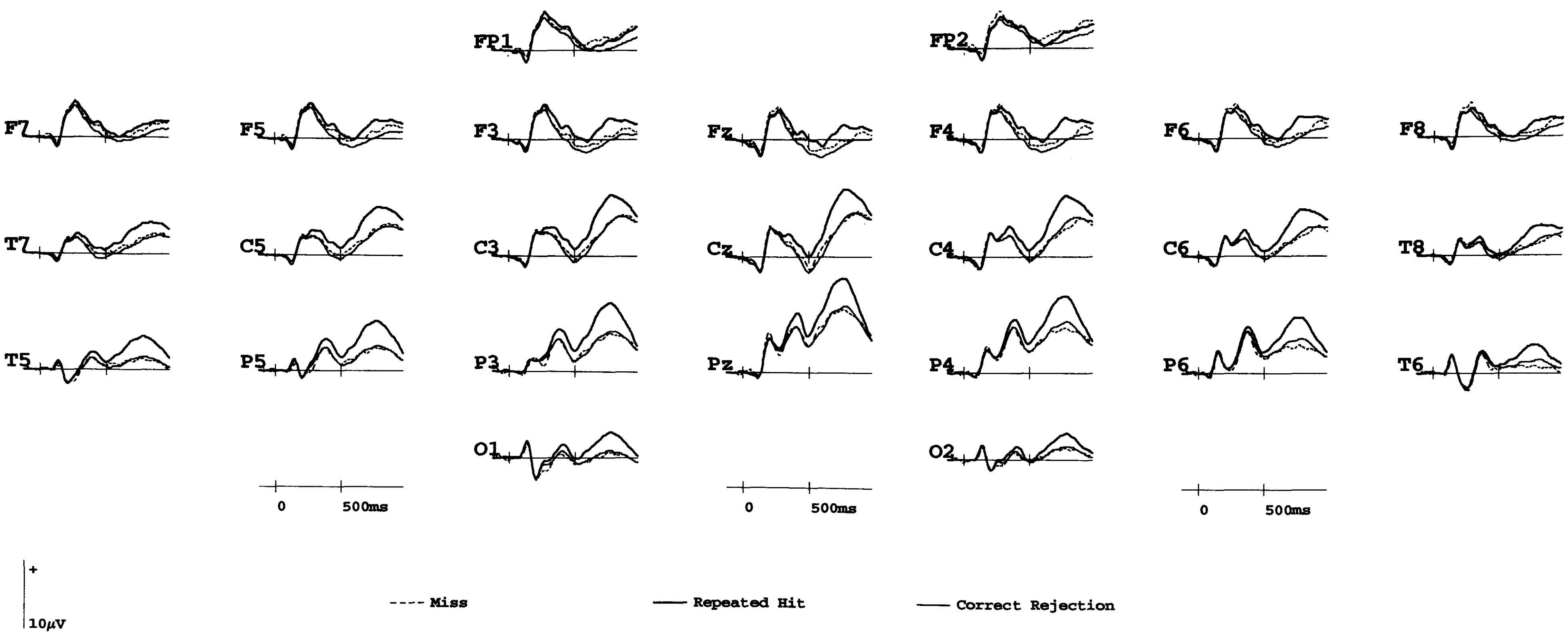
Appendix 8. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at sites FP1/2, F7/8, F5/6, F3/4, T7/8, C5/6, C3/4, T5/6, P5/6, P3/4, Fz, Cz and Pz in Experiment 5.



Appendix 9. Grand averaged ERPs elicited by hits, repeated hits and correct rejections at sites FP1/2, F7/8, F5/6, F3/4, T7/8, C5/6, C3/4, T5/6, P5/6, P3/4, Fz, Cz and Pz in Experiment 6.



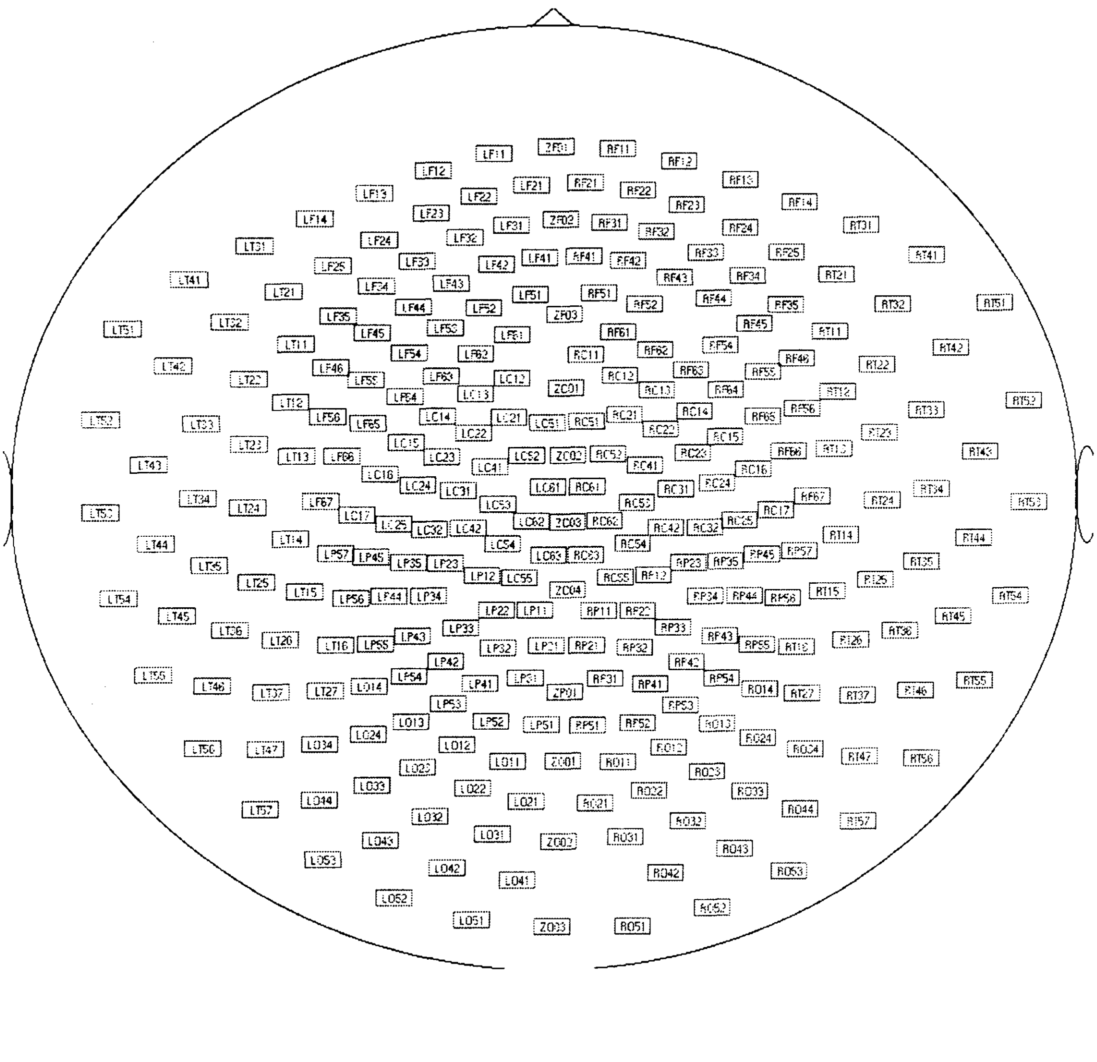
Appendix 10. Grand averaged ERPs elicited by misses, correct rejections and repeated hits at sites FP1/2, F7/8, F5/6, F3/4, T7/8, C5/6, C3/4, T5/6, P5/6, P3/4, Fz, Cz and Pz in Experiment 6.



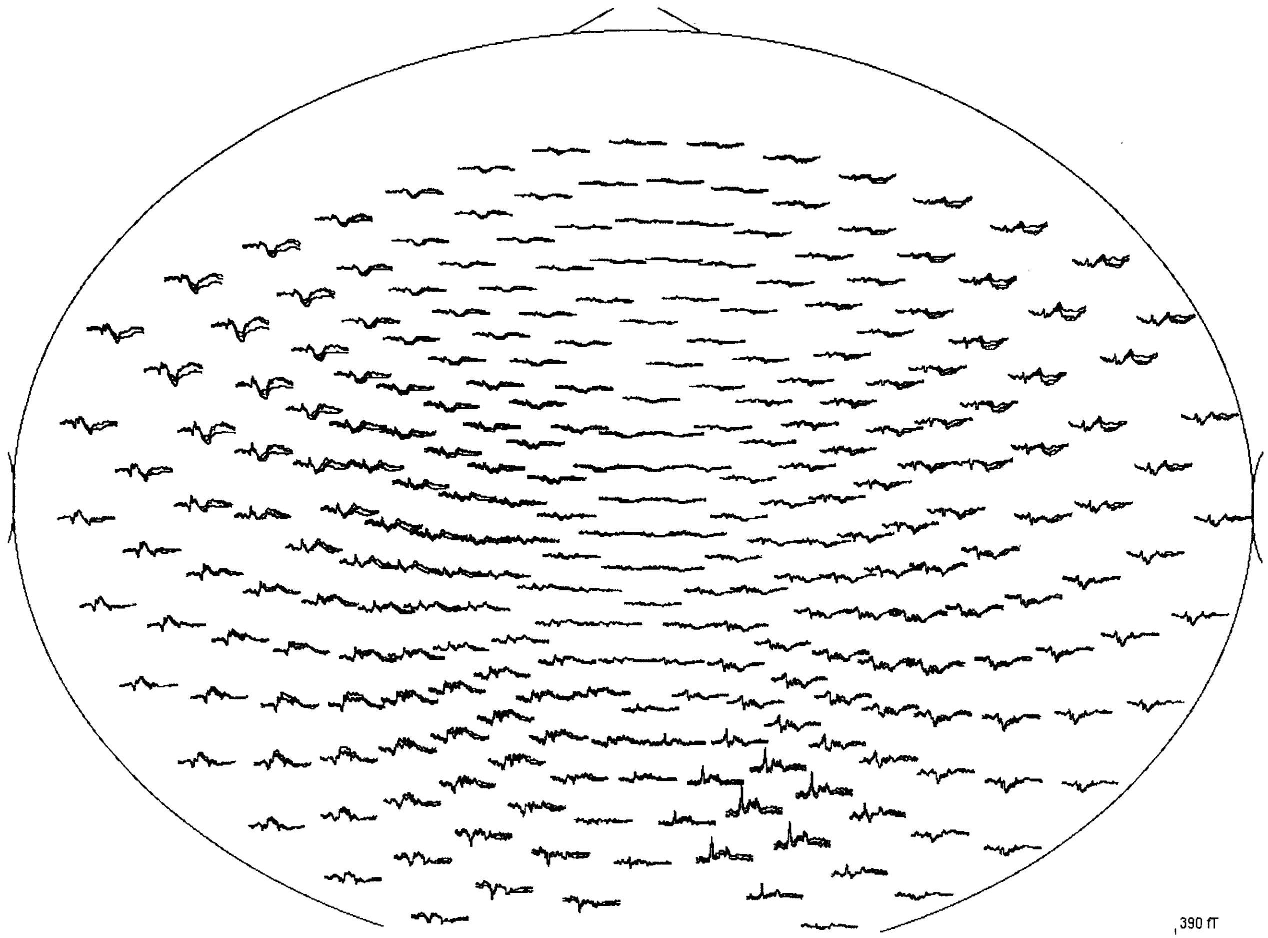
Appendix 11. Data from the 15 participants who provided incorrect response to new words in Experiment 7.

	Word class		
	Old	New	New repeated
p(correct)	0.67 (0.15)	0.93 (0.08)	0.84 (0.12)
RT	629 (329)	527 (300)	587 (395)
p(incorrect)	0.32 (0.15)	0.07 (0.08)	0.16 (0.12)
RT	696 (465)	811 (376)	735 (307)

Appendix 12. 272 whole-head MEG electrode array locations used in Experiment 7.



Appendix 13. Grand averaged ERFs elicited by correct responses to hits, correct rejections and repeated hits at all electrode locations in Experiment 7.



__ Hit __ Correct Rejection __ Repeated Hit

Appendix 14. Grand averaged ERPs elicited by hits, correct rejections and repeated hits at all ROIs in Experiment 7. L= left, R = right, A= anterior, C= central, P= posterior, S = superior, M= mid-lateral, I = inferior, MD= midline.