ELECTROPHYSIOLOGICAL STUDIES OF MEMORY FOR PICTURES AND WORDS

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Electrophysiological Studies of Memory for Pictures and Words

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FIGURES

Abstract

The retrieval of information from explicit memory has been associated with three temporally and topographically dissociable ERP correlates, an early bilateral and late right frontal component as well as a left parietal effect. The three studies in this thesis investigated that material-specificity of these ERP old/new effects to address the question whether the ERP correlates of memory retrieval vary according to the nature of the information that is retrieved. The studies compared the ERP correlates for retrieval of pictures and words, when presented in the same modality at study and test and when presented across modalities (i.e., words at study – pictures at test or vice versa) in the two phases.

Results provided little evidence for the engagement of different neural generators for the retrieval of the different types of stimuli. The topographic differences that emerged, suggested the engagement of a common set of generators activated at different levels and with a different time-course, depending on the type of encoding stimulus and retrieval cue.

However, the results did provide further evidence regarding the functional interpretations of the established old/new effects. All experimental conditions revealed a left parietal effect which was largest when the encoding stimuli were presented in pictorial form. Given that the rich perceptual information inherent in pictures leads to a greater incidence of episodic retrieval for pictures (picture superiority effect) the current finding provides further support for the functional interpretation of this effect as the neural correlate of recollection. All experimental conditions also revealed a late right frontal effect which showed no differences in magnitude or topography between the different conditions. This insensitivity to the type of encoded material and the type of retrieval cue supports the interpretation of the effect as the neural correlate of post-retrieval monitoring processes. New functional properties of the early bilateral frontal effect emerged. The effect was only present when stimuli were presented in the same modality at study and test. Thus, the effect appears to be highly sensitive to the perceptual similarity of an item between study and test, which suggests a functional correlation to perceptual data-driven processes, proposed to be one of the bases of familiarity-driven recognition.

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CHAPTER 1

Memory

1.1. Introduction

In the early 1970s, experimental findings from amnesic patients first hinted at the existence of multiple forms of memory. Since then, one important trend in current research has been the attempt to fully delineate the neural basis of memory processes involved in the different kinds of direct and indirect tasks. Efforts to do so have been complicated by the realisation that there probably is not a one-to-one mapping between systems or processes postulated by theories of memory and the underlying neural structures which may instantiate the theoretical constructs (Dunn & Kirsner, 1989). Also, there is growing evidence that a given task is not necessarily a 'pure' measure of a single kind of memory process (Dunn & Kirsner, 1989; Jacoby, 1991; Richardson-Klavehn & Bjork, 1988).

The recording of the electrical activity of the brain in the form of event-related potentials (ERPs) can be used to identify neural activity associated with the memory processes involved in different direct and indirect tasks (see Johnson, 1995; Kutas & Dale, 1997; Rugg & Coles, 1995). The experimental work presented in this thesis uses the ERP method (reviewed in Chapter 2) to explore issues in long-term memory retrieval. A number of studies have shown that recollection is associated with a particular ERP signature (e.g. Paller & Kutas, 1992; Smith, 1993; Wilding & Rugg, 1996, also see Chapter 3). The aim of the first study presented in this thesis (Chapter 5) was to explore how far this ERP signature, discussed more fully in Chapter 3, is material specific. In order to do so, the study compares the ERP signature of recognition memory for pictures and names of common objects directly. The subsequent studies (Chapters 6 and 7) explore this issue further by determining if, and if so how, this ERP signature is influenced by modality change between study and test in a recognition memory task.

In order to provide a theoretical context for the studies presented in this thesis, the remainder of the current chapter consists of three sections. The first section provides a review of the functional and neuroanatomical organisation of long-term memory. This section focuses on the influential 'systems' and 'processing' frameworks that have guided a great deal of the research in this field. Recognition memory tasks have been one of the major tools in the investigation of explicit memory. Therefore, in the second section of this chapter, a dual-process model of recognition memory is discussed. This discussion introduces and contrasts the specific memory processes, thought to be involved in recognition memory tasks. Both sections provide the framework for the interpretation of the ERP studies of explicit memory reviewed in Chapter 3 and the interpretation of the experimental work presented in this thesis. The studies presented in this thesis investigate the material specificity of the ERP correlates of explicit memory (see Chapter 3). To this end, the studies employ pictures and names of common objects as experimental materials. In order to provide a framework for the further interpretation of the experimental results, the third section of this chapter discusses the picture superiority effect. More specifically, the section reviews the cognitive and functional anatomical evidence for possible differential perceptual and semantic processing of the two types of stimulus.

1.2. Models of Memory

Although a variety of terms have been used to describe the different forms of memory, striking consistency among them is evident. One kind of memory is thought to provide the basis for conscious recollection of facts and events from the past. This is the kind of memory usually referred to as 'remembering' in everyday conversations. It is usually assessed through recognition and recall tasks, tasks which severely amnesic patients fail to perform. This kind of memory has been termed 'explicit' (Graf & Schacter, 1985; Schacter, 1987), 'declarative' (Cohen, 1984; Cohen & Squire, 1980; Squire, 1994), 'aware' (Jacoby, 1983), and 'relational' (Eichenbaum, 1982). Explicit or declarative memory can be contrasted with a collection of nonconscious memory abilities, many of which are intact in otherwise severely amnesic patients. This type of 'nondeclarative' (Squire & Zola-Morgan, 1988), 'unaware' (Jacoby, 1983) or 'implicit' (Graf & Schacter, 1985; Schacter, 1987) memory comprises a collection of phenomena, all thought to be dependent on different underlying neural substrates (Squire, 1994). Implicit memory, as opposed to explicit memory, influences behaviour without any awareness of the previous experience with an item. It therefore does not give any access to information about past experiences.

Explicit retrieval is typically measured by 'direct' memory tests which require subjects to recollect information studied in specific prior episodes. Typical direct memory tests are recognition, recall and cued recall. By contrast, implicit memory is typically revealed in 'indirect' tests which show a bias in performance without relying on the subject's ability to use his or her memory to perform the task. A typical indirect memory task is word-stem completion in which subjects study a list of words (e.g. PAPER, HOUSE). They are then presented with a list of word stems (e.g. PAP, HOU) some of which can be completed with previously studied items. The instruction is to complete the stem with the first word that comes to mind. In the completion of the word stems, subjects typically show a bias to complete the stem with previously studied words, a bias termed 'priming' (Roediger & McDermott, 1993; Schacter, 1987).

1.2.1. Functional Dissociations

The principal basis for the functional dissociation between explicit and implicit memory comes from findings of impaired explicit but intact implicit memory performance in severely amnesic subjects and dissociations between performance on direct and indirect memory tests in normal subjects (Moscovitch et al., 1993; Richardson-Klavehn & Bjork, 1988; Roediger & McDermott, 1993).

Perhaps the best known amnesic case is patient H.M., who in 1953 underwent bilateral medial temporal lobectomy to relieve his otherwise intractable epilepsy (Scoville & Milner, 1957). Following surgery, H.M. exhibited profound anterograde amnesia, that is he was unable to remember information encountered since his operation. His anterograde amnesia affected information from all sensory modalities and included impairment of both verbal and nonverbal memory (for review see Corkin, 1984; Milner, Corkin & Teuber, 1968). However, during the 1960s, several studies indicated that H.M.'s memory impairment was not as global as originally assumed. He showed considerable retention of perceptual-motor skills such as mirror tracing (Milner, 1962), tactual maze tasks (Milner et al., 1968), and a variety of other tracking tasks (Corkin, 1968). Preserved skill learning has been observed in other cases of amnesia (for review see Parkin, 1982) and with other tasks (e.g., mirror reading, Cohen & Squire, 1980). The first evidence that amnesic patients also exhibit preserved priming effects came from work by Warrington and Weiskrantz (1968, 1970). They showed that, in a fragment-identification task, amnesics' performance was facilitated by previous exposure to the fragments to the same extent as the performance of normal subjects.

Since these early demonstrations, numerous studies have shown preserved memory in amnesic patients in performance of indirect memory tests together with impaired memory performance in direct memory tests (Bowers & Schacter, 1993; Moscovitch, Vriezen & Goshen-Gottstein, 1993; Richardson-Klavehn & Bjork, 1988; Schacter, 1987; Shimamura, 1986). For example, Graf and Mandler (1984) found normal priming effects in amnesic patients in the word-stem completion paradigm, which stood in contrast to the direct version of this task. When subjects were told to use the stems to retrieve study-list words, amnesics were severely impaired relative to controls. Similarly, Graf, Shimamura and Squire (1985) reported that studying category exemplars enhanced the likelihood that those exemplars would be given in response to category cues in a generation task. This priming effect was equivalent in normal and amnesic subjects. However, when asked to use category cues to retrieve studied words, amnesic patients showed impairment in comparison to normal subjects.

Evidence of dissociation in performance on direct and indirect memory tasks has also been found in studies of normal subjects (Richardson-Klavehn & Bjork, 1988; Roediger & McDermott, 1993; Schacter, 1992; Schacter, Chiu & Ochsner, 1993). Typically these dissociations are shown by a differential influence of an experimental variable on the performance in one or other test. These dissociations can either influence performance on one test and leave performance on the other test unchanged, or influence performance on both tests in opposite directions. For example, Jacoby and Dallas (1981) used a levels of processing manipulation which required subjects to study an item either deeply (a semantic categorisation task) or shallowly (a vowel counting task). This manipulation influenced the direct task (subjects showed better recognition for semantically studied words) whilst leaving performance on an indirect task (perceptual identification) unaffected. Jacoby (1983) introduced a processing requirement that affected performance on both tests in opposite directions. At study, subjects either had to read a word aloud, or generate the word in response to a cue. Performance on a direct memory task was better for words that were generated during the study phase. In the indirect task (word identification), in contrast, priming was greater for words that were read during the study phase. Finally, changing modality (e.g., auditory to visual) from study to test, typically has no influence on performance in direct memory test, but reduces priming as evidenced indirect tests (Roediger & Blaxton, 1987).

1.2.1.1. Process Purity

Dissociations of the kind described above have been severely criticised. The most prominent criticism concerns the assumption of 'process purity' (Jacoby & Kelley 1992; Richardson-Klavehn & Bjork, 1988). The construction of memory tasks cannot distinguish whether one or more processes contributes to performance on the task, that is that performance of the task is likely to reflect the isolated operation of a single memory system. Therefore, performance in a specific memory test might involve contribution from multiple processes and/or systems, rendering the assumption of a transparent and discreet relationship between task and process somewhat implausible (Dunn & Kirsner, 1989). Consequently, direct and indirect tasks cannot be assumed to map exclusively on explicit and implicit memory processes.

More directly, the problem concerns the contamination of performance in indirect tasks by explicit memory processes (Richardson-Klavehn & Bjork, 1988). This contamination can happen either voluntarily, when subjects use items presented in an indirect task as retrieval cues; or involuntarily, when after completion of the indirect task explicit retrieval for the item occurs spontaneously. Bowers and Schacter (1990) extensively investigated this issue (see also Schacter, Booker & Bowers, 1989) using the criterion of test awareness. They defined test awareness as situations in which subjects realised during the performance of an indirect task that test items had been previously encountered. Thus, the concept of test awareness encompasses both possibilities, involuntary and voluntary explicit retrieval during an indirect memory test. Bowers and Schacter (1990) showed that test awareness did not influence levels of single word priming. However, test awareness did influence associative (i.e., conceptual) priming effects, in that only test aware subjects revealed priming for new associations. They concluded that single item priming and associative priming reflect different processes because only the latter could be observed in test aware subjects. Their investigations indicated that, at least for some forms of priming, contamination of indirect tests through explicit memory strategies did not alter the results.

Finally, it has been argued that dissociations can occur simply as a result of scaling or sensitivity differences between tasks and therefore be a result of nonlinearities in the relations between the measures used (e.g., nonlinearities due to floor and ceiling effects; see Dunn & Kirsner, 1988; Hintzman, 1990; Olton, 1989). Furthermore, it has been argued that different tasks, by nature, place demands on different cognitive processes (e.g., perceptual, attentional, response-related processes) and consequently dissociations are to be expected whenever tasks are compared (for further discussion of this issue see Hintzman, 1990). In spite of extensive criticism regarding the use of functional dissociations as a basis for inferences with respect to cognitive functioning, the results from studies with amnesic and normal subjects have been the basis for a variety of theories attempting to account for the observed dissociations. Two of these accounts, systems and process theories of memory will be discussed below.

1.2.2. System Models of Memory

One important element of the systems view of memory has been to characterise the neural substrates of the proposed memory systems and their processing mechanisms. Evidence from the specific impairment of declarative memory in amnesia, as well as evidence from animal lesion studies, has pointed in the direction of the medial temporal lobe as an important element in the neural circuitry supporting declarative memory (Cohen & Eichenbaum, 1993; Cohen & Squire, 1980; Eichenbaum, 1997; Gabrieli, 1993; Squire, 1992a; Squire & Knowlton, 1995; Squire, Knowlton & Musen, 1993; Squire & Zola-Morgan, 1991; Zola-Morgan & Squire, 1993, 1988; Verfaillie & Keane, 1997). Critical areas comprising the medial temporal lobe memory system include the hippocampus with its adjacent anatomically related cortices (including enthorinal, perirhinal and parahippocampal cortices) and structures of the midline diencephalon, especially the mediodorsal thalamic nucleus and the mammillary nuclei. Together, these structures form a 'core' memory system necessary for explicit retrieval. The function of the core memory system is not entirely understood, and a number of models attempting a description of its operations have been proposed (e.g., Damasio, 1989; McClelland, McNaughton & O'Reilly, 1995; O'Keefe & Nadel, 1978; Teyler & Discenna, 1986). The following paragraphs describe two system models, each having considerable impact on behavioural research.

1.2.2.1. Declarative and Non-Declarative Memory

The systems model of Squire and colleagues (Squire, 1992a, 1994; Squire & Knowlton, 1995; Squire et al., 1993; Squire & Zola-Morgan, 1991; Zola-Morgan & Squire, 1993) is directly based on the neuroantomical account of declarative memory described above. They postulate the distinction between a declarative memory system, dependent on the functioning of the medial temporal lobe memory system and a set of distinct cortical and subcortical systems, referred to as non-declarative memory. Declarative memory is associated with awareness at retrieval and encompasses retrieval of information about specific episodes as well as retrieval of general knowledge (i.e., semantic memory). In contrast, non-declarative memory, which includes processes such as priming, classical conditioning, habit formation, is unaware (i.e., unaccompanied by the phenomenological experience of remembering).

Declarative memories have the important property of 'flexibility of access' which distinguishes them from inflexible non-declarative memories. The flexibility of declarative memories is the consequence of the relational processing of information carried out by the medial temporal lobe memory system. The basis for the relational processing is the hippocampus and its widespread connections to numerous cortical and subcortical structures. For example, the parahippocamal and entorhinal cortices (major input pathways to the hippocampus) receive inputs from numerous areas of sensory and association cortex, providing multimodal information about current experiences. Similarly, the hippocampus projects to numerous subcortical structures (including thalamus, septum and hypothalamus) via the fornix. The widespread connections with these brain regions place the hippocampus in an ideal position to receive information during the processing of incoming stimuli. This enables the hippocampus to process the different kinds of relations between incoming stimuli and also between these stimuli and pre-existing 'memory traces'.

At retrieval the medial temporal lobe memory system provides an 'index' of those brain regions in which processing occurred during specific study episodes (Cohen & Eichenbaum, 1993; McClelland et al., 1995; Squire, 1992b; Teyler & Discenna, 1986). By this means, subsequent activation of any given element of the episode (e.g. the presentation of a retrieval cue) can give rise to activation in other parts of the network to which the element is related. Thus, information can be accessed from a variety of retrieval cues, providing the required information in all manners of situation, most importantly in novel contexts. Thus the retrieved information is available to guide behaviour in situations quite different from those in which it was acquired.

The flexibility of the declarative memory system stands in contrast to the inflexibility of the non-declarative system that can be expressed only through recapitulation of the original learning episode. Non-declarative memory is thought to depend on a collection of cortical and subcortical neural systems subserving processes like skill-learning, priming and habit-formation (for neural substrates underlying non-declarative memory see Gabrieli, 1997; Squire, 1992b, 1994; Squire & Knowlton, 1995; Squire et al., 1993; Verfaillie & Keane, 1997).

1.2.2.2. Episodic and Semantic Memory I

A similar model was proposed by Tulving, Schacter and colleagues (Schacter, 1994; Schacter & Tulving 1994; Tulving 1972, 1983, 1985; Tulving & Schacter 1990). On the basis of dissociations found in the performance of amnesic patients, they proposed a distinction between two forms of declarative memory; namely, episodic and semantic memory (for critique of this account see McKoon, Ratcliff & Dell, 1986 and the reply by

Tulving 1986). Tulving and colleagues postulated two different kinds of retrieval, each supported by an episodic and a semantic system respectively. The distinction between the systems is primarily based on the kinds of phenomenological awareness that accompanies retrieval from episodic and semantic memory. According to Tulving (1985), retrieval from the episodic system is accompanied by 'autonoetic' or self-referential awareness, whereas retrieval from the semantic memory system lacks this self-referential quality, an experience he terms 'noetic'. Tulving and colleagues argued that the episodic memory system is destroyed in cases of severe amnesia, leaving the semantic system intact. In recent years the distinction between episodic and semantic retrieval has focused on the actual underlying neuroanatomical systems (see section 1.3.2.). One reason for this was the expansion of the model to incorporate a collection of processes, instantiated by cortical and subcortical structures, underlying the spared learning abilities in amnesia. In accordance with Graf and Schacter's (1985) original suggestion, it is these processes that are now commonly referred to as implicit.

Importantly, in Tulving and Schacter's systems view, the terms 'implicit' and 'explicit' refer to forms of expression of retrieved information, rather than memory systems as such, which is an important distinction from the model proposed by Squire and colleagues. Tulving and colleagues do not assume a one-to-one mapping between states of awareness and forms of memory. What their model does provide, however, is an account of the relationship between the different systems. Tulving's (1995) *SPI*-Model proposes that information is encoded *serially*, progressing from one memory system to the next, each system's output being the input to the next system in the hierarchy. Each system represents information in the appropriate form so that information is stored in *parallel*. Information can be retrieved from each system *independently*, allowing retrieval from one system without concomitant retrieval from any of the other systems.

According to Tulving's SPI model (1995) the formation of semantic memories depends on successful encoding into episodic memory. This assumption has recently been challenged by findings of a limited anterograde amnesia in patients who experienced circumscribed hippocampal damamge in early childhood (Mishkin, Vargha-Khadem & Gadian, 1998; Vargha-Khadem, Gadian, Watkins, Connelly, Van Paesschen & Mishkin, 1997). Vargha-Khadem et al. (1997) proposed that these patients have a pronounced impairment of episodic memory (i.e., the ability to remember events in their everyday lives), concomitant with relative preservation of semantic memory (i.e., the ability to acquire new factual information or knowledge about the world). This acquisition of near normal factual knowledge is most noticeable in the normal development of social and language competence, the acquisition of reading and writing skills while attending mainstream school and low-average to average performance on standard tests of intelligence, including measures of vocabulary, information and comprehension. However, scores in tests of delayed recall are close to floor level, thus indicating a profound impairment of episodic memory.

These findings have two implications. Firstly, they challenge the proposed view that encoding is a serial process with semantic memories accumulating through repeated episodic encoding (Tulving, 1995). Secondly, they suggest *qualitative* differences in amnesia with damage to different structures within the medial temporal lobe memory system. Until now, most discussions of the role of the hippocampal system in human memory have treated this system as a single, though complex entity. Accordingly, differences in the severity of the amnesia caused by medial temporal damage were regarded as due to differences in the amount of bilateral damage to the hippocampal system as a whole, irrespective of which components were affected. Hence, whereas extensive damage to the entire system leads to a profound amnesia, damage limited to the hippocampus produces a significant but *quantitatively* limited amnesia, involving both episodic and semantic components. The seemingly qualitative difference in amnesia of the Vargha-Khadem patients and stronger consideration of the hippocampal system's anatomy suggests other possibilities. Vargha-Khadem and colleagues (Mishkin et al., 1998; Vargha-Khadem et al., 1997) suggest a hierarchical organisation of this system with the hippocampus itself sitting at the top of the hierarchy. Directly below it in this hierarchy is the entorhinal cortex and below the entorhinal cortex lie the perirhinal and parhippocampal cortices. As discussed before, it is the perirhinal and parahippocampal cortices which receive input from the end stages of cortical sensory processing streams belonging to the various sensory modalities. Just as information undergoes greater and greater convergence as it ascends the hierarchy, output from the hippocampus gradually diverges as it descends the hierarchy via the reciprocal connections between the levels within it, thereby ultimately reactivating the various sensory processing streams. Vargha-Khadem and colleagues suggest that this hierarchical organisation indicates that, rather than performing a single, global mnemonic function, successively higher levels of the system perform increasingly complex mnemonic functions. They argue that the hippcampus is needed to form the richest and most complex associations ultimately supporting episodic memory. Lower levels of the system, however, may be sufficient, even in the absence of the hippocampus, to support the less complex associations required to form semantic memories (for a discussion of the relevant animal lesion studies see Mishkin et al. 1998, Mishkin, Suzuki, Gadian & Vargha-Khadem, 1997). Taken to the extreme, this view suggests that episodic encoding is dependent on successful semantic encoding, a reversal of the notion first proposed by Tulving (1985).

The suggestion that circumscribed hippocampal damage leads to a qualitatively limited amnesia which disproportionately affects episodic memory (Vargha-Khadem et al., 1997) has been criticised by Squire and Zola (1998). They argue that damage to the medial temporal lobe causes proportional impairment in both semantic and episodic memory performance and that the impairment is quantitative in nature depending on the extent of the lesion in the medial temporal system. In their review of the test performance shown by the patients of Vargha-Khadem and colleagues (Mishkin et al., 1998, Vargha-Khadem et al., 1997) and other cases of early hippocampal damage, they suggest that all patients show impaired performance on tests of acquisition and retrieval of factual knowledge as well as residual capacities in tests of explicit memory. They therefore suggest that the ability of these patients to acquire (some) factual knowledge and their general social abilities are based on residual capacities for episodic learning. This issue remains unresolved and future research is required to determine whether there is indeed a differential role of hippocampal structures for the acquisition and retrieval of episodic and semantic information.

1.2.3. Transfer-Appropriate-Processing

As discussed above, a critical aspect of the system models is the assumption that the memory traces that are retrieved are not actually stored within the medial temporal lobe memory system. Rather, the function of the medial temporal lobe system is to reactivate traces of past processing which reside within the neural systems (probably the cortex) to which it is reciprocally connected (Cohen & Eichenbaum, 1993; Damasio, 1989; Teyler & Discenna, 1986). According to this proposal the medial temporal lobe memory system stores the 'addresses' of multiple cortical regions in which information was processed during specific episodes. It is the reactivation of these 'input' areas during the retrieval process, which therefore most probably provides the neural basis for explicit memory. Consequently, brain regions important for initial encoding may also be active during retrieval. While entirely identical processes are probably not involved during acquisition and retrieval (Craik, Govoni, Naveh-Benjamin & Anderson, 1996), it is nonetheless widely accepted that there is at least some overlap in the regions activated during encoding and retrieval of similar kinds of information.

These ideas bear great similarity to the framework of 'transfer-appropriate-processing' (Blaxton 1989; Morris, Bransford & Franks, 1977; Roediger, Weldon & Challis, 1989) and 'encoding specificity' (Tulving & Thomson, 1973). The importance of the transfer-appropriate processing (TAP) model to the understanding of memory has been emphasised by recent attempts to incorporate TAP within system models as a processing principle which relates to both declarative and non-declarative memory (Roediger, 1990; Tulving & Schacter, 1990).

Proponents of the TAP framework (Blaxton, 1989; Jacoby, 1983; McDermott & Roediger, 1996; Roediger, 1990; Roediger et al., 1989) argue that the dissociations observable between performance on direct and indirect memory tasks reflect differences in the underlying processing demands, rather than differences in underlying memory systems. By this view, the ability to access or make use of memory information is dependent upon the degree to which the processing operations required at test overlap with those performed at study.

The starting-point for the TAP approach to memory was the observation that priming in the word-fragment completion task depended on matching surface characteristics of the items between study and test. Roediger and Blaxton (1987, see also Weldon & Roediger, 1987, Weldon, Roediger, Beitel & Johnston, 1995) initially showed that visual presentation of items at study resulted in greater priming in the word-fragment completion task than auditory presentation and that change of typography also reduced priming in the mismatching condition. They argued that the results constituted a dissociation between indirect tests of memory, which did not fit with the proposal of multiple memory systems. At the same time, modality change or a change in surface features of items between study and test was shown not to affect direct tests such as free or cued recall (Roediger, Weldon, Stadler & Riegler, 1992, Weldon & Roediger, 1987). On the basis of the earlier concepts of encoding-specificity (Tulving & Thomson, 1973) and transfer-appropriate processing (Morris et al., 1977), they argued that dissociations in performance between different types of memory tests are best explained in terms of the overlap of mental operations between study and test. Using an earlier categorisation by Jacoby (1983), Roediger and Blaxton (1987) suggested a distinction between 'data-driven' (i.e. perceptual, pre-semantic) and 'conceptually-driven' (elaborative, semantic) processing. They argued that most indirect memory tasks depend predominantly on data-driven processing, whereas most explicit tests benefit from conceptual processing at study. Importantly, Roediger and Blaxton (1987) pointed out that the distinction between data-driven and conceptually-driven processing should be considered as representing the endpoints on a continuum, with most tasks involving components of both types of processing, rather than as a dichotomy. Thus, according to the TAP framework, dissociations can be found between data- and conceptually-driven tasks, independent of their status as direct or indirect measures of memory.

An important point in the TAP approach is that there is no necessary correlation between direct and indirect memory tests and conceptually driven and data-driven processing respectively. This means that one can develop indirect, conceptually driven tests and direct, data-driven tests. Evidence for a dissociation between direct and indirect tests according to their processing orientations would thus provide the most convincing evidence for the feasibility of the TAP framework. Blaxton (1989, 1985 cited in Roediger, Srinivas & Weldon, 1989) provided just such evidence. She developed a number of indirect, conceptual and direct, data-driven tasks and tested these under various study conditions. She showed that performance on conceptually-driven tasks of free recall, cued recall (both direct) and answering general knowledge questions (indirect) was enhanced most when target items had been generated rather than read at study and when subjects formed mental images of items' referents at study. Conversely, the data-driven tasks of word fragment completion (indirect) and graphemic cued recall (direct) were performed best when subjects read rather than generated items at input and when the physical features of study and test items matched in terms of modality (pictures vs. words) and typography. Blaxton (1989) interpreted the results as evidence that dissociations among memory tasks are better explained in terms of the degree of overlap between mental operations at study and test than in terms of different memory systems underlying task performance.

The transfer appropriate processing approach thus appears to be able to account for the observed patterns of dissociations which results from the selective effects of independent variables on task performance in normal subjects. However, work with memory impaired subjects has rendered more equivocal results. According to the TAP framework, amnesic patients should show normal performance on data-driven tasks, whilst being impaired on conceptually-driven tasks. This hypothesis holds for a lot of the tasks on which amnesics have shown intact priming (Roediger & McDermott, 1993; Shimamura, 1986). However, preserved priming in free association tasks with semantic cues (e.g. Graf et al., 1985) and in word completion with new associates (Graf & Schacter, 1985) cannot be covered by the simple view that preserved priming always reflects data-driven processing.

Blaxton (1992) tested the TAP framework directly in a study with mildly amnesic temporal lobe epilepsy and temporal lobectomy patients. She found that patients' performance was relatively intact (as compared to normal control subjects) in data-driven tasks, but was impaired on conceptually-driven tasks. She argued that these results were consistent with the transfer appropriate processing account in that patients were unable to perform a certain type of processing, independent of the nature of the memory task. However, the findings from three other studies failed to replicate these results (Carlesimo, 1994, Cermak, Verfaillie & Chase, 1995, Gabrieli, Keane, Stanger, Kjelgaard, Corkin & Crowdon, 1994). In these studies, amnesic patients showed normal levels of priming on both data- and conceptually driven tasks alongside impaired performance in direct tasks. Performance was independent of the nature of processing demanded by the tasks. Cermak et al. (1995) who closely replicated the design of Blaxton's (1992) original study, argued that Blaxton's findings might have been a consequence of the relatively mild amnesia and the special pathological characteristics of her patient group.

Additionally, recent evidence from patients suffering from Alzheimer's Disease (AD) suggests that different cortical regions subserve conceptual and perceptual priming. Gabrieli et al. (1994) showed intact perceptual but impaired conceptual priming in a group of AD patients. This pattern is thought to reflect the damage caused by the disease to regions of the temporal and inferior parietal cortex held to be responsible for the representation of lexical and semantic information, whilst leaving more posterior regions, implicated in perceptual priming (Schacter, 1992, 1994) intact. Such a neuroanatomical dissociation of function does not entirely complement the purely functional account, such as proposed by the TAP framework, which in the extreme could be taken to rest on the assumption of a single, unitary memory system.

Thus, as a principle of memory, the transfer appropriate processing approach cannot account fully for the inability of amnesic patients to perform at normal levels in direct memory tests or their ability to perform at normal level in indirect memory test, regardless of the processing requirements. It can, however, explain the dissociations found in studies with normal subjects. Given that there are aspects of the operation of memory that are captured by the processing approach, systems models need to take better account of how memory systems may process information. As Cohen and Eichenbaum (1993) point out, retrieval from declarative memory may be subject to constraints broadly captured by the transfer appropriate processing approach. However, there are other aspects of the operation of memory which are not captured by the processing view. One of these is in how far task instructions place demands on the medial temporal lobe memory system that is damaged in amnesia. Furthermore, from the study of amnesic patients it seems clear that implicit retrieval can occur independent of the processing demands of the task and independent of processing carried out by the medial temporal lobe memory system. Thus it seems that implicit memory does indeed depend on neural substrates distinct from those damaged in memory impaired subjects. However, systems and processing theories of memory are not necessarily inherently incompatible and a joint approach may ultimately lead to a precise description of the neural substrates of memory and their processing operations (Hayman & Tulving, 1989; Roediger et al., 1989; Schacter, 1993; Tulving, 1995).

1.3. Memory and the Prefrontal Cortex

Episodic memories consist not only of the content of an experience, but also of information about the context of this experience (i.e., the where and when). This contextual information distinguishes episodic from semantic memory, which is devoid of any contextual information. The ability to place previous experiences in the context of time and space is called 'source memory' (Johnson, 1992; Johnson & Chalfonte, 1994; Johnson, Hashtroudi & Lindsay, 1993). In contrast to global anterograde amnesia which prevents the acquisition and retrieval of any kind of new declarative memories, 'source amnesia' merely impairs the ability to retrieve the context in which information was acquired, whilst leaving the retrieval of the actual informational content undisturbed. Source amnesia has been shown to occur in connection with frontal lobe damage (Janowski, Shimamura & Squire, 1989; Schacter, Harbluk & McLachlan, 1984; Shimamura & Squire, 1987) and correlates with impaired performance on test of frontal lobe function. Glisky, Polster and Routhieaux (1995) showed that in elderly people performance on tests of frontal function correlated very well with performance on source tasks, but was uncorrelated with performance on tests of recognition memory for the same items. Conversely, performance on tests of medial temporal lobe function correlated well with recognition test performance, but was uncorrelated with the performance on source tasks. This type of double dissociation suggests that different neural substrates are involved in the retrieval of content and the retrieval of the context in which this information was acquired (but see Pickering, Mayes & Fairbairn, 1989). It also implicates frontal lobe function in the processing required for successful episodic retrieval.

1.3.1. Working-With-Memory

Accounts differ as to exactly how the frontal lobes contribute to the support of episodic remembering. Moscovitch and his coworkers (Moscovitch, 1992, 1994,1995; Moscovitch & Umilta, 1991) suggested that frontal structures support performance on explicit memory tests requiring strategic retrieval. According to this account, the prefrontal cortex performs two functions: (i) selection and implementation of encoding strategies that organise the input to the hippocampal component, and (ii) selection and implementation of retrieval strategies that organise and evaluate the output from the hippocampal component, determine the correct spatio-temporal context of this output and use the resulting information to guide further mnemonic searches, or to direct behaviour in a task-dependent way. Moscovitch (1992, p.262) describes the function of the prefrontal cortex in memory as follows: "...the frontal lobes are necessary for converting remembering from a stupid reflexive act triggered by a cue to an intelligent, reflective goal-directed activity that is under voluntary control". Moscovitch calls the frontal structures 'working-with-memory' structures as they operate on the input to the hippocampal system and the output from it, in the absence of any involvement in the retrieval process itself. Thus, the prefrontal cortex contributes to performance on episodic memory tasks, but plays a supporting role to the medial temporal lobe structures, which, according to the working-with-memory framework, retrieve information automatically in response to the appropriate cue.

In this framework, retrieval from the hippocampal system is defined as 'shallow', in that it is not embedded in the spatial and temporal context with respect to other events. Thus, there is no temporal order imposed on those memories, nor any other kind of organisation. The organisation of this output is the role of the frontal lobes. According to Moscovitch and colleagues, this aspect of the strategic involvement of the frontal lobes in episodic memories is demonstrated in the symptom of confabulation which often accompanies damage to the prefrontal cortex (e.g., Moscovitch & Melo, 1997; see also Burgess & Shallice, 1996; Shallice & Burgess, 1991). Accordingly, confabulations are not seen as pure fabrications, but are thought to consist of disorganised memories that are the outcome of automatic ecphoric processes instantiated in the medial temporal lobe memory system. Due to a lack of organisation imposed by frontal lobe function, accurately remembered elements of one event are thought to be combined with those of other events, without regard for their internal consistency or temporal and spatial relationship. Thus, according to Moscovitch and colleagues, confabulation gives an impression of remembering when it relies on the shallow output from the hippocampal system alone.

1.3.2. Noetic and Autonoetic Consciousness

A different account of the role the frontal lobes play in episodic memory comes from Tulving and colleagues (Tulving, 1985, 1986, 1993; Tulving & Schacter, 1990; Wheeler, Stuss & Tulving, 1997). They argue that the frontal lobes play a decisive role in the distinction between semantic and episodic memories. According to this framework, episodic and semantic memory are not only characterised by the retrieval of different forms of information, they are also distinguished by the subjective states of awareness associated with the retrieval of information. By this view episodic memory not only delivers information about specific episodes in the past, it is also associated with an 'autonoetic' state of consciousness, providing this particular form of memory with a self-referential status. Semantic memory, in contrast, is associated with a 'noetic' state of awareness, a simple status of 'knowing', without any explicit knowledge about the details of the episode in which the information was acquired. Tulving and colleagues argue that it is this difference in state of consciousness that is the definitive difference between semantic and episodic memory. Semantic memory provides information about the world from the view of an observer, whereas episodic memory involves the re-experiencing and mental travel to the past that makes the rememberer a participant rather than a mere observer (Wheeler et al., 1997). Episodic memory is seen as the way in which memories are made personal and connect with the self of the rememberer. Tulving and colleagues map the specific states of awareness connected with the retrieval from semantic and episodic memory onto the differential involvement of the prefrontal cortex in the two types of retrieval. They argue that it is the mediation of the prefrontal cortex which endows episodic memory with the autonoetic state of consciousness that distinguishes episodic from semantic memories.

1.3.3. Episodic and Semantic Memory II

A less functionally, but more neuroanatomically oriented account of frontal lobe function was provided by Squire and associates (Squire, 1994; Squire & Knowlton, 1995; Squire et al., 1993). Like Tulving and colleagues, they proposed that it is the contribution of the prefrontal cortex to memory performance which makes the critical distinction between semantic and episodic memory. However, their account does not map any particular states of awareness on the contribution of particular neuroantomical systems to the two types of memory retrieval. Rather, the account given by Squire and colleagues is closely tied to neuroantomical systems and assumes that both episodic and semantic memory are dependent on the functioning of the medial temporal lobe memory system, while episodic memory is seen as additionally depending on the integrity of the prefrontal cortex (but see section 1.2.2.2.).

1.3.4. Functional Anatomical Studies of Memory Function in the Frontal Cortex

The role of the prefrontal cortex in memory retrieval and encoding has been investigated extensively using modern neuroimaging methods such as Positron Emission Tomography (PET) and functional Magnetic Resonance Imaging (fMRI). The former measures changes in regional blood flow through the detection of positrons emitted from radioactive isotopes, the latter detects changes in blood oxygenation levels (BOLD-signal) associated with changes in regional blood flow and volume.

Numerous studies have observed activations of the prefrontal cortex during long-term memory tasks (for review see Buckner & Koutstaal, 1998; Buckner & Petersen, 1996; Fletcher, Frith & Rugg, 1997; Schacter & Buckner, 1998). Investigations of semantic retrieval have reliably shown activations in left inferior prefrontal regions encompassing Brodman areas 10, 45, 46 and 47. Early studies of language function required subjects to generate and/or elaborate on the meaning of words (e.g. Petersen, Fox, Posner, Mintun & Raichle, 1988). Although not specifically intended as such, these tasks, as well as similar tasks that followed (e.g., Demb, Desmond, Wagner, Vaidya, Glover & Gabrieli, 1995) were excellent long-term encoding tasks. The connection between these language tasks and memory encoding was tested more direcly in later studies. Kapur and colleagues (Kapur, Craik, Tulving, Wilson, Houle & Brown, 1994) compared brain activation in deep encoding tasks (animacy decision) with that in shallow encoding tasks (letter detection). As expected, this levels of processing manipulation (Craik & Lockhardt, 1972) led to significantly higher recognition performance after deep than after shallow encoding. Imaging data contrasting the two encoding conditions showed robust left inferior prefrontal activation for deep in comparison to shallow encoding in the same areas previously activated in language tasks (see Gabrieli, Desmond, Demb, Wagner, Stone, Vaidya & Glover, 1996 for other encoding tasks). In a similar vein, Fletcher, Frith, Grasby, Shallice, Frackowiak and Dolan (1996) showed activation in these regions for a verb generation task accompanied by an easy distractor task in comparison to the verb generation accompanied by a difficult distractor task. Higher recall performance after encoding under easy distraction was again associated with significantly greater activation in left inferior prefrontal cortex. The precise nature of the operations which are mediated by the prefrontal cortex and lead to memory encoding are still under investigation. From the encoding manipulations employed to date, it seems that processing for meaning is a crucial factor.

Nearly all studies investigating explicit memory retrieval have shown activation in right anterior and dorso-lateral prefrontal cortex (predominantly Brodman areas 9, 10 and 46). This pattern of findings, which has been shown across a wide range of tasks and materials (for review see Buckner & Koutstaal, 1998; Buckner & Petersen, 1996; Fletcher et al., 1997; Schacter & Buckner 1998), was quite unexpected as lesions to the right prefrontal cortex do not result in the same severe anterograde amnesia as damage to the medial temporal lobe system. As discussed above, lesions to the frontal cortex are usually associated with deficits in source memory, memory for temporal order and metamemory. Accordingly, research has focused on the conditions under which these activations occur. Explicit retrieval involves many demands that can broadly be categorised into processes related to retrieval effort and retrieval success. The concept of effort captures a set of processes that are instantiated to gain access to the past, whereas retrieval success refers to post-retrieval processes operating on the outcome of the retrieval operation. Two main experimental strategies have been used to investigate the functional significance of the right frontal activations in the light of these concepts: (i) producing high and low levels of successful retrieval by manipulating study conditions, and (ii) manipulating the number of previously studied items that appear during a particular test. Both paradigms have so far yielded mixed results. A range of studies (for example Kapur, Craik, Jones, Brown, Houle & Tulving, 1995; Nyberg, Tulving, Habib, Nilson, Kapur, Houle, Cabeza & McIntosh, 1995; Schacter, Alpert, Savage, Rauch & Albert, 1996a) using both types of manipulations did not result in different levels of right prefrontal activation, thus suggesting an explanation in terms of retrieval effort. However, a recent study by Rugg and colleagues (Rugg, Fletcher, Frith, Frackowiak & Dolan, 1996; see also Rugg, Fletcher, Allan, Frith, Frackowiak & Dolan, 1998 and Buckner, Koutstaal, Schacter, Wagner & Rosen, in press a) showed different levels of prefrontal activation associated with differences in the density of previously studied items at test, suggesting that retrieval success might be the mediating variable for right frontal activations.

A recent fMRI study by Wagner, Desmond, Glover and Gabrieli (1998) suggests a possible explanation for these disparate findings. In their study, they manipulated the task instructions while keeping study conditions constant. Recognition success was varied using a levels of processing manipulation at study (studying words multiple times semantically vs. once non-semantically) while varying the density of items studied during test. Task instructions were delivered in two ways. A standard old/new recognition decision was contrasted with a 'biasing' condition in which subjects were told which density of old items was to be expected in the next test block. Right prefrontal activation did not differ across high and low density conditions under standard test instructions, whereas under biasing instructions it was greater during the high density condition. Wagner et al. (1998) suggested that right prefrontal activation does not reflect retrieval success and that it is sensitive to retrieval context, with recruitment of retrieval processes varying across retrieval context (see also Buckner, Koutstaal, Schacter, Dale, Rotte & Rosen, 1998a and Buckner, Koutstaal, Schacter, Wagner & Rosen, 1998b for similar results comparing interleaved and blocked retrieval conditions). Further research is needed to elucidate the functional significance of the prefrontal activations observed for memory retrieval. Other methods, like event-related potentials, which investigate retrieval processes in the temporal rather than the spatial domain might be useful tools in this process (see chapter 3 for a review of ERP effects of retrieval from episodic memory).

1.3.5. Summary – Functional and Neuroanatomical Models of Memory

The research presented in this thesis is primarily concerned with explicit memory retrieval, the ability to consciously remember past events. To provide a framework for the interpretation of this research, the foregoing review presented current ideas on the functional and neuroanatomical bases of explicit and implicit retrieval. Broad agreement exists as to the processing mechanisms by which memories are encoded and retrieved. By this view, cortical areas activated during the processing of an incoming stimulus are reactivated at retrieval and thus provide a network of information accessible from a variety of cues in a variety of (novel) situations. Whereas processing theorists do not attempt to further elucidate the neural bases of memory retrieval, systems theorists have advanced a neuroanatomical model of long-term memory. The encoding and retrieval of experiences is thought to rely primarily on a 'core' memory system situated in the medial temporal lobe and comprising the hippocampus and its adjacent cortices. Damage to this core system is associated with global anterograde amnesia (but see section 1.2.2.2.). Although the medial temporal lobe memory system is necessary for encoding, the information itself is thought to be stored in those areas of the cortex that mediated the initial sensory, perceptual and conceptual processing of the material.

Retrieval mediated by the medial temporal lobe memory system alone provides information about a previously encountered item, without placing this information in a spatio-temporal context. Retrieval associated with contextual information (i.e., episodic retrieval), is thought to be mediated by strategic processes instantiated by the prefrontal cortex. Damage to the frontal lobes is associated specifically with impaired source memory and memory for temporal order. Thus, the involvement of the prefrontal cortex is thought to be the distinguishing feature between episodic and semantic memories.

Typically, the neural correlates of retrieval from explicit memory have been studied using recognition memory tasks. In keeping with this tradition, the studies presented in this thesis use a simple recognition paradigm to investigate the material-specificity of the ERP correlates of long-term memory retrieval. The following section will outline the basic principles of dual-process models of recognition memory, in order to provide a framework for the interpretation of the ERP memory effects disucssed in Chapter 3, as well as the results of the present investigations.

1.4. Dual-Process Theories of Recognition Memory

Recognition memory is experimentally defined by the ability to correctly distinguish between items that have been previously presented, and items that are new to the experiment. The most commonly used method of investigation is a study-test paradigm, in which participants are shown a series of items at study which are then re-presented at test, along with a number of new items. At test participants are required to identify those items that they have seen before. Traditionally, recognition memory has been explained in terms of a single matching process, based on the strength of memory traces (see Snodgrass & Corwin, 1988 on signal detection models). However, these single process models of recognition memory have gradually given way to more complex dual-process models (Atkinson & Juola, 1973, Mandler, 1980). One of those models, formulated by Jacoby and coworkers (Jacoby & Dallas 1991, Jacoby, Toth & Yonelinas, 1993) will be introduced below.

As proposed for earlier models (Atkinson & Juola, 1973; Mandler, 1980), Jacoby and coworkers regard recognition memory as based on two types of processes: recollection, which involves the retrieval of contextual information about the episode in which the item occurred, and familiarity, the recognition of an item as old without the retrieval of any contextual information. In the formulation of their theory, they point to the memory impairment found in amnesics. As discussed before, amnesics show chance performance on direct memory tests such as recognition and recall, whilst performing at normal levels on indirect tasks such as word-stem completion. Jacoby and coworkers argued that, for amnesics, the process of recollection is not available any more, whereas familiarity provides the basis for any judgement of previous occurrence. This close alliance of familiarity to implicit memory processes is a strong deviation from the earlier conceptualisation of familiarity as a strength-based explicit or direct memory process as postulated in original signal detection and early dual process models (Atkinson & Juola, 1973). The potential relationship between familiarity and implicit memory processes like priming and the validity of this conjecture will be discussed below.

1.4.1. The 'Fluency-Heuristic'

Jacoby and Dallas (1981) proposed that recollection and familiarity rely on two different types of information. They argued that recollection is the central process supporting recognition memory and relies on the elaboration of an event's study context and can be influenced by factors like levels of processing. Familiarity, however, results from the application of the so-called 'fluency-heuristic'. According to this account, a person is capable of judging an item as old because the processing of this item is relatively fluent in comparison to new items. The effectiveness of the fluency-heuristic is based on the facilitation of processing through a prior encounter of the item and the similarity of perceptual characteristics of this item between study and test. The application of the fluency-heuristic is, however, only part of the process leading to the experience of familiarity. A second important process is the attribution of this fluency to an event in the past. Originally, Jacoby and Dallas (1981) argued that subjects notice a difference in fluency of processing between old and new items and consciously attribute this difference to a past experience with the item. This characterisation of the attribution process has, however, changed. More recent descriptions (e.g., Whittlesea, Jacoby & Girard, 1990) argue that the attribution of fluency occurs unconsciously. Thus, they see the attribution process as the basis for subjective experience, rather than as constructed within it. This shift in the formulation of the attribution process brings it closer to the conceptualisation of familiarity as an unconscious, automatic process as would be expected from its proposed connection with implicit memory processes.

Support for a connection between the familiarity process and relative perceptual fluency comes from several studies. Jacoby and Whitehouse (1989) tested the influence of subliminal pre-exposure of an item on recognition memory. At study, participants were presented with words they were instructed to remember for a subsequent memory test. The test lists contained items in four different conditions: old items preceded by an identical prime; old items preceded by an unrelated prime; new words preceded by an identical prime; and items not preceded by a prime. Pre-exposure of an identical prime facilitated recognition for old words, whereas pre-exposure of an unrelated prime disrupted recognition. For new words preceded by an identical prime, the false alarm rate increased significantly with respect to controls. However, when subjects were aware of the pre-exposed item results showed the opposite pattern. Participants were less likely to call an item that was preceded by an identical prime old than one that was preceded by an unrelated prime. This effect presumably occurred because the subjects correctly attributed the differences in fluency between old and new items to the pre-exposure.

Stronger support for the connection between recognition memory and attributed fluency comes from studies producing illusions of memory in the absence of an actual memory representation. Whittlesea et al. (1990) (but see Watkins & Gibson, 1988) manipulated fluency by altering the visual clarity of the to-be-recognised word. At study, participants were confronted with short lists of rapidly presented words, each of which was followed by a single word that they first had to pronounce and then to judge as old or new. Visual clarity was altered by occluding the presentation of the word with a mask of dynamic visual noise varying between different degrees of occlusion. The manipulation was orthogonal to whether the word was old or new. Results showed that participants were more likely to call a new word old when the particular word was presented in light noise than when it was presented in heavy noise, suggesting that easier perceptual processing biased participants to attribute the fluency to having seen the word at study. As in the previous study (Jacoby et al., 1989), knowledge about the manipulation abolished the effects.

1.4.2. Familiarity as Perceptual Priming

As mentioned earlier, the formulation of familiarity as an automatic and unconscious process, linking it to implicit memory processes (Richardson-Klavehn, Gardiner & Java, 1994), is a significant deviation from the conceptualisation of familiarity in earlier models of recognition memory. Jacoby and Dallas (1981) made the explicit connection between amnesia and the familiarity component of recognition memory, suggesting that it is the automatic memory processes thought to mediate familiarity which provide the basis for the preserved memory capacities in amnesia. As discussed previously, amnesics show preserved memory in predominantly in data-driven, indirect tasks. This then links the automatic memory processes thought to mediate the familiarity component of recognition memory to perceptual priming. Mayes (1991) extensively discussed this issue, suggesting three possible connections: (i) priming and recognition are anatomically and functionally distinct; (ii) priming may support familiarity as a basis for recognition, but not recollection; (iii) priming does support familiarity and is therefore a necessary but not sufficient condition for accurate familiarity based judgements. He argued that if it is indeed automatic memory processes that support preserved memory capacities in amnesia, it is necessary to show unequivocally that amnesics show priming for all instances in which priming can be observed in normal subjects, including priming for novel targets such as abstract shapes, nonwords and novel associations (i.e. conceptual priming, see section 1.2.3. in chapter 1). This issue is still under investigation and results are equivocal (see Bowers & Schacter 1994 for review on priming of novel stimuli in amnesia).

Recent evidence from normal subject populations, however, calls into question the claim that it is only perceptual priming that supports familiarity based recognition. In an attempt to dissociate automatic and consciously controlled effects from effects of study test compatibility Jacoby (1996) investigated the effects of associative context on automatic and controlled influences in associative word stem completion (study: table – chair, test: table-ch

…) using the Process Dissociation Procedure (Jacoby, 1991). This procedure puts automatic and controlled processes in recognition in opposition to each other, thus providing estimates of the contribution of familiarity and recollection to recognition memory performance. The procedure also provides the opportunity to study the influence of independent experimental variables on one or the other process independently. Jacoby (1996) conjectured that by reinstating the associative context established at study, both conceptually and data-driven processing could serve as sources of automatic influences on recognition memory, whereas only data-driven processing could support automatic influences when associative context was not reinstated. Results of the study showed that both recollection and familiarity based performance (as estimated by the PDP) were enhanced when the associative context was reinstated. In order to study if it was just data-driven or also conceptual processing which contributed to the enhanced familiarity based performance observed in the above experiment, Jacoby (1996) varied the paradigm in order to eliminate any contribution of data-driven processing to memory performance. In a second study, he introduced a modality change of the items from study to test, arguing that this would eliminate any contribution of data-driven processing, leaving conceptually driven influences on memory performance intact. Results showed that both recollection and familiarity where enhanced when associative context was reinstated, while familiarity did not differ from baseline in the no-context control condition. Jacoby (1996) argued that the results indicated that conceptually driven processes contribute to familiarity based performance as the reinstated context enhanced familiarity based memory performance in comparison to the no-context condition, in the absence of data-driven processing.

In a similar vein Toth (1996, Experiment 3) used the PDP to obtain quantitative estimates of recollection and familiarity after varying levels of processing at study. During the test phase subjects were given exclusion and inclusion instructions (Jacoby, 1991) combined with a response-signal technique in which response latency was varied from fast (500 ms) to slow (1500 ms). Three main questions were addressed: (i) the extent to which the short response delay decreased conscious recollection; (ii) whether the response time manipulation affected only recollection, or whether familiarity was also affected; and (iii) the extent to which prior semantic processing increased familiarity. The result of interest was that estimates of familiarity for semantically processed words were significantly higher than those for non-semantically processed words at both delays, indicating that conceptual processing contributes to familiarity based responding. Finally, Wagner, Gabrieli and Verfaellie (1997) also used a conceptual – perceptual manipulation and showed that familiarity-based explicit recognition (as indexed by the use of PDP and the independence Remember-Know procedure (Yonelinas & Jacoby, 1995)) increased with conceptual processing at study, whereas word-identification priming (an indirect test) and familiarity based word-stem completion (as indexed by PDP) increased with study-test perceptual overlap. The authors argued that these dissociations indicate that familiarity based recognition may be more sensitive to conceptual than to perceptual processing and that it is functionally distinct from the process mediating implicit perceptual memory.

1.4.3. Summary – Dual-Process Models of Recognition Memory

Dual-process models propose the contribution of two distinct processes to recognition memory performance, familiarity and recollection. Whereas familiarity gives a feeling of knowing without providing any information about the study episode, recollection allows the conscious retrieval of contextual information. Thus, dual process models distinguish not only between different retrieval mechanisms, but also incorporate a distinction in terms of the information that is retrieved. Whereas recollection is thought to be the central process supporting recognition and memory the processes contributing to familiarity based recognition are still under debate.

1.5. Memory for Pictures – Why is it special?

In order to vary information processing at encoding, the studies presented in this thesis used pictures of common objects and their names as the stimulus material. The use of pictorial material in memory research has uncovered important differences in the ways pictures and words are processed and remembered. Consequently, it has long been established that pictures are better remembered than words in recall as well as recognition (Nickerson, 1965; Paivio, 1971, Shepard, 1967). In addition, on-line processing tasks have shown differences in reaction times; categorization is faster for pictures and naming is faster for words (Potter & Faulconer, 1975, Smith & Magee, 1980). The question arising from these findings concerns the representation of knowledge in memory generally. More specifically, it raises the issue of how pictures are stored in memory. The following sections will give an overview of the most recent hypotheses concerning the representation of pictures in memory and review the evidence for differential processing at encoding and retrieval from a neuroanatomical perspective.

1.5.1. The Dual-Code Hypothesis

Two general approaches can be distinguished. Dual-code theorists advocate the existence of at least two types of memory storage: one verbal and another nonverbal, or imaginal (Paivio 1971, 1986, 1991). According to his theory, it is the mode of presentation that largely determines which store will be used. Thus, pictures will predominantly be encoded nonverbally, while words, whether presented visually or auditorily, will predominantly be encoded verbally. The systems representing the items are assumed to be independent but interconnected and therefore able to support each other in recall and recognition. However, the proposed existence of two memory stores does not in itself explain why one should show superior memory characteristics over the other. In his theory, Paivio (1971, 1986, 1991) proposed two different explanations. The first rests on the greater benefit for pictures of access to the two memory stores. In his dual-encoding hypothesis he proposes that many pictures are likely to be named spontaneously when presented, which results in two memory traces instead of just one. Words may be similarly dually encoded if accompanied by visual imagery. Paivio argues that events that are represented in two codes (i.e., verbal and imaginal), are more likely to be remembered than events represented with a single code (e.g., verbal only). He assumes that pictures are usually named when encountered whereas spontaneous imaging of word referents is less likely to occur. Consequently, pictures are more likely to be dually encoded and hence more likely to be remembered. This hypothesis is compatible with the finding of higher retrieval rates for pictures than for concrete words and higher rates for concrete than abstract words. The second explanation claims a mnemonic superiority for the imaginal code per se, although the exact reason is not understood (Paivio, 1986). Thus, even in the absence of dual coding, pictures should still enjoy a mnemonic advantage over words.

1.5.2. The Sensory-Semantic Model

In contrast, common-code theorists propose that both pictorial and verbal information is stored in a single, amodal form, where the constituents of memory are represented as abstract concepts and propositions (Anderson & Bower, 1973). The explanation of the picture superiority effect therefore has to take recourse to processing differences between pictures and words rather than differences in storage. The sensory-semantic model of Nelson and associates (Nelson, 1979; Nelson, Reed & McEvoy, 1977) rests on two assumptions. First, it is proposed that access to semantic features is faster and more direct from pictures than from words. By this argument, processing of pictures normally attains deeper levels than does the processing of words, resulting in a levels-of-processing type effect. The deeper (in the sense of more semantic) processing of pictures leads to better retention. Second, Nelson and associates claim that the visual sensory features (e.g. size, colour, shape) of pictures are more distinctive and varied than those of words. By this argument, greater distinctiveness at encoding would lead to greater informational overlap between studied representation and retrieval cue, thus enhancing declarative memory for pictures over that for words. This approach is closely allied to the transfer-appropriate processing framework (Roediger, 1990; Roediger & Blaxton, 1987; Roediger et al., 1989; also see Chapter 1) which proposes that memory performance depends to a large extent on the overlap between processing at study and processing at test.

Transfer-appropriate processing is the framework for a third proposal concerning the locus of the picture superiority effect. In a set of experiments, Weldon and Roediger (1987) showed that pictures showed the expected superiority over words in recall whereas in a word fragment completion task words produced greater priming than pictures. When participants were given a picture fragment identification task, however, pictures once again produced greater priming than words. Weldon and Roediger (1987) argued that the indirect tests of word-fragment completion and picture-fragment identification were data-driven tests, whereas free recall (as well as recognition) is a conceptually driven test. They proposed that the picture superiority effect is based on stronger conceptual processing of pictures (i.e., pictures access meaning codes more readily than words) which gives them an advantage in conceptually driven tests like recognition and recall. This perspective emphasises the congruence of operations between study and test, without making claims about the representation of the material in memory. On the basis of the above argument, Weldon and Coyote (1996) argued that if pictures engage more conceptual processing than words, then they should produce more priming on implicit conceptual tests (see Chapter 1). However, using category production and word association as conceptual implicit tests they failed to find a picture superiority effect. Weldon and Coyote (1996) proposed that conceptual processing plays a minor role, if any, in superior picture recall and that visual distinctiveness, as proposed as the second basis for picture superiority in Nelson's theory (see above), is a more important factor. A study by Rajaram (1996) supported this argument by showing that perceptual variables influenced Remember judgements in a Remember-Know paradigm.

1.5.3. The Neural Correlates of Picture Memory

A different line of investigation into the picture superiority effect has concentrated on the possible differences in the neural correlates underlying memory for pictures and words. The two approaches taken to investigate the issue are described below. The neuropsychological studies described here have mostly concentrated on medial temporal lobe lesions, as early research suggested that processing for the two stimulus types in the medial temporal lobe memory system might be lateralised. More recently, modern methods of functional imaging have become available, allowing a more direct approach to the functional anatomical study of memory retrieval and with that to the comparison of the neural correlates of picture and word memory.

1.5.3.1. Neuropsychological Studies

Previous research has characterised memory deficits resulting from unilateral medial temporal lobe damage as material specific, suggesting that damage to the left hemisphere results in verbal memory impairment with preservation of visuospatial function and the converse with right-sided damage (Milner, 1966, 1968; Saykin, Robinson, Stafiniak, Kester, Gur O'Connor & Sperling, 1992; for review see Smith, 1993). Implicit within this hypothesis are two assumptions: (i) that the medial temporal lobe memory systems are independent; and (ii) that severe amnesia does not typically follow unilateral damage to the medial temporal lobe because memory for the alternative material types is fully preserved in the intact medial temporal lobe.

More recent evidence suggests that a modification to the laterality hypothesis may be necessary. A study by Kroll and associates (Kroll, Knight, Metcalfe, Wolf & Tulving, 1996) tested the hypothesis that false memories are errors in conjunction between unrelated memory fragments. Based on the suggestion that it is the hippocampal formation that 'binds' together aspects of incoming information into retrievable engrams (Cohen & Eichenbaum 1993), Kroll et al. (1996) argued that medial temporal lobe damage would prompt a heightened incidence of conjunction errors. In their study, they tested patients with lesions to the left or right medial temporal lobe and normal controls in a verbal and a pictorial continuous recognition memory task. In the verbal version, subjects were presented with two-syllable words, which were either repeated directly (e.g. **SIGNAL** – **SIGNAL**), for which only one syllable was repeated (e.g. **FERTILE** – **REPTILE**), or which were reconstructed from syllables of two different words (e.g. VAL**LEY** – **BAR**TER – **BARLEY**). In the pictorial version, subjects were presented with abstract pictures and faces which were either repeated or reconstructed using features from two other stimuli. Subjects were required to respond 'old' to those stimuli that were repeated directly and 'new' to all others. The dependent measure was the number of false alarms subjects made to new stimuli made up of previously seen components. Results showed that patients with damage to the left medial temporal lobe were much more likely to show a high false alarm rate to words made up of previously seen components than either right medial temporal patients or normal controls. When pictorial stimuli where used, patients with damage to either the right or left medial temporal lobe showed an elevated false alarm rate in comparison to normal controls. The results indicate that, at least where pictorial material is concerned, both medial temporal lobe memory systems, right and left, are necessary for normal memory retrieval.

Jha, Kroll, Baynes and Gazzaniga (1997, see also Metcalfe, Funnell & Gazzaniga, 1995) extended the original study by Kroll et al. (1996). They compared the different types of encoding that may be differentially affected by callosotomy. In this study, patients with complete callosotomy were tested on three different tasks in order to characterise which types of memory processes rely most heavily on callosal integration. The tasks employed in the study were verbal conjunction memory, pictorial conjunction memory (see Kroll et al., 1996) and paired associate learning of words. As in the Kroll et al. (1996) study, the dependent measure was the number of false alarms to items made up of previously seen components. The performance of the callosotomy patients was compared to the performance of patients with unilateral and bilateral lesions in the medial temporal lobe. This comparison allowed the characterisation of those encoding tasks and materials that require integration of information from both intact medial temporal structures, thus testing the assumption that the two medial temporal systems are independent in their operation. Similarly to the Kroll et al. (1996) study, in the verbal conjunction task only patients with left medial temporal lesions showed an elevated false alarm rate. Callosotomy patients and patients with right medial temporal damage did not differ from normal controls. Jha et al. (1997) reasoned that whole word encoding does not require participation of the right hemisphere. The picture conjunction task was split into two subcategories. In recognition tests with abstract pictures and faces, which were not easily verbalisable, damage to either medial temporal lobe, and callosotomy, tended to increase the false alarm rate to new items made up of old components. For easily verbalisable conjunctions (types of houses with types of cars) it was only damage to the left medial temporal lobe that increased the false alarm rate. As before, results indicated that nonverbal binding processes cannot be accomplished by isolated hemispheres, but require callosal integration. The paired associate learning task used in this study was adapted to increase interference across two study lists by combining a cue word with two different associates across two lists (A-B A-C interference task). Subjects were presented with three study-test trial blocks for each paired associate list. In this test, callosotomy patients and patients with right temporal lobe lesions performed significantly better than patients with left temporal lesion but performed significantly worse than age-matched controls. The same pattern arose for a final cued recall in which both items associated with the cue could be produced. For all groups, however, items from the second study list were remembered better. Jha et al. (1997) concluded that on verbal tasks that require the formation of new associations, the left hemisphere alone is not adequate for normal encoding and/or retrieval. Callosal integration is necessary, especially when the original learning operation is followed by interfering information.

Finally, a study by Dobbins and coworkers (Dobbins, Kroll, Tulving, Knight & Gazzaniga, 1997) investigated the performance of patients with left and right unilateral hippocampal lesions in a multiple-list free recall task. The laterality hypothesis predicts severe impairment with left lesions, whereas right lesions should not impair performance on this task. However, both groups showed comparable and severe verbal episodic memory deficits. Dobbins et al. (1997) interpreted the findings as evidence against the laterality hypothesis and suggested that previously found material specific impairment in patients with left medial temporal lobe damage might have been due to a specific combination of material and task demands

The findings of these studies indicate that encoding and retrieval in the medial temporal lobe memory system are not necessarily material specific. At a minimum, the suggestion is that pictorial material depends on processing in both left and right medial temporal memory systems and that the systems therefore do not always operate independently. The dependence of verbal cued recall on involvement of both hemispheres suggests that the apparent laterality of verbal memory is conditional upon the task requirements and not solely a function of the material type. More drastically, it could be suggested (Metcalfe et al., 1995) that processing in the two hemispheres is material independent, but differs in process with a right hemisphere advantage for rote memorization and veridical encoding and a left hemisphere advantage for interpretation and integration of incoming information.

1.5.3.2. Functional Neuroanatomical Studies

Modern imaging methods provide a useful tool to study the neural correlates of information processing in vivo. They thus provide the opportunity to directly address the question whether it is indeed differing neural correlates that underlie the encoding and retrieval of pictures and words or whether differential processes within a unified store contribute to the emergence of the picture superiority effect. However, only a small number of studies so far have directly compared the neural correlates of picture and word processing. An early study by Stern and associates (Stern, Corkin, Gonzalez, Guimaraes, Baker, Jennings, Carr, Sugiura, Vedantham & Rosen, 1998) used fMRI to study novel picture encoding in normal subjects. The comparison between an intentional encoding condition and a passive viewing condition of colourful magazine pictures showed statistically significant increases in the fMRI signal bilaterally in the posterior hippocampal formation and parahippocampal gyrus and in the fusiform and lingual gyri bilaterally. Of importance was the fact that the study succeeded in showing hippocampal activation at encoding, something which so far had not been possible with the use of verbal stimuli. This study provided a first hint that the processing of pictures does indeed differ from that of words during encoding. However, selective activation of medial temporal lobe areas by pictorial stimuli has been explained in terms of novelty encoding. Tulving and co-workers (Tulving, Markowitsch, Craik, Habib & Houle, 1996, see also Tulving, Markowitsch, Kapur, Habib & Houle, 1994) used a picture retrieval task to compare activation for a memory condition (indexed by the OLD-NEW subtraction) and activation for the viewing of novel stimuli (indexed by the NEW-OLD condition). The latter subtraction resulted in significant increases in regional blood flow in the right hippocampal formation, the right parahippocampal gyrus, as well as in medial prefrontal and orbitofrontal cortex. Tulving et al. (1996) argued that the results indicate an involvement of the hippocampal formation in novelty assessment. That is, the hippocampus might be relatively more active during retrieval in the service of novelty assessment than during retrieval of highly familiar information.

In a later study, Grady and associates (Grady, McIntosh, Rajah & Craik, 1998) compared the encoding of pictures and words directly. They used PET to map the brain regions activated during the encoding of the two stimulus types. Comparing activation patterns for pictures and words directly, they found that encoding of pictures resulted in greater activity of bilateral ventral and dorsal extrastriate cortex and of bilateral medial temporal cortex. This difference in activation between word and picture encoding was larger over the right than the left hemisphere. Thus they replicated the medial temporal activation found in the original study by Stern et al. (1996) but added a new perspective on picture encoding, namely the engagement of posterior cortical areas involved in early visual processing. They concluded that the picture superiority effect, which they showed in a subsequent recognition memory test, may be mediated by more effective and automatic engagement of areas important for visual memory. This conclusion is supported by a study conducted by Haxby and colleagues (Haxby, Ungerleider, Horwitz, Maisog, Rapoport & Grady, 1996) which compared encoding and recognition of faces using PET. In comparison to a sensorimotor control task, both encoding and recognition showed activation of bilateral areas in the ventral occipitotemporal cortex. Interestingly, this activation was observed during both encoding and retrieval, lending some support to the notion that areas activated during encoding are reactivated during retrieval (see above). It also supports the conclusion by Weldon and Coyote (1997) and Rajaram (1996) that it is indeed the perceptual features which pictures have in addition to their semantic code that is the basis for the picture superiority effect.

A fMRI study by Kelly and co-workers (Kelley, Miezin, McDermott, Buckner, Raichle, Cohen, Olinger, Akbudak, Conturo, Snyder & Petersen, 1998) investigated the hemispheric specialization in dorsal frontal cortex and medial temporal lobes for verbal and nonverbal memory encoding. In their study, subjects viewed words, nameable line-drawn objects and unfamiliar faces. Both robust dorsal frontal and medial temporal activation was observed, the lateralisation of which was, however, strongly material dependent. Encoding of words produced left-lateralised activation, whereas encoding of unfamiliar faces produced homologous right-lateralised activation. Encoding of nameable objects, which are amenable to both verbal and nonverbal encoding, yielded bilateral activations. Similar results were found by Klingberg and Roland (1998) who observed material dependent lateralisation in the prefrontal cortex and by Martin, Wiggs and Weisberg (1997) who showed the same type of lateralisation for medial temporal lobe activity.

In summary, neuroimaging studies of picture and word encoding have so far yielded mixed results. They suggest a differential involvement of areas in the occipital cortex in the encoding (and retrieval) of pictures and words, with pictures additionally engaging occipital areas associated with perceptual processing. Results of medial temporal activations are inconclusive with some studies supporting the neuropsychological evidence of bilateral engagement of medial temporal areas in picture memory but others showing strong lateralisation in the activation patterns for the two types of stimuli. Replication of these results with various task demands and protocols is, however, necessary, as all studies conducted so far differed in their designs, aims and procedures.

1.5.4. Summary – Picture Memory

The picture superiority effect indicates that the processing of words and pictures differs, thus prompting a mnemonic advantage for pictures over words. Several theories have been developed to account for this advantage. The combined evidence from cognitive behavioural and neuroimaging studies suggests that it is the more distinct sensory code (i.e., colour, size and shape) of pictures that forms the basis for the picture superiority effect. With respect to the laterality hypothesis of medial temporal lobe memory function, results are inconclusive. Neuropsychological studies strongly suggest the involvement of the bilateral medial temporal lobe structures in pictorial encoding and retrieval. While these results are supported by some neuroimaging studies, others provide evidence for the lateralisation to the left and right medial temporal lobe of verbal and non-verbal memory processes respectively. In light of these differences between verbal and non-verbal memory processes, pictures provide the ideal means to study the modality specificity of the neural correlates of explicit memory retrieval, as indexed by the ERP old/new effects reviewed in Chapter 3. If retrieval from long-term memory varies according to the nature of the information retrieved, qualitative difference in these ERP effects could be expected. This question was addressed by the first study, presented in Chapter 5, which compared the neural correlates of recognition memory for pictures and words directly.

1.6. Conclusions

The remainder of the thesis is organised as follows: The principles of data collection, processing and analysis for the ERP technique are introduced in Chapter 2. Chapter 3 provides a review of ERP studies of retrieval from long term memory and their functional interpretation in the framework of dual-process theories of recognition memory. Chapter 4 will provide an overview over the general methods common to all three empirical studies presented in the thesis. The results of these studies will be presented in Chapters 5-7. Finally, Chapter 8 will provide a general discussion of the results of the empirical studies in the light of the functional and neuroantomical issues considered in the present chapter.

CHAPTER 2

Event-Related Potentials

2.1. Introduction

Event-related potentials (ERPs) are a well-known electrophysiological technique used to study the neural correlates of psychological processes on-line by monitoring the brain's electrical activity during the processing of information. The technique exploits the properties of electrical fields generated by the synchronous activity of a collection of neurons. Under suitable conditions these electrical fields propagate through the conductive media of the brain and skull and reach the scalp from where ERPs can be recorded through the placement of electrodes.

ERPs are part of the ongoing electroencephalogram (EEG) and are based on changes in the electrical activity which are recorded time-locked to a particular event, such as the presentation of a stimulus on the computer screen. Thus, ERPs offer a direct measure of neural activity (specifically, the fraction detectable at the scalp) associated with the processing of events in 'real time' and with an extremely high temporal resolution (in the order of ms). The technique also offers the advantage that neuronal activity can be recorded and analysed for different classes of items and contingent on the subject's task performance. These are precisely the limitations of haemodynamic neuroimaging methods such as PET and fMRI which offer a high degree of spatial resolution (in the order of mm) at the cost of very poor temporal resolution (tens of seconds in the case of PET). Thus, haemodynamic methods and ERPs are complementary neuroimaging methods which can be used to address questions about the functional and physiological bases of higher mental functioning.

As with the other neuroimaging techniques employed to monitor the brain's activity, the ERP technique has a number of limiting factors that constrain the range of tasks that can be employed as well as the inferences which can be drawn from the observed results. The present chapter will give an overview of the principles underlying ERP research, the basic techniques used to record and analyse the signal and the description and interpretation of the resulting waveforms. It will also discuss the major constraints that apply to ERP research and the influence of these constraints on the interpretation of results.

2.2. Electrogenesis

The electrical activity recorded at the scalp results from changes in the polarisation of individual neuronal cell membranes which produce localised electromagnetic fields (Wood, 1987; Wood & Allison, 1981). At the level of individual cells these fields are due to transmembrane current flow which can occur in two forms (i) as an all-or-none action potential or (ii) as a graded post-synaptic potential which is either inhibitory or excitatory. Whereas both types of transmembrane current flow create extracellular electrical fields it is likely that only post-synaptic potentials give rise to the ERP. Evidence for this view comes from the fact that both cortical surface ERPs and intracellular post-synaptic potentials persist at levels of anaesthesia which are sufficient to block the generation of action potentials (Wood & Allison, 1981).

The localised fields generated by a number of neurons summate spatially and create the so-called 'potential field' (Wood, 1987; Wood & Allison, 1981). The shape of the potential field, which can be either 'open' or 'closed', is determined by the geometry of cells and cell groups (Allison & Wood, 1981; Coles & Rugg, 1995). The 'open field' is created by axially symmetric cells with long apical dendrites oriented in parallel. The resulting elongated bipolar structure and axial symmetry of such neurons causes current flow to be predominantly along the long axis of the neurone, producing a potential field resembling that generated by a charge dipole. This type of open field can be recorded at a considerable distance from its origin, so long as the two recording electrodes lie on different isopotential lines of the potential field. Examples of neurons of this kind are the Purkinje cells or pyramidal neurons found in neocortex, paleocortex, hippocampus (note that through the shape of the hippocampus no open field is created here) and cerebellum. A 'closed field' is created by neurons with dendrites extending in all directions from the cell somas. If the neurons are arranged with the somas inward and the dendrites proceeding radially outward, as might occur in a nuclear structure, the net current flows inward resulting in a zero potential in extracellular space. Hence, no activity can be recorded at the scalp. The EEG therefore does *not* represent a measure of the total activity of the brain, since only a proportion of the brain's activity ever reaches the scalp.

In order for a potential field to be detected, neurons not only have to be ordered in a certain geometric fashion, but also have to be synchronously active to produce a current flow big enough to propagate outwith the bounds of the generating structure and to the scalp. The potential measured at the scalp at a given point and at a given time represents the algebraic sum of all fields reaching that point during this time. As open field currents pass through the brain, the surrounding tissues and the scalp, they linearly summate with one another. The resulting scalp recorded EEG therefore reflects the linear summation of fields generated in multiple regions. Magnitude and latency of these scalp recorded potentials are governed by the laws of volume conduction (i.e., attenuation of the field currents passing through the brain and its surrounds is different for the different distances between neuronal source and recording electrodes).

2.3. ERP Recording and Signal Extraction

Typically, ERPs are recorded from electrodes attached to the scalp according to the 10-20 system (Jasper, 1958; see Figure 4.1 for the electrode montage used in the present studies). The basic unit of data elicited in ERP recording is the potential difference between two scalp locations (i.e., two electrode sites). The ERP waveform consists of a sequence of such data points sampled at discrete intervals. The sampling rate of the recording has to be chosen in a way that it encompasses all frequencies of interest. The minimum sampling rate has to be twice the highest frequency of interest to avoid aliasing (i.e., the appearance of spurious low-frequency components due to sampling with long point-to-point intervals; for further information see Picton, Lins & Scherg, 1994).

ERPs are usually recorded from both midline and lateral scalp sites. Recordings are made with respect to a common reference point, usually the ear lobes, chest or mastoid bones. Thus the input into the amplifier is the difference between the electrical activity recorded at the electrode site and the activity recorded at the reference site which cancels out those signals common to the reference and the recording electrodes. Consequently, while the absolute value of the potential difference depends upon the choice of reference, the profile of the field is reference independent (Binnie, 1987).

At the time of recording the EEG consists of two parts, the neural activity evoked by the stimulus and the neural activity which is unrelated to the stimulus. The most widely used signal extraction procedure is signal averaging which is performed over the point by point digital values. The main assumptions underlying this procedure are that: (i) the stimulus-related signal remains constant over time, and (ii) the noise is random and uncorrelated with the signal of interest. If these criteria are met, averaging over trials will reduce the contribution of the noise in the averaged ERP whilst leaving activity which is constant across trials unaffected. The signal-to-noise ratio improves as a function of the square root of the number of trials used for averaging (Gratton & Fabiani, 1990; Picton et al., 1994).

The method of signal averaging therefore requires experiments to be designed such that a set of to-be-averaged trials is recorded under constant conditions. Variations in amplitude or the latency of a component ('latency jitter') across individual trials will result in an unrepresentative average. Similarly, ERPs cannot be recorded for psychological processes which change rapidly over only a few trials (e.g., habituation).

One means of assessing whether the averaged ERP is representative of single trials is to inspect individual samples of the EEG and to measure the latency and/or amplitude of particular peaks and troughs in the waveform. Though this method can be applied in some paradigms, low signal-to-noise ratio usually precludes this form of analysis.

Another method to enhance the signal-to-noise ratio is to reject certain classes of trials prior to averaging. The most common sources of contamination are ocular movement and blinks which cause a positive potential over anterior scalp locations. The concurrent recording of EOG (electro-oculogram) allows monitoring of these artefacts. For the purpose of averaging a certain criterion in terms of a maximum voltage can be set within which activity on the EOG channel must fall for the trial to be accepted. The same method can be employed for non-ocular artefacts like drift or muscle activity. This procedure is valid to the extent that the task-related activity falls within the range of the criteria set for rejection.

2.4. The Description of ERPs

After the application of the signal extraction procedures, the resulting ERP waveforms contain peaks and troughs which can be described in terms of their latency, amplitude and polarity relative to a reference point, usually a pre-stimulus baseline. Whilst this convention allows the ERP to be described (e.g., P200 = positive peak at 200 ms post-stimulus), it does not give any insight into the underlying processes which determine the shape of the ERP. Traditionally peaks and troughs of the waveform have been identified with ERP components. The greatest impediment to this simple approach is the spatial and temporal overlap of different components in the waveform. Component overlap refers to the fact that activity recorded at a particular scalp site may result from the summation of electrical activity that is generated by several different sources in the brain, which may even have different time courses. Thus, the resulting peak or trough in the waveform might not coincide with the maximum or minimum level of activity of any single generator. In addition, the peak latency of a particular peak or trough may not accurately reflect the timing of an underlying brain process because of latency jitter across trials. Therefore, care should be taken when identifying a particular peak or trough as reflecting a single component.

In principle, modulations of either individual or multiple component features can give rise to changes in the morphology of the ERP. These modulations can take the form of changes in latency, magnitude or scalp distribution. It is a reliable difference in ERP scalp distribution across two experimental conditions that indicates a 'qualitative' difference in the brain activity which generates the ERPs in each condition. Accordingly, if the scalp distribution is used as a defining feature of an ERP component two main approaches to the description and classification of ERP components can be distinguished (see Coles & Rugg, 1995; Rugg, 1995):

(i) ***Physiological approach***: In this approach, the defining characteristic of a component is its anatomical source within the brain. In the extreme, a component is defined as the contribution of a single generator to an ERP field. However, a less extreme physiological interpretation could be based on a definition in terms of the contribution of a number of generators. Importantly, such definitions do not involve specification of the function of the given region(s). Thus, to the extent that a neural generator participates in a number of functions, the same ERP component may occur on a variety of tasks and be modulated by a number of factors. According to this approach, an ERP component cannot change its scalp distribution since this would imply that different brain regions are involved in the creation of this component.

(ii) ***Functional approach***: Here a component is defined in terms of the information processing operation with which it is correlated. Thus, a component is defined in terms of the cognitive function thought to be performed by one or more brain systems whose activity is recorded at the scalp. The functional approach relies on the comparison of ERPs evoked under different experimental conditions. It is this difference between the conditions, evoked through manipulation of the processing operations, which defines the cognitive function. It is important to note that the functional approach does not require a one-to-one mapping between a component and a neural generator, as long as the contributing brain structures form a homogeneous functional processing system. Under the functional approach it is conceivable that two or more modulations of the ERP, each with a radically different scalp distribution, could reflect identical functions (see Rugg & Coles, 1995 for an example).

A major problem for the interpretation of ERP waveforms according to the functional approach is the assumption of 'pure insertion'. Pure insertion refers to the fact that experimental conditions have to be created which differ only with respect to the process of interest but are equivalent in all other respects.

The functional and physiological approaches to component definition are complementary to the extent that particular cognitive functions are localised to particular neural circuits. Even where this mapping of functional state to brain state is not discreet, in practise ERP researchers tend to adopt elements of both approaches in identifying ERP components. Coles and Rugg (1995) argued that a component should be defined by a combination of its polarity, latency, scalp distribution and sensitivity to the experimental manipulations. A consistency in polarity and scalp distribution over different conditions implies a consistency in physiological source whilst consistency in latency and sensitivity implies consistency in information processing operations. Also, Picton and Stuss (1980) suggested that a number of approaches should be combined, using both physiologically and psychologically based manipulations as a way of defining the sources of variability in ERPs.

In the following section, the interpretation of ERP modulations is discussed in order to show how ERPs are used to inform our understanding of the functional neuroanatomy of cognition.

2.5. Functional Interpretation of ERP Effects

The emphasis in the analyses of any ERP experiment is on the differences between ERPs evoked under different experimental conditions and how these might be related to cognitive processes. In order to make functional claims on the basis of statistically reliable differences between ERPs, it is necessary to assume a consistent relationship between brain states and functional states.

Because the ERP technique is correlational (i.e., an ERP effect is not necessarily a direct reflection of the physiological process under scrutiny, but might reflect a process contingent upon the actual process of interest), functional interpretations of ERP effects have to be made with caution. Different kinds of ERP effects can be observed as a function of experimental conditions. All differences, be it in terms of latency, amplitude or scalp distribution, indicate that the neural processing of the evoking stimuli was not identical across conditions. However, the absence of any differences between ERPs across experimental conditions does not imply that neural processing was identical, as scalp-recorded ERPs do not reflect the totality of brain activity. Also, the onset latency of an ERP effect does not approximate the point in time at which neural processing begins to differ. Rather, the onset latency of the effect merely determines an upper boundary on the time at which processing differs.

To draw functional inferences on the basis of differences in neural activity an important distinction has to be made between *qualitative* and *quantitative* differences in ERP activity across experimental conditions. A *quantitative* difference between two ERPs refers to differences in the amplitude or latency of some part of the ERP which is not accompanied by any differences in the relative distribution of the two ERPs over the scalp. Differences like these are usually taken as evidence for the engagement of similar brain regions which are differentially activated. The functional interpretation would be that similar cognitive processes are probably engaged in each condition. Differences in amplitude and latency may, however, have a number of different causes. Significant latency jitter across individual trials may give rise to the temporal smearing of an ERP component, resulting in the reduction of its size and its apparent latency. Alternatively, however, amplitude modulations may reflect genuine experimentally induced quantitative changes in the activity of the given generators. Such modulations must result either from changes in the number of excitated cells within the generator, or changes in the synchrony of neuronal firing. The larger the amount of input and the more synchronous the neuronal activity, the larger the amplitude of any given effect. Here, a functional interpretation must depend on how changes in the activity of the generator circuit relate to the function which it instantiates.

A *qualitative* difference between two ERPs refers to differences in the distribution of the electrical activity, associated with the different experimental conditions, over the scalp. A significant 'topographic' difference is taken as the necessary basis for postulating qualitative differences in brain activity. Such differences can arise if different brain regions contribute to each effect. Alternatively, identical regions may be activated but with differing levels of relative activation. These qualitative differences are ususally taken as evidence for the engagement of different functional processes, following the assumption that different brain states indicate different functional states. Whilst evidence of differing scalp distributions does not demand this interpretation (see Rugg & Coles, 1994), within a given experiment it is the strongest form of evidence that functionally distinct processes are in fact engaged. Note that qualitative differences cannot only arise between experimental conditions but can also arise within one experimental condition over the time course of the recording.

However, even the knowledge that differing brain states are underlying the ERPs in different experimental conditions does not allow any conclusions as to the intracerebral location of the generator(s). Firstly, given that ERP effects arise from the spatial summation of an unknown number of potential fields, it is impossible to determine how many generators are involved and, as the entire brain acts as a volume conductor, where the fields originate. Secondly, in principle there is no unique solution to the problem of source localisation, since a particular scalp field may be generated by an indeterminate number of different configurations of intracerebral sources (the so-called 'inverse problem'). The studies reported in this thesis do not attempt to explicitly map ERP effects onto intracerebral sources. However, the studies do use topographical information to speculate about the neural generators of the observed ERP effects.

The assumptions discussed above denote those which are most commonly adopted in order to make functional claims on the basis of electrophysiologically generated activity. These assumptions are implicit in the interpretation of the ERP studies of long-term memory reviewed in the next chapter. Similarly, these are the assumptions that underlie the functional interpretations applied to the experimental work reported in this thesis.

CHAPTER 3

Event-Related Potentials and Memory

3.1. Introduction

Research using event-related potentials (ERPs) has a history stretching over more than 30 years. Over the last decade or so the technique has found its way into the investigation of various areas of memory research such as implicit memory, especially the phenomenon of priming, explicit memory, and working memory (for reviews see Johnson 1995; Kutas & Dale, 1997; Rugg & Coles, 1995). The aims of this research are to investigate the temporal characteristics of the processes contributing to performance on memory tasks and to relate what is known about the functional neuroanatomy of memory to the ERP correlates of this performance.

Typically, the neural correlates of explicit memory retrieval have been studied using recognition memory tasks. The most commonly used method of investigation is a study-test paradigm in which participants are shown a series of items at study which are then re-presented in the test phase, along with a number of new items. At test participants are required to identify those items that they have seen before. These tasks have the advantage of allowing control over perceptual characteristics of the items, lag between repetition of items, and the time-locking of the onset of the item with the ERP recording. The ERP memory effects reviewed in this chapter have predominantly been interpreted within a framework based on current dual process models of recognition memory. To recap briefly, dual-process models propose that recognition memory is based on two types of processes relying on two different types of information (see Chapter 1, section 1.5). One of the possible processes contributing to recognition is recollection, which involves the retrieval of contextual information about the episode in which the item occurred. The second proposed process is that of familiarity, the recognition of an item as old without the retrieval of any contextual information.

The review presented in this chapter will focus on the use of ERPs in the investigation of retrieval from long-term memory, primarily the investigation of explicit memory. The studies presented in this thesis are a direct extension of this previous work. To provide a context for these studies, a review is presented of the different approaches used to study explicit memory with the help of ERPs and how the results have contributed to the elucidation of the functional significance of the resulting ERP memory effects.

The basic logic of all the studies reviewed in this chapter is as follows. Each study contrasts ERPs evoked by stimuli presented in different experimental conditions. The critical contrasts in the studies reviewed below are those between items presented for the first time (new items) and those presented before (old items). In tests of recognition memory subjects are asked to make an overt judgement in response to each item, i.e. 'old' or 'new'. These judgements can be either correct or incorrect. Thus four response categories are possible: items correctly called 'new' (correct rejections), items correctly called old (hits), old items incorrectly called new (misses), and new items incorrectly called old (false alarms). Any differences in the ERPs that emerge as a function of these experimental conditions allows conclusions about the possible modulation of the cognitive process in question, and thus about the functional significance of the observed ERP effect.

3.2. The Left Parietal Old/New Effect

The basic experimental finding, from studies employing the typical study-test procedure, has been the so-called 'left parietal ERP old/new effect' (for review see Johnson, 1995; Rugg, 1995). The effect takes the form of an enhanced positive shift in the ERP for items correctly detected as old as compared to those correctly rejected as new. (Paller & Kutas, 1992; Paller, Kutas & McIsaac, 1995; Smith, 1993; Wilding, Rugg & Doyle, 1995). The ERP old/new effect typically onsets around 400 ms post-stimulus, lasts for about 300-600 ms, and is maximal over left temporo-parietal sites (see Figure 3.1). Critically, the left parietal old/new effect cannot be found for misses and false alarms. This indicates that the effect is associated with the successful retrieval of information from memory only, and does not simply reflect the fact that an 'old' response has been made (as in the case of false alarms), or that the item has been repeated (as in the case of misses).

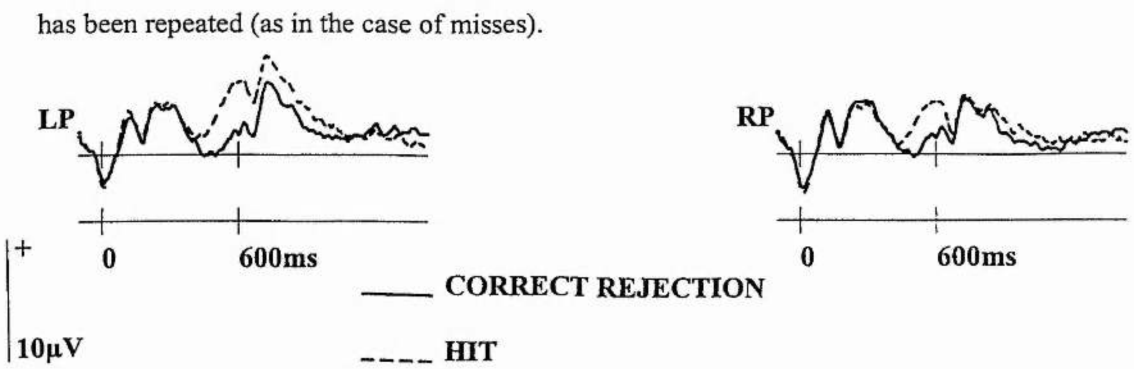


Figure 3.1 The left parietal old/new effect. Data taken from Schloerscheidt & Rugg, (1997).

3.2.1. The Left Parietal Old/New Effect and the P300

The early studies of ERP effects in recognition memory tests interpreted the left parietal old/new effect in terms of the functional significance of the heavily investigated P300 (or P3b) component. The P300 is an endogenous component known to be influenced by a number of 'cognitive' factors which could potentially also influence ERP differences between old and new items in recognition memory tasks (for review see Donchin & Coles, 1988; Johnson, Pfefferbaum & Kopell, 1985; Kutas & Dale, 1997). For example, the amplitude of the P300 is inversely related to the relative frequency with which the evoking stimulus occurs (i.e., the rarer the stimulus, the larger the P300 amplitude), and the peak latency of the component is influenced by the time it takes the subject to categorise a stimulus (as measured by response time). Interestingly, it is exactly these functional characteristics of the P300 which allow this component to be distinguished from the left parietal old/new effect. Firstly, it is typical practise for old and new items to be equated in probability of occurrence in tests of recognition memory. Moreover, the response probabilities, i.e. the number of old and new responses made by subjects, often do not differ markedly either. Thus, hit and correct rejection conditions generally do not differ in terms of their subjective relative frequency of occurrence within an experiment. Furthermore, if the P300 and the old/new effect were indeed modulations of the same functional component, it is unclear why misses and false alarms do not show an old/new effect as the subjective probability of such a response is the same as that for all other items.

Testing this issue directly, Smith and Guster (1993) found that the left parietal old/new effect was present even when the probability of responding to an old item was much higher than that of responding to a new item. If the old/new effect and the P300 reflected functionally identical processes, the ERPs to correct rejections should have shown a positive shift with respect to hits. Similarly, Friedman (1990) showed that the old/new effect does not reflect variation in stimulus probability and Karis, Fabiani and Donchin (1984) reported that the old/new effect is not an outcome of decision confidence. Further, and possibly the most convincing, evidence for a functional dissociation between the P300 and the left parietal old/new effect comes from the difference in scalp distribution between the two components (Friedman, 1990; Smith & Guster, 1993). Although each component has a parietal maximum, the P300 is typically largest over the midline and diminishes symmetrically with distance from it, whilst the old/new effect is asymmetrical with a maximum over left parietal sites. This difference in scalp distribution suggests that different or at least only partially overlapping neural generators contribute to the two components. Taken together, the differences in scalp distribution and those in functional properties provide evidence to reject the notion of a simple correspondence between the P300 and the left parietal old/new effect.

3.2.2. The Left Parietal Old/New Effect – Signature of Familiarity or Recollection?

Based on the assumptions that the ERP old/new effect is indeed functionally different from the P300 component, and that it is related to processing associated with successful recognition, research has focused on the functional significance of the effect. Debate about its functional role has been influenced heavily by dual process models of recognition memory (see section 1.5., Chapter 1), focusing functional accounts of the left parietal effect on the processes of familiarity and recollection.

Initially, a number of studies favoured a functional explanation of the left parietal old/new effect in terms of a familiarity account (Friedman, 1990; Potter, Pickles, Roberts & Rugg, 1992; Rugg & Doyle, 1992). For example, Rugg and Doyle (1992) investigated the interaction of the ERP old/new effect with the normative frequency of words. ERPs showed a positive shift from about 500 ms post-stimulus only for low-frequency items correctly classified as old, an interaction which also held when ERPs were formed only from items correctly classified as old which were assigned a high confidence judgement (Rugg, Doyle & Wells, cited in Rugg, 1995a). Rugg and Doyle interpreted the results on the basis of the familiarity explanation for the well-documented recognition advantage for low- over high-frequency words (e.g., Jacoby, 1991; Mandler, 1991). According to this argument low-frequency words experience a greater relative increase in familiarity between study and test than high-frequency words, which already have a relatively high baseline familiarity value. Following this argument, Rugg and Doyle interpreted the prominence of the left parietal old/new effect for low-frequency words as a reflection of the greater increase in familiarity accorded to those items.

Rugg and Doyle's (1992) conclusion that the left parietal ERP old/new effect is the neural correlate of familiarity driven recognition was predicated on the assumption that the recognition memory advantage for low-frequency words is driven by familiarity. A number of behavioural studies challenge this account (Gardiner & Java, 1990; Guttentag & Carroll, 1994, 1997) however, and attributed the recognition memory advantage for low frequency words to recollection instead. This suggested a re-interpretation of the functional significance of the left parietal old/new effect in terms of recollection, rather than familiarity.

A number of studies support the validity of this re-interpretation. In an early study Smith and Halgren (1989) recorded ERPs in left- and right- anterior temporal lobectomy patients using a modified study-test recognition paradigm. Patients who had undergone a left lobectomy (LTL) showed no old/new effect whereas right lobectomy (RTL) patients and normal controls showed a normal sized left parietal repetition effect. Interestingly, in spite of the missing ERP component, the LTL patients showed near normal task performance. Smith and Halgren (1989) concluded that although the LTL patients were poor at recollection, familiarity based recognition was intact. They argued that these patients performed the task based on familiarity-driven recognition whereas RTL patients and normal controls would base their recognition judgements also on recollection. Smith and Halgren (1989) therefore suggested that the ERP old/new effect is indeed the signature of recollection.

Using a different approach to manipulate the use of familiarity and recollection-driven recognition, Paller and Kutas (1992) investigated the nature of the old/new effect in the absence of overt recognition. In their study they employed a levels of processing manipulation (Craik & Lockhard, 1972) at encoding, using an imagery task as the deep encoding task and a letter-counting task for shallow encoding. At test, subjects were simply required to identify briefly displayed old and new words in the absence of any overt recognition judgement. Behaviourally the depth of processing manipulation did not influence the likelihood of identifying an old word correctly, i.e. both classes of old items were equally well primed. However, ERPs elicited a larger old/new effect for those old items encoded deeply than those encoded shallowly. Paller and Kutas (1992) interpreted these findings in the light of the levels of processing assumption that deep encoding facilitates later recollection whilst shallow encoding does not. Accordingly, they argued that the ERP old/new effect provides the neural signature of recollection. They also concluded that the old/new effect is independent of implicit memory processes and does only occur when the subject is aware that an item has previously been processed. Interestingly, their result supports the notion that the ERP old/new effect is indeed independent of the requirement to overtly discriminate between old and new items and thus provides a means to study cognitive processing covertly. However, the conclusions of this study are predicated on the assumption that semantic processing does not influence familiarity-driven recognition (thought to rely on perceptual priming, i.e. implicit memory), but exclusively influences recollection. Recent evidence (Jacoby, 1996; Toth, 1996; Wagner, Gabrieli & Verfaellie, 1997) calls this assumption into question (see section 1.5.2, Chapter 1).

In an attempt to operationalise recollection in a more testable way, Smith (1993) recorded ERPs using a modified recognition memory task (R/K procedure) first suggested by Tulving (1985) and later developed by Gardiner and Java (1993). In the test phase of this task subjects are first required to make an old/new decision. Subsequently, for those items called old, subjects are required to decide if they recollect any information about the episode in which the item was studied ('R) or if they 'just know' ('K') that the item is old. 'R' and 'K' judgements are thought to map onto the phenomenological experience of recollection and familiarity respectively, thus providing a tool to dissociate the two bases of recognition memory. Smith (1993) found that although an old/new effect was present for both R and K judgements, this effect was significantly larger for R responses. He interpreted this finding as conclusive evidence for the idea that the ERP old/new effect reflects the degree to which subjects recollect the study episode. In the context of this conclusion it is interesting that K responses, which are interpreted as reflecting the familiarity process, do show an old/new effect. In the light of this finding the conclusion that the ERP old/new effect does reflect recollective processes can only be valid if it is accepted that R/K judgements are not process pure. It must be assumed that K judgements are contaminated with recollection, an assumption that would predict the observed attenuated old/new effect for K judgements, but is inconsistent with the exclusivity assumption underlying the use of the R/K procedure. The problem of process impurity thus renders the R/K procedure a less useful tool for isolating the functional significance of the ERP old/new effect.

The studies reviewed so far suggest that the left parietal old/new effect is indeed the neural correlate of recollection rather than familiarity. However, the conclusions drawn in these studies are not unambiguous. The studies by Paller and Kutas (1992) and Smith and Halgren (1989) both assume that familiarity-driven recognition is connected to priming processes, and thus to implicit memory. As discussed in Chapter 1 (section 1.5.2), however, it is not at all clear what relationship exists between familiarity and implicit memory. Similarly, the study by Smith (1993) used a procedure originally designed to study the phenomenological experience of memory. The use of this procedure to study underlying memory processes therefore leaves the obtained results open to question. Given these difficulties it seems clear that an alternative means to operationalise recollection is needed.

3.2.3. Source Memory – The Operationalisation of Recollection

In a series of studies Wilding and colleagues provided this much needed way of operationalising recollection. In their studies they employed a source memory task, in which subjects are not only required to decide if an item is old or new, but also to provide information about the context in which the item was studied. This allows ERPs to be separated according to the likelihood that episodic recollection, as defined by the subject's ability to provide information about the study context, occurred. In their source memory studies Wilding and colleagues used a two-stage retrieval task. After an initial old/new judgement subjects were required to furnish a source judgement for those items deemed to be old. The rationale behind the use of this kind of task is that a correct source judgement can only be made if information from the study episode is recollected. This allows ERPs to be separated according to whether items have been recollected (when a correct source judgement was made), or if they have been recognised as old on the basis of familiarity (when the source judgement is incorrect or has not been made at all).

In their first study, Wilding, Doyle and Rugg (1995) presented subjects with words either in visual or auditory modality. At tests, subjects were again presented with words either visually (Experiment 1) or auditorily (Experiment 2). They were required to report whether items shown on a computer screen were old or new, and for those items judged old, to report the modality they had been studied in. The critical assumption was that subjects would only be able to report the correct modality of study presentation if they recollected the context of this episode. Wilding et al. (1995) found that the standard left parietal old/new effect was present when subjects could accurately recognise and report the modality of the study presentation. However, a weaker, less temporally extended old/new effect was also found for items that were correctly recognised but received incorrect context judgements (experiment 2 only). Importantly, the topographic distribution of the old/new effects did not differ as a function of the accuracy of the source judgement, suggesting that the processes associated with the two kinds of responses had the same underlying neural generators. Wilding et al. (1995) interpreted their results as showing that recognition accompanied by incorrect source judgements was the result of partial or weak recollection, allowing subjects to make correct old/new judgements, but not correct source decisions.

Unfortunately, using study modality as the critical variable to distinguish the different classes of old items resulted in a possible confound. Maintaining the same modality between study and test, as was the case for half the test items in each of the two experiments, is thought to engender greater priming effects than a change of modality between study and test. Due to the possible link between priming and familiarity-driven recognition (see section 1.5.2, Chapter 1), a familiarity account of the left parietal old/new effect could not be excluded unequivocally. However, two further studies of source memory (Wilding & Rugg, 1996) provided further support for the link between recollection and the left parietal old/new effect.

3.3. The Right Frontal Old/New Effect

Like the original studies, Wilding and Rugg (1996) used a source memory paradigm, but this different types of items were used to avoid possible confounds related to priming. At study subjects were presented with items spoken in either a male or a female voice. At test, subjects were presented visually with the words from the study phase intermixed with new words. For each item they were required to make an initial old/new judgement, followed by a source (voice) judgement for those items classified as old.

As expected, ERPs over left parietal electrode sites show an enhanced positivity for old items correctly assigned to source (hit/hit items) in comparison to items incorrectly assigned to the study context (hit/miss) and new items. The larger magnitude of the old/new effect for items correctly assigned to source clearly connects this component to recollection. However, in this study a second, topographically and temporally distinct ERP effect was found. This effect was maximal over frontal sites and, late in the recording epoch, showed the opposite asymmetry to the left parietal old/new effect, being largest over the right hemisphere. This frontal effect appeared to onset around the same time as the left-parietal old/new effect, but unlike the parietal effect it showed no sign of abating by the end of the recording epoch.

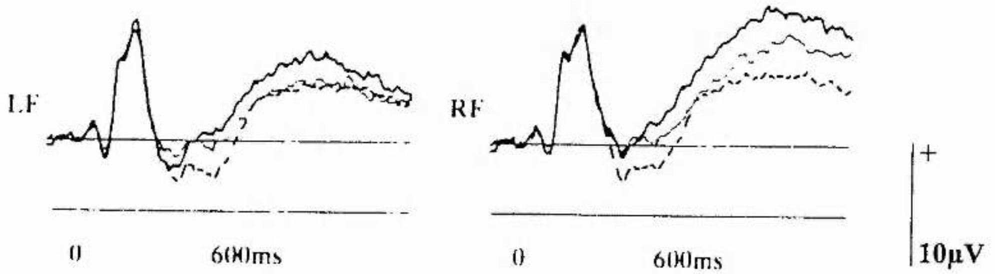


Figure 3.2: The 'right frontal ERP old/new effect'. ERPs are shown at lateral frontal and parietal sites. The solid line depicts ERPs elicited by correctly recognised old items, correctly assigned to their study context (*Hit-Hit*). The thin solid line depicts ERPs for correctly recognised old items not assigned to their study context (*Hit-Miss*). The dashed line depicts ERPs to *correct rejections*. Data from Wilding, 1995, unpublished doctoral thesis. Reproduced with the kind permission of the author.

The longer recording epoch (1434ms in comparison to 904 ms in Wilding et al., 1995), and the larger number of recording sites (19 vs. 13) used in these studies enabled Wilding and Rugg (1996) to show that the two effects were dissociable, not only in their time course, but also in terms of their scalp distribution. These results suggest that the two effects are generated by different neural substrates.

As can be seen from Figure 3.2, the magnitude of both effects is larger for items associated with correct source judgements than for items associated with incorrect source judgements. Thus, as in the earlier studies, the difference between the two response categories was of a quantitative rather than a qualitative nature. Wilding and Rugg (1996) argued that these results support those from the earlier studies (Wilding et al., 1995) in suggesting that successful recognition memory engages the same processes, regardless of whether contextual information about prior study episodes is retrieved and that recognition accompanied by incorrect source judgements is the result of partial or weak recollection.

As in their earlier study, Wilding and Rugg (1996) argued that the lack of qualitative differences between ERPs associated with and without recollection provides no support for dual process models of recognition memory. If it is assumed that different neural generators mediate the two proposed processes, then the findings by Wilding and Rugg present a considerable problem for the model. It could be argued that the absence of a qualitative difference between successful and unsuccessful retrieval of source suggests that the familiarity process is nothing more than weak or partial recollection, which results in item but not context information becoming available. However, caution is necessary in drawing these conclusions. As was discussed in Chapter 2, the ERP method only detects a fraction of the total neural activity occurring within the brain. Thus, the absence of an ERP correlate of familiarity that is topographically different from that of recollection is by no means conclusive evidence that it does not exist. The absence of such a correlate may simply be due to the fact that it is not detectable at the scalp.

3.4. Functional Accounts of the Old/New Effects

The interpretation of the parietal and frontal old/new effects given by Wilding and Rugg (1996) drew upon the working-with-memory framework proposed by Moscovitch and colleagues (Moscovitch, 1992,1994,1995; Moscovitch & Umilta, 1991; see Chapter 1). The model proposes 'dedicated memory modules', which process information without any interpretation, and 'central working-with-memory' structures, which operate on the outcome of the dedicated memory modules. Wilding and Rugg argued that, consistent with previous proposals (Paller & Kutas, 1992; Paller, Kutas & McIsaac, 1995; Smith, 1993; Smith & Halgren, 1989), the left parietal old/new effect is the neural correlate of successful retrieval of episodic information. The strongest basis for this interpretation comes from the fact that the effect is larger for items correctly assigned to source than those incorrectly attributed to source, as correct retrieval of source information is a defining feature of episodic retrieval (i.e. recollection). They further argued that the quantitative difference in the magnitude of the parietal effect between items correctly and incorrectly attributed to source suggests that recollection is graded and/or sensitive to the quality and amount of information retrieved. The latter option is the one more consistent with dual-process theories of recognition memory, which model recollection as an all-or-none process (e.g., Yonelinas & Jacoby, 1995). Whilst graded recollection contradicts the model, a difference in quality and quantity of information which either is or is not sufficient to make the required source judgement can be accommodated by the dual-process model.

At the neuroantomical level Wilding and Rugg (1996) suggested that the left parietal old/new effect reflects processes dependent on the medial temporal lobe memory system, which is thought to be responsible for retrieval from declarative memory and for supporting simple judgements of prior occurrence (see Chapter 1). This interpretation receives support from a study with intracranially recorded ERPs that showed components generated within medial temporal lobe structures that are sensitive to item repetition in recognition memory tests (Heit, Smith & Halgren, 1990; Smith, Stapleton & Halgren, 1989). However, as scalp electrodes appear to be largely insensitive to ERP activity generated locally within the hippocampus and adjacent structures (see Chapter 2, section 2.2), Wilding and Rugg suggested that the parietal old/new effect is the electrophysiological correlate of the interaction between the medial temporal lobe memory system and the cortical regions, reactivated during retrieval. Thus, while the parietal old/new effect may be an index of memory processes subserved by structures of the medial temporal lobe, the effect is most likely to be generated elsewhere, possibly in cortical regions responsive to the input from the medial temporal lobe (McClelland et al., 1995).

Like the parietal old/new effect, Wilding and Rugg (1996) proposed that the right frontal old/new effect is associated with recollection. The fact that this effect was absent in previous studies of recognition memory was taken to suggest that the effect was not linked to the actual retrieval of information, but was mediated by the differing demands that source memory judgements require. They suggested a connection between the function of the right frontal ERP old/new effect and the function suggested to underlie recognition memory with contextual retrieval (Moscovitch, 1992, 1994; Squire, 1994). More specifically Wilding and Rugg suggested that whilst the left parietal effect is an index of retrieval from declarative memory supporting simple recognition judgements, the frontal old/new effect indexes a function which operates on the products of this retrieval process and is necessary for the recovery of contextual information. Thus, Wilding and Rugg (1996) associated the right frontal effect with the operation of 'working-with-memory' processes (Moscovitch 1992, 1994), thought to be strategic and under voluntary control. Specifically, Wilding and Rugg suggested that the frontal old/new effect reflected the integration of disparate retrieved information into a coherent explicit representation of the previous study episode. Consequently, the processing reflected by the frontal old/new effect was not seen as an obligatory consequence of recollection, rather it is assumed that the processes will only be engaged when there is a specific task requirement to discriminate the source of recollected information.

A study by Senkfor and Van Petten (1998) directly compared ERPs elicited by an item recognition task with those elicited by a source task in a within subject design. Like Wilding and Rugg (1996) they found a left parietal effect in both tasks, but a late onsetting right frontal effect only in the source memory task (see also Johnson, Kounios & Nolde, 1996 for similar results). Supporting the earlier suggestion made by Wilding and Rugg (1996) they argued that the right frontal effect is the outcome of the specific retrieval requirements associated with source judgements. Contrary to Wilding and Rugg (1996), however, Senkfor and van Petten (1998) did not find any magnitude differences between items correctly and incorrectly assigned to source over frontal sites (though they did find the same magnitude difference as Wilding and Rugg over temporal sites). This result led them to suggest that the right frontal ERP old/new effect is the signature of retrieval effort rather than post-retrieval processes, as suggested by Wilding and Rugg (1996) (also see section 1.3.4, Chapter 1 for a discussion of the functional significance of right prefrontal activation in functional anatomical studies of memory retrieval). However, this suggestion seems rather debatable in the light of the rather late onset (concurrent with the left parietal effect) and the long duration of this effect. If the effect was indeed a correlate of retrieval effort one could expect the effect to onset earlier than the 'on-line' retrieval signature provided by the left-parietal effect.

To exclude an explanation of the effect in terms of the two-stage response strategy required by the source task used in their work and in the Wilding and Rugg (1996) study, Senkfor and Van Petten (1998) conducted a second experiment. In this study subjects were again given an item recognition task and a source task in which they had to discriminate the gender of the voice items were spoken in at study. However, the reponse requirements for the source task were slightly altered. Instead of an initial old/new judgement followed by a source judgement, subjects only had to make one response. They were required to indicate whether it was the same or a different voice the item had been spoken in at study, or whether the item was new. Thus subjects only had to make one button press in response to each item in both the item recognition and the source memory task. In spite of the alteration of the response requirements, the right frontal old/new effect was present, thus excluding an explanation in terms of a two-stage response strategy. In this study too few source errors were committed to allow analysis of the incorrectly assigned items. Thus the lack of a magnitude difference between items correctly and incorrectly assigned to source could not be replicated.

The results of Senkfor and Van Petten's (1998) second experiment were supported by a study conducted by Wilding and Rugg (1997a). In their study they recorded ERPs in a memory 'exclusion task' first introduced by Jacoby and colleagues in connection with the Process Dissociation Procedure (Jacoby 1991). The study phase of this experiment was the same as in previous experiments; subjects heard words in either a male or a female voice. At test, rather than a two-stage response, only one response was required. Subjects were instructed to respond to an item as 'old' only when it had been presented in one of the two voices at study. Items spoken in the other voice, or genuinely new items, were responded to as 'new'. Correctly recognised old items were thus separated into 'targets' and 'non-targets', categories for which different responses had to be made. Critically, as in previous source memory studies, subjects in the exclusion task had to discriminate the gender of the speaker's voice at study in order to correctly exclude non-targets. Consequently, as source information had to be retrieved for both categories of old items, ERPs were expected to show left parietal and right frontal old/ new effects for both categories of old items. As expected, both categories exhibited reliable left parietal old/new effects. However, only ERPs to target items also showed a right frontal old/new effect. Although the voice for the non-target items was correctly discriminated, ERPs for this category did not exhibit a right frontal effect. Thus, as in the Senkfor and Van Petten (1998) study, a right frontal effect was exhibited after a single response. More importantly, however, the results suggested that the processes reflected by the right frontal effect are not necessary for the accurate discrimination of source information and that the retrieval of source information is not sufficient to elicit the frontal old/new effect. This finding argues against the functional interpretation of the effect given above, linking it to post-retrieval processes which act to integrate and maintain a representation of the study episode. In light of this, Wilding and Rugg (1997a) proposed that the frontal old/new effect, while contingent upon successful retrieval of source, reflected more strategic, or task-dependent aspects of processing.

Further difficulties for the interpretation of the right frontal ERP old/new effect arose when the effect was observed under conditions where there is no overt task requirement to make source discrimination. Donaldson and Rugg (1998) investigated associative recognition in a study in which subjects were first presented with word pairs, and then at test were asked to discriminate old from new word-pairs. In experiment 1 only, the old/new judgement was followed by a second judgement. This required subjects to decide whether recognised old pairs had been initially presented with one another (same pair) or in a different pairing (rearranged pair). In experiment 2 subjects were only required to make an old/new judgement without any additional pair discrimination. In both studies a left parietal old/new effect was observed for correctly recognised same and rearranged pairs relative to correctly rejected new pairs. This effect was larger for same than rearranged pairs in each study. However, only same pairs were associated with a right frontal old/new effect, also in both studies. Thus, the right frontal old/new effect occurred irrespective of whether subjects were asked to make the judgement on the pairing of the item, and it only occurred for same pairs, though rearranged pairs were correctly recognised and correctly endorsed as such.

The data suggest that the right frontal old/new effect is not under voluntary control and that it does not specifically reflect strategic or task-dependent aspects of processing (Wilding & Rugg, 1996, 1997a). Support for this notion comes from two studies. Wilding and Rugg's (1997a) exclusion data show that the effect is not present when correct source discrimination occurs, thus the specific task requirement of source discrimination is not sufficient to elicit the effect. Donaldson and Rugg's (1998) data suggest that a task does not even have to require a source discrimination in order to elicit the effect, thus indicating that the specific task demands of source discrimination are also not necessary. The effect may therefore reflect processes acting to integrate and maintain a representation of the study episode, but this process is not specifically engaged by tasks requiring the use of this representation to guide behaviour.

3.5. The Early Left/Bilateral Frontal Component – A Third Old/New Effect?

In the first of the experiments conducted by Donaldson and Rugg (1998) the late right frontal effect was preceded by an earlier component. This early effect onset around the same time as the left parietal effect and showed a bilateral distribution. A similar effect had been observed by Wilding and Rugg (1997b) in a study of source memory. In this study subjects were visually presented with words which they had to read out loud and words presented auditorily. At test, they were required to make an initial old/new judgement to items presented visually; for those items judged old they further had to indicate if they had been spoken or heard at study. Like Donaldson and Rugg (1998), Wilding and Rugg (1997b) observed two frontal components. Not only were these components differentiated due to their time course and scalp distribution, the earlier bilateral component also dissociated between items for which modality changed between study and test and those which were presented in the same modality. The effect was smaller for those items correctly recognised and correctly assigned to source which had been presented in different modalities at study and test than for those which had been presented in the same modality. No such differentiation was observed for the later right-sided component. This finding suggests that the two effects have at least partially non-overlapping neural generators and hence are functionally dissociable.

This conclusion found support in the results of a study by Tendolkar, Doyle and Rugg (1997). In their study they used an associative recall paradigm to study the effects of retroactive interference. Subjects studied two lists of word pairs in which the same cue words were paired with two different items. At test they were required to judge whether a test item had been presented before and if yes, which word it had been associated with in the first (retroactive interference condition) or the second (proactive interference condition) of the study lists. The control condition was a mere repetition condition for which no associate could be retrieved. For these items there was a 'don't know' option for the second response. ERPs did not differentiate between the three types of repeated items. Accordingly, as expected, ERPs to all recognised items showed a left parietal effect. Unexpectedly, however, they also elicited an early, slightly left lateralised frontal effect, which onset around 100 ms earlier than the left parietal effect. This effect is most probably equivalent to the effects found in the studies by Donaldson and Rugg (1998) and Wilding and Rugg (1997b), both of which did not analyse for the possibility of an earlier onset of the frontal than the parietal effect. Interestingly, in the Tendolkar et al. (1997) study the early frontal effect was not followed by a later right lateralised effect, thus indicating that the effects are indeed functionally dissociable.

All three studies discussed above required the retrieval of contextual information and used a two-stage response task. This suggests that the effect could be the result of these specific response requirements. However, a study by Rugg, Mark, Walla, Schloerscheidt, Birch and Allan (1998) refuted this possibility. In their study subjects made a simple old/new recognition decision to items previously studied in either a deep or a shallow task. As expected results showed a left lateralised parietal effect, which was significant only for those items studied under semantic conditions. In addition they found an early bilateral frontal effect which, interestingly, did not differentiate between items studied in the two conditions. Rugg et al. (1998) suggested that the effect may reflect familiarity-driven processing which is thought to be insensitive to encoding manipulations like levels of processing (Gardiner & Java, 1993; Jacoby & Dallas, 1981; but see Jacoby, 1996; Toth, 1996). These findings confirm that the early left/bilateral frontal effect is functionally dissociable from the later right lateralised effect first described by Wilding and Rugg, (1996). They also indicate that the requirement to retrieve contextual information is not a necessary condition for the emergence of the effect. The results suggested a connection of the early left/bilateral effect with familiarity-driven recognition processes. This suggestion, as well as the boundary conditions under which the effect emerges, await further investigation.

3.6. Summary and Conclusions

The studies reviewed in this chapter provide the context for the research presented in this thesis. The review has explored a variety of ways in which ERPs have been used to investigate explicit memory. During the time the reviewed research was conducted methodology has continuously improved. On the ERP side, longer recording epochs and the employment of larger numbers of electrodes has provided more information about time course and scalp distribution of the effects. Methodologically, the use of testable operational definitions of recollection has allowed stronger conclusions to be drawn about the functional significance of the effects.

Three main ERP correlates of explicit memory, differing in time course and scalp distribution, have been identified: (i) a left parietal effect, which indexes recollection and supports the ability to make simple old/new judgements concerning the prior occurrence of items in a memory test and (ii) a late right frontal effect, which indexes post-retrieval processes operating on retrieved information, (iii) an early left/bilateral frontal effect, which has tentatively been associated with familiarity-driven retrieval processes. This indicates that multiple processes, with at least partially non-overlapping neural generators, are involved in explicit memory. As a means of distinguishing between the different effects an important functional distinction has been raised between processes supporting explicit retrieval per se, and distinct post-retrieval processes. This distinction is based on the notion of separate memory systems contributing to retrieval as such and the strategic use of the retrieved information as described in chapter 1.

The research presented in this thesis follows from the work reviewed in this chapter. It is aimed at investigating the generality of the ERP effects of explicit memory for different stimulus materials, namely names and pictures of common objects. Before introducing the general questions and the first experiment in Chapter 5, Chapter 4 will provide an overview over the general methods used in the experimental work presented in this thesis.

CHAPTER 4

General Methods

The following section provides an overview of the experimental procedures common to each of the studies reported in this thesis. The method section for each individual experiment details the procedures that are specific to each study. The common elements of all studies were the selection criteria for the subjects, the preparation of picture stimuli, stimulus presentation parameters, methods of ERP recording and methods of analyses. Each of these will be detailed in turn in the following sections.

4.1. Subjects

Experimental subjects were recruited from the undergraduate and post-graduate population of the University of St. Andrews. All subjects were native English speakers, had normal or corrected-to normal vision, and were right-handed. They ranged in age from 17 – 36 years and were remunerated at £3.50/hour for participation in experiment 1 and £5/hour for participation in experiments 2 and 3.

4.2. Experimental Stimulus Materials

The picture stimuli used in each experiment were of common objects such as a spoon, a knife, a telephone, a glove. The stimuli were prepared by taking photographs of these objects and digitising them using an EPSON GT-6500 scanner. The software used for acquisition was ADOBE Photoshop 3.0 which allowed the preparation of the stimuli in a way that roughly equated size and luminance (for examples see end of this chapter). A pool of 180 stimuli was created in this way, 123 of which were used for experiment 1, and a slightly different selection of 126 for experiments 2 and 3. When presented on the monitor, each picture had a maximum size of 6x6 cm, equivalent to a vertical and horizontal visual angle of 3 degrees at approximately 1m viewing distance, and was presented in central vision on a computer monitor against a grey background. The procedures used to create and display item lists are detailed in the method section for each experiment.

In order to create the pools of word stimuli for each of the experiments, pictures were shown to 5 native English speakers who were asked to name each picture in turn. Pictures for which less than 4 native speakers agreed on the name were not included in the experiments. In each experiment the words were displayed in central vision, in black upper case letters, on a computer monitor with a grey background. In Experiment 1, words subtended a vertical visual angle of 0.6 degrees and a maximum horizontal angle of 1.8 degrees. In Experiments 2 and 3, words subtended a vertical angle of 0.8 degrees and a maximum horizontal angle of 2 degrees. The procedures used to create and display the word lists are detailed in the method section for each experiment.

4.3. ERP-Recording

Scalp EEG was recorded with respect to the left mastoid from 25 tin electrodes embedded in an elasticated cap. The recording montage was based on the International 10-20 system (Jaspers, 1958). EEG was recorded from the following sites: the midline sites were Fz, Cz, and Pz, left and right hemisphere sites were Fp1/Fp2, F3/F4, F7/F8, LF/RF (frontal, 75% of the distance between Fz and F7/F8), C3/C4, T3/T4, LT/RT (anterior temporal, 75% of the distance between Cz and T3/T4), P3/P4, T5/T6, LP/RP (parietal, 75% of the distance between Pz and T5/T6) and O1/O2. The full montage is depicted in Figure 4.1 An additional channel recorded EEG from the right mastoid bone, allowing scalp recordings to be re-referenced off-line to represent recordings with respect to linked mastoids. EOG was recorded bipolarly from electrodes positioned above the supra-orbital ridge of the right eye, and adjacent to the outer canthus of the left eye. Inter electrode impedance levels were kept below 5 KΩ and EEG and EOG were amplified with a bandwidth of 0.03 – 35Hz (3dB points). Signals were sampled for 1536 ms at a rate of 6 ms per point (digitised at 12 bit resolution) beginning 102 ms prior to stimulus onset.

Prior to electrode placement, the skin underlying each electrode site was lightly abraded. Following electrode placement, conducting gel was injected in the well of each electrode. This procedure reduced the level of impedance between electrode pairs, thereby attenuating the induction of environmental electromagnetic artefact.

The hard disk of an IBM PC compatible computer was used to store EEG data on-line. Analysis of the data was conducted off-line following each recording session. In order to reduce the possibility of waveform contamination from extra-cerebral artefact, individual trials were excluded from the averaging process if any of the following criteria were violated: (i) peak EOG activity exceeding +/- 98 μV; (ii) drift from baseline exceeding 44 μV (computed as the difference between the first and last data point of each waveform), and (c) saturation of the A/D converter. To obtain satisfactory signal-to-noise ratio, a minimum of 16 artefact-free trials per experimental condition was required. If a subject did not contribute a sufficient number of trials to any of the experimental conditions of interest, he/she was excluded from the analyses. All ERP analyses were performed on averaged data that had undergone a smoothing procedure using a 5-point binomial filter.

4.4. Analyses of ERP-Data

The main analyses of data from all experiments were performed on the mean amplitudes of 4 consecutive latency regions: 300–600, 600–900, 900–1200, 1200–1400 ms post-stimulus, measured with respect to the pre-stimulus baseline. These latency regions were chosen on the basis of initial exploratory Analysis of Variance (ANOVA) of data from lateral and midline sites over successive 100 ms latency regions, starting at 100–200 ms, for Experiment 1. These comparisons revealed a consistent pattern of results from 300 ms post-stimulus onwards, in that ERPs to correctly recognised items were more positive than those elicited by new items. The same latency regions were chosen for the subsequent experiments in order to keep the results comparable.

All analyses were conducted with repeated measures ANOVA. Three different sets of analyses were performed on the data collected in each experiment:

1. Analyses of mean amplitudes measurements

These analyses were performed on the mean amplitudes of the chosen latency regions. The purpose of the analyses was to establish the presence of old/new effects (i.e., differences between the ERPs elicited by correctly recognised and new items). To this end, a global ANOVA was performed on the standard montage of all 25 electrodes, employing the factors of response category and electrode site. These analyses were followed up with planned comparisons on a selection of anterior and posterior sites, based on the hypotheses described in Chapter 5. Only those results involving the factor of response category are reported in the respective tables.

In the analyses of mean amplitude, each electrode site was regarded as a separate observation. One disadvantage of this approach concerns the possible violation of the 'sphericity' assumption underlying the repeated measures ANOVA. This assumption requires that the covariance between each pair of measurements within the set of repeated measures is approximately equivalent. Used in conjunction with mean amplitude measurements of ERPs, it is likely that the sphericity assumption is strongly violated, because the covariance of measurements derived from electrodes which are spatially close is likely to be greater than is the covariance of measurements derived from electrodes which are spatially more distant. In the data analysed here, the inhomogeneity of co-variance was compensated for by using the Geisser-Greenhouse correction (Winer, 1971), a procedure which adjusts the degrees of freedom of the relevant F-ratio by a measure of the degree to which the co-variance assumptions underlying the repeated measures ANOVA are not met. All ANOVAs are reported with the corrected degrees of freedom.

2. Analyses of subtracted mean amplitude measurements – Magnitude analyses

These analyses were performed on the mean amplitude of the 'subtraction' or 'difference' waveforms for each condition. Subtraction waveforms were produced for each subject by subtracting, point-by-point, the mean amplitude of the waveforms elicited by new items from the mean amplitude of the waveform elicited for correctly recognised items. Subtraction waveforms represent the magnitude of the ERP old/new effect directly and therefore allow the comparison of the magnitude of this effect across different experimental conditions, even when there are differences in the gross morphology of the waveforms elicited in these conditions. As before, a global ANOVA was performed on all 25 electrode sites which was followed up with planned comparisons on a selection of anterior and posterior electrode sites.

3. Analyses of rescaled subtracted mean amplitude measures - Topographic analyses

Analysis of variance was also used to contrast the distribution of ERP effects across the scalp in the different experimental conditions. These topographical analyses were performed on subtraction waveforms which were rescaled according to the procedure recommended by McCarthy and Wood (1985). Rescaling of raw ERP data is necessary for this kind of analysis because analysis of variance assumes that changes in amplitude represent additive effects of underlying factors. For ERP data this assumption is violated since changes in the strength of a generator have multiplicative effects. This breach of the basic assumptions of the ANOVA means that interactions between experimental conditions and electrode site can arise as a function of a difference in strength rather than location of the underlying generator(s). To address this problem, McCarthy and Wood (1985) proposed a rescaling method which calculates the size of the ERP effect in each condition at each electrode site relative to the size of the effect at all other sites. As a results, the pattern of relative differences in effect size across the scalp is maintained while removing differences due to amplitude. This in turn allows the interactions between experimental condition and electrode site to be ascribed to differences in the identity of the underlying generators.

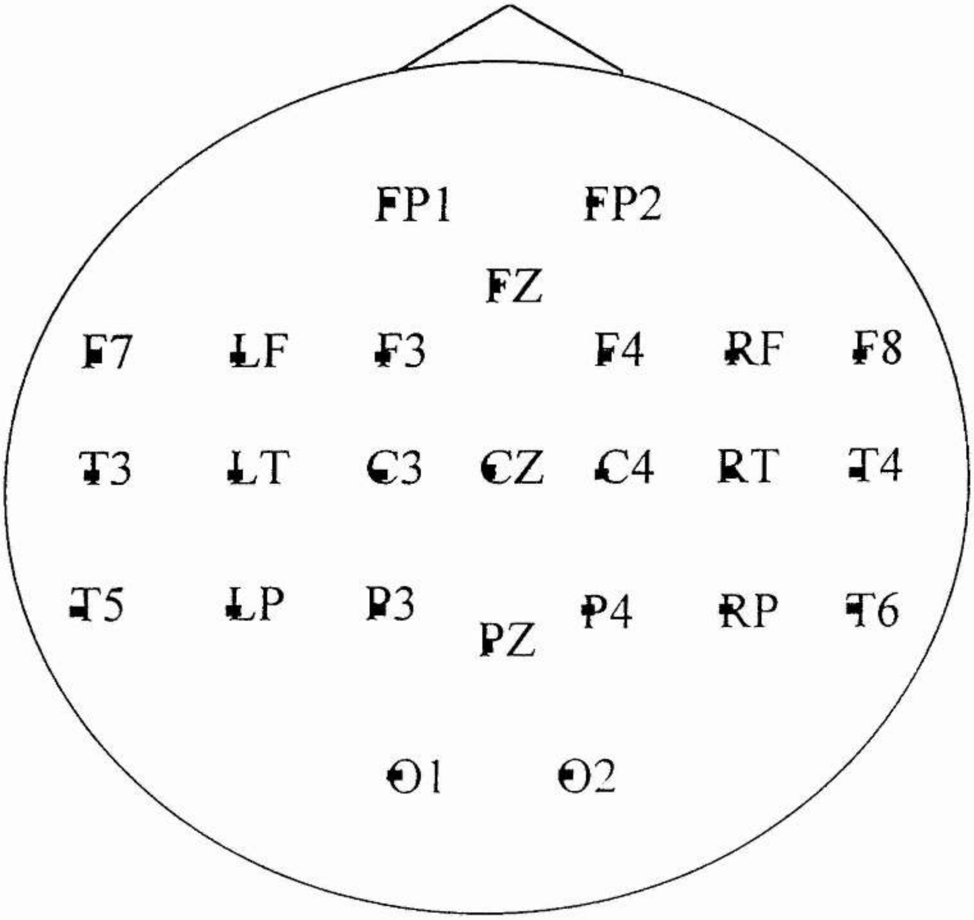
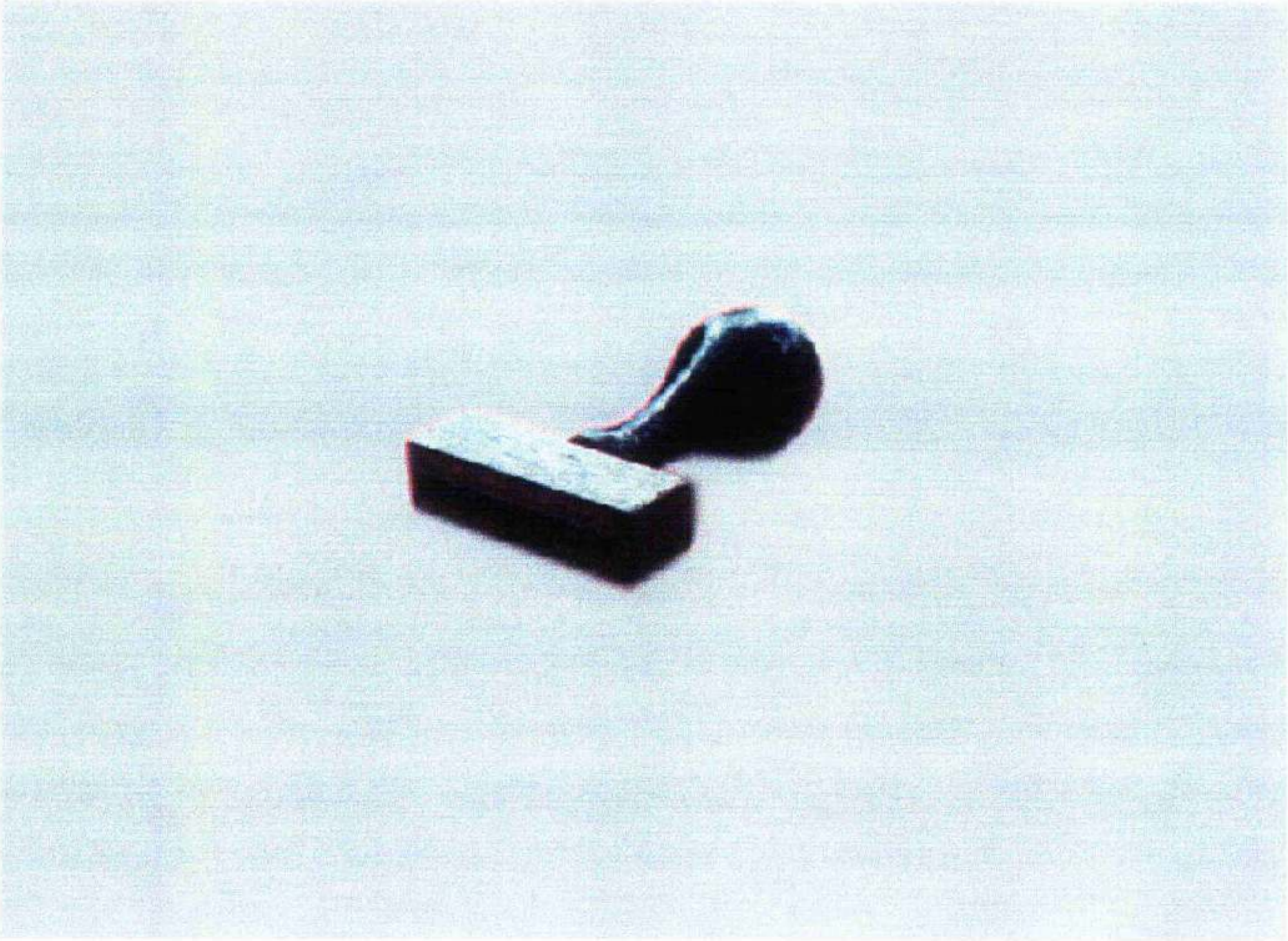
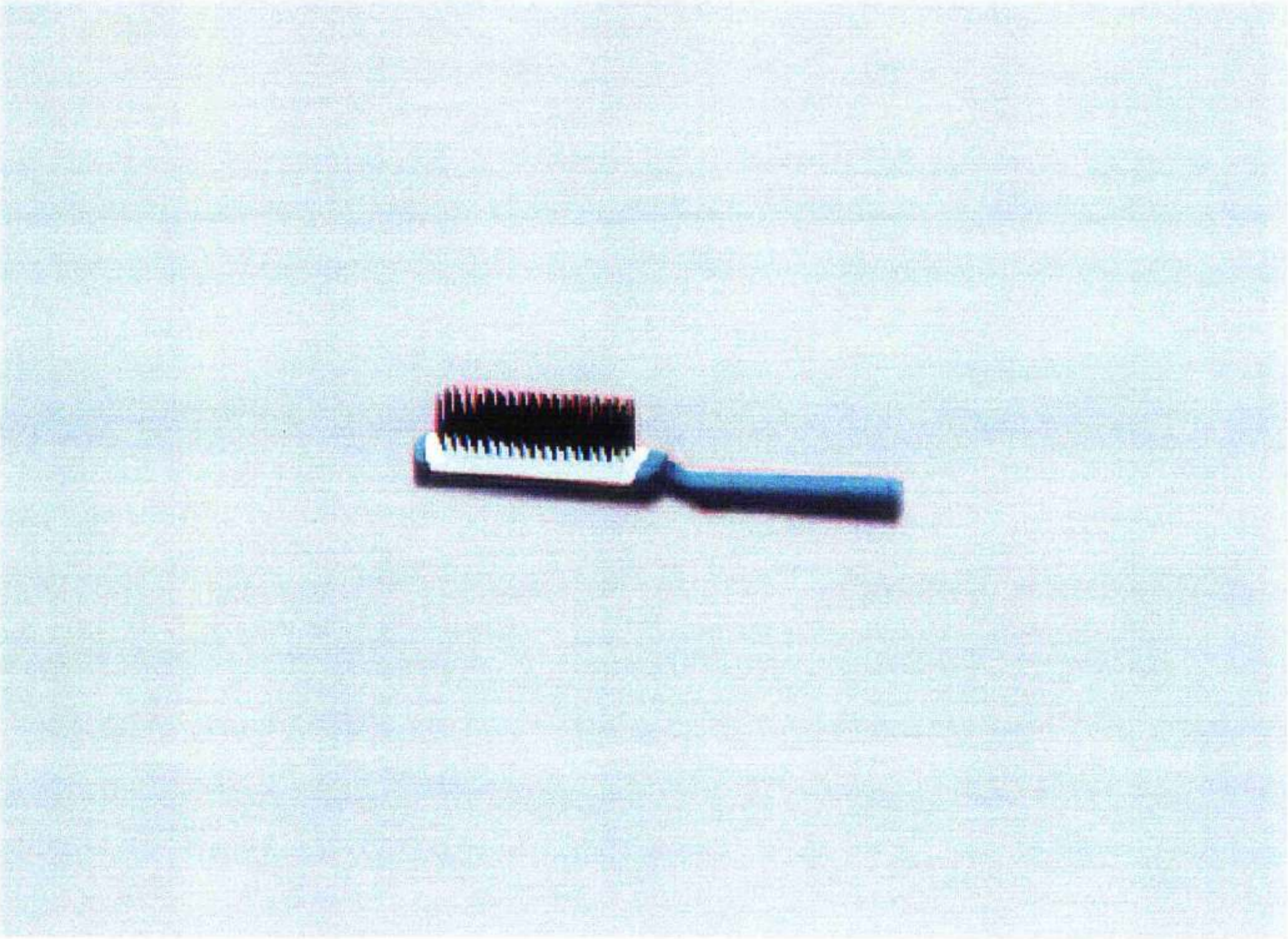


Figure 4.1: Locations on the scalp of the electrode montage used in the present studies. The montage consists of 25 electrode sites which are positioned at Fp1, Fp2, Fz, Cz, Pz and the following homologous left and right hemisphere sites: F7/F8, LF/RF (frontal, 75% of the distance from Fz to F7/F8), F3/F4, T3/T4, LT/RT (anterior temporal, 75% of the distance from Cz to T3/T4), C3/C4, T5,T6, LP/RP (lateral parietal, 75% of the distance from Pz to T5/T6), P3/P4, O1 and)2.





CHAPTER 5

Experiment 1

5.1. Introduction

So far, ERP studies investigating the temporal and functional characteristics of long-term memory have predominantly used verbal material, presented either in visual or auditory form. Only a small number of studies have used pictorial or facial stimuli. When undetaken, such studies have typically investigated the possibility of differential semantic processing of pictures and words (Barret & Rugg, 1990 a, b; Barrett, Rugg & Perrett, 1988; Noldy, Stelmack & Campbell, 1990; Simos & Molfese, 1991, but see below). Given this state of affairs, it is interesting to establish whether the neural correlates of explicit memory retrieval, as indexed by the left parietal, the left/bilateral early frontal and the late right frontal ERP old/new effect, are modality-dependent. More specifically, do the ERP effects vary according to the nature of the information that is retrieved? This question is especially interesting and important in light of the current models of long-term memory retrieval described in Chapter 1 (Damasio, 1989; Eichenbaum, Schoenbaum, Young & Bunsey, 1996; McClelland et al., 1995). To recap briefly, according to these models declarative memories are retrieved by virtue of the hipocampally-driven reinstatement of the cortical activity that represented the episode when it was first experienced. By this argument, if two items are encoded by virtue of distinct encoding operations involving non-overlapping neural substrates, retrieval of these two episodes, as reflected by ERPs, might also differ. Additionally, any differences, or the lack thereof, would hopefully elucidate further the functional significance of the two frontal components.

There is a small number of studies (Berman, Friedman & Cramer, 1991; Muente, Brack, Groother, Wieringa, Matzke & Johannes, 1997) that have compared ERP correlates of recognition memory for words and pictures directly. In a continuous recognition memory study Berman et al. (1991) compared ERP memory effects for different repetition lags for the two stimulus types. Behaviourally, they observed a decrement in recognition performance with increase in lag for words, but not for pictures, consistent with the picture superiority effect. For the ERP waveforms, they observed an increased positivity for correctly recognised old items in comparison to new items, onsetting around 250 ms post-stimulus for both types of stimulus. The authors showed that two different components contributed to this effect, an early one, with a peak amplitude around 450 ms post-stimulus, and a late positive component, peaking around 580 ms post-stimulus. The late component showed maximum amplitude over posterior recording sites and is most probably analogous to the left parietal old/new effect discussed in chapter 3. The early and late components differed in scalp topography and, furthermore, only the early component was influenced by stimulus type and repetition lag. Unfortunately no analyses were performed to investigate whether the magnitude and scalp topography of the late positive component interacted with stimulus type. Similarly, the study by Muente et al. (1997) compared the ERP effect to unfamiliar faces in a continuous recognition task and an indirect memory task (detection of famous faces/detection of nonwords) with those for concrete nouns. In the continuous recognition memory task, both words and faces elicited an ERP old/new effect which was largest over right parietal sites. Comparison of the subtraction waveforms for both types of stimulus did not reveal any differences in magnitude or topography.

Given statistical shortcomings and the restricted number of electrode sites (6) in the Berman et al. (1991) study, and the unusual finding of a right parietal old/new effect for words in the study by Muente et al. (1997), the question remains whether the ERP memory effects reviewed in Chapter 3 are material specific. The present study addressed this issue by comparing the neural correlates of picture and word retrieval, as indexed by ERP effects, directly.

As discussed in Chapter 1 (section 1.6.3.1.) evidence is accumulating that, as far as processing in the medial temporal lobe memory system is concerned, picture encoding and retrieval are mediated bilaterally. Taking into account that the left parietal old/new effect observed in studies using verbal material is thought to reflect processes mediated by the medial temporal lobe memory system, the tentative prediction for the present ERP study could be that the temporo-parietal old/new effect that is lateralised to the left for the retrieval of words may be bilateral for the retrieval of pictorial stimuli. No prediction can be made about the frontal effects, as their functional significance is still unclear. Other differences in ERP effects may also emerge. It has to be kept in mind, however, that the absence of effects cannot be taken as evidence that there are no differences in memory representation and retrieval for pictures and words. The presence of effects could, however, elucidate differences in the temporal dynamics of retrieval of pictures and words and would possibly also allow tentative conclusions concerning possible differences in the location of the representational systems of these two types of stimuli.

5.2. Method

5.2.1. Subjects

Subjects were 25 students from St. Andrews University (mean age 21.3 years, ranging from 18–25 years). The data from 5 subjects were rejected due to noise in the signal. The data from 2 subjects were rejected because task performance was too poor to permit the formation of ERPs from an acceptable number of trials, and the data from two further subjects could not be included due to excessive eye artefacts. Of the remaining 16 subjects who contributed to the study, 9 were female. All subjects were right-handed (as defined by writing-hand) and gave written consent prior to participating in the study.

5.2.2. Experimental Materials

Stimuli consisted of 123 digitised colour photographs (see Chapter 4) and 123 object names. These names were matched in frequency to the names of the objects depicted in the pictures (for naming of pictures see Chapter 4) by selecting concrete nouns of the same frequencies from the Francis and Kucera (1982) corpus. The selected words (names) ranged in length from 3-9 letters and in frequency from 0-300 occurrences per million. Picture names which could not be found in the Francis and Kucera (1982) corpus were assumed to have a frequency of 0 and a matching concrete noun with a frequency between 0 and 10 occurrences per million was selected. Consequently, the mean occurrence rate of 41 occurrences per million for the words was slightly higher than that of the picture names with 31 occurrences per million. A full listing of all picture names and word labels used can be found in Appendix A.

The 120 critical items of each stimulus type (words + pictures) were randomly divided into 2 lists of 60 items. The remaining 3 items were used as fillers. Each of these lists served as a study list. Test lists were created by combining the two study lists of each item type and including a further four unstudied filler items. Two versions of each test list were formed, differing only in the serial order of the items. Thus, there were two test lists per study list, containing the same old and new items in different positions. Each test list began with three filler items.

5.2.3. Procedure

Each subject was presented with two study-test blocks, one block using pictures for study and test, the other one using words in both phases. Half of the subjects saw the pictures first, and half initially saw the words. Study and test lists were administered such that each item was employed equally often as an old and new item, and appeared in two different serial positions.

Before the start of the experiment, the subjects were fitted with an ERP recording cap as described in Chapter 4. It was then explained that they were taking part in a memory experiment that consisted of two study-test blocks. They were asked not to use any strategies to enhance their memory performance, but to concentrate on the study task. The task was to imagine the actual size of the depicted object or the object referenced by its name, and to state if it would be larger or smaller than the computer screen. The stimulus remained on the computer screen until the subject made a response, after which the experimenter clicked a computer mouse to display the next item.

The test task followed the study phase after an interval of approximately 5 minutes, during which time the subject had to count backwards in 3s from a random number. Each trial started with the display of two square brackets (i.e., [ ]) for 2000 ms. These brackets were located so as to encompass the outer edges of the largest possible stimulus of the list. Thus, for pictures the brackets were approximately 6 cm apart, for words approximately 3.5 cm. This display was followed by a fixation cross (+) for 500 ms. The fixation cross extended vertically to the same degree as the words or pictures by which it was followed. There then followed a 172ms blank period following which the test item was presented for a duration of 500 ms.

Subjects were required to judge whether each test item was old (presented in the study task) or new. They were instructed to respond as quickly and accurately as possible by pressing one of two microswitch keys with the index finger of one or the other hand. The assignment of hands to the two response keys was counterbalanced across subjects. They were asked to remain relaxed throughout each recording, to maintain fixation, and to blink only when the brackets were present on the monitor.

ERPs were formed for 3 critical response categories: correctly classified new items (*correct rejections*); correctly recognised pictures (*picture hits*); and correctly recognised words (*word hits*).

5.3. Results

5.3.1. Behavioural Results

Mean (s.d. in parentheses) hit and false alarm rates for pictures were 90.3% (6.6%) and 8.7% (5.9%) respectively, those for words were 87.5% (8.6%) and 9.3% (10.5%) respectively. A *t*-test comparing the discrimination index 'P(hit) – P(false alarm)' for the two stimulus types was not significant.

For pictures, mean reaction times (RTs) for hits and correct rejections were 869ms (199ms) and 924ms (197ms) respectively. RTs for words were 978ms (184ms) and 1019 ms (179 ms) respectively. A 2x2 ANOVA, employing the factors of stimulus type and response category, revealed a main effects of stimulus type [$F(1,15) = 14.71$, $p < .01$] and response category [$F(1,15) = 11.18$, $p < .01$]. These effects reflect faster RTs for pictures than for words, and for hits than for correct rejections.

5.3.2. ERPs

Grand average ERP waveforms elicited by hits and correct rejections are illustrated in Figures 5.1 (pictures) and 5.2 (words). The same grand average waveforms are shown for selected lateral frontal and parietal sites in Figure 5.3. For both stimulus types, ERPs elicited by correctly recognised items (hits) show a left temporo-parietal positive-going shift with an onset around 400 ms post-stimulus. An additional, frontally distributed positive shift for the hit category is evident in the ERPs to pictures only. This frontal shift onsets around 250 ms post-stimulus and shows a slight left hemisphere maximum which, over time, shifts to a more right-sided distribution (see also Figure 5.6).

Three sets of analyses were carried out. The first set contrasted the mean amplitudes of the hit and correct rejection ERPs for each stimulus type separately. The mean number of trials for the correct rejection and hit response categories for pictures was 46 in each condition. The mean number of trials for these conditions for words was 44 and 47 respectively. Initially, global ANOVAs were carried out on all 25 sites, employing the factors of response category (hits vs. correct rejections) and electrode site. These comparisons were made in order to establish differences in the ERPs to hits and correct rejections. Where appropriate, they were followed up with subsidiary ANOVAs on a selection of frontal and lateral parietal sites. The selection of these sites was based on the original research question (see introduction) and on the emergence of a widespread frontal ERP effect for pictorial stimuli (see Figure 5.1). The following subsidiary comparisons were carried out when appropriate:

(a) ANOVA on a selection of left and right lateral frontal (LF, RF) and parietal (LP, RP) electrodes, employing the factors of response category (hit vs. correct rejection), location (frontal vs. parietal) and hemisphere (left vs. right).

(b) ANOVA on the lateral parietal (LP, RP) electrodes only, employing the factors of response category (hit vs. correct rejection) and hemisphere (left vs. right).

(c) ANOVA on a selection of frontal sites (F7/8, LF/RF, F3/4), also employing the factors of response category (hit vs. correct rejection) and hemisphere (left vs. right).

The second set of analyses was carried out on the subtracted mean amplitude measurements in order to compare the magnitude of the ERP old/new effects elicited by the two stimulus types. The same analyses were performed as for the non-subtracted mean amplitude measurements. On this occasion, however, the factor of response category was substituted with the factor of stimulus type (pictures vs. words).

The third set of analyses compared the topographic distribution of the ERP old/new effects elicited by the two types of stimuli. These analyses were carried out on the subtracted and rescaled mean amplitude measurements (see Chapter 4). The analyses consisted of a global ANOVA for each latency region, followed up, where appropriate, with a subsidiary ANOVA on a selection of lateral frontal (LF, RF) and parietal (LP, RP) sites. The subsidiary comparisons employed the factors of stimulus type (pictures vs. words), location (frontal vs. parietal) and electrode site.

5.3.2.1. Analyses of the Mean Amplitude Measures

Table 5.1 summarises the results of the ANOVAs performed on the mean amplitude measurements of the ERPs elicited by hits and correct rejections for pictorial and verbal stimuli.

Global ANOVA of the mean amplitude measurements for pictorial stimuli revealed a response category x electrode site interaction in all latency regions but the 900–1200 ms region. Here it revealed a main effect of response category only. This confirmed the presence of a positivity for correctly recognised items over new items. The existence of a left hemisphere lateralisation for parietal sites was confirmed by subsidiary ANOVAs on LP and RP which revealed a response category x hemisphere interaction in the 300–600 ms latency region. The same subsidiary ANOVA of the 600–900 ms latency region revealed a main effect of response category, but no effect was found in the following two latency regions. The existence of a corresponding frontal effect for pictures was confirmed by a main effect of response category emerging from 300–1200 ms post-stimulus from subsidiary ANOVAs on the selection of frontal sites. This main effect was qualified by response category x hemisphere x site interactions in the 300–600 and 600–900 ms latency regions which indicated that the effect was lateralised to the left hemisphere and largest nearest the midline. For the 1200–1400 ms region, ANOVA on the same sites revealed a marginal response category x hemisphere effect. This trend supported the impression from a visual inspection of the data that the frontal effect shifted from a left- to a more right-sided distribution over time (see Figure 5.6). Subsidiary ANOVAs on the lateral frontal and parietal sites revealed only a main effect of response category in the 300–600 and 600–900 ms latency regions, confirming the absence of any differences in the response categories between anterior and posterior sites. No effects emerged in the later latency regions for this subsidiary comparison.

Global ANOVA of the mean amplitude measurements for verbal stimuli revealed reliable interactions between response category and site for the latency regions from 300–1200 ms. These results confirmed the presence of a positive shift for hits over correct rejections. In addition to a main effect of response category, subsidiary analysis on LP and RP in the 600–900 ms latency region gave rise to a marginally significant response category x hemisphere interaction revealing a trend for a left lateralised temporo-parietal old/new effect (but see below: further analyses). ANOVA on the two lateral parietal sites in the 300–600 and 900–1200 ms latency regions revealed a main effect of response category only. This confirmed the continued presence of an old/new effect, which however, does not show any trend towards specific lateralisation. Subsidiary analysis on the selection of lateral frontal and parietal sites resulted in a reliable response category x location interaction for the epochs from 300–1200 ms, indicating that the old/new effect was confined to posterior sites. This result was confirmed by subsidiary analyses on the selection of frontal sites which revealed no effect in any of the epochs apart from 900-1200 ms, when it resulted in a response category x site effect. This effect indicated the existence of a small positivity for hits, which was larger nearest the midline. No significant effects were found for the 1200–1400 ms latency region.

5.3.2.2. Across Stimulus Comparisons

Table 5.2 summarises the results of the global and subsidiary ANOVAs carried out on the subtracted mean amplitudes. These analyses were carried out in order to compare the magnitude of the old/new effects elicited by the two types of stimuli. Figure 5.4 displays the subtraction waveforms for all 25 sites, Figure 5.5 displays the same ERPs for a selection of lateral frontal and parietal sites. As can be seen from those figures, pictures seem to display a slightly larger effect than words over frontal sites. At posterior sites, there does not seem to be a difference in magnitude initially, but towards the end of the recording epoch words seem to display a slightly larger effect.

Global ANOVA revealed a stimulus type x site interaction for the latency regions from 300–1200 ms. This confirmed the existence of magnitude differences between the two stimulus types for these epochs. As expected from the visual inspection of Figures 5.4 and 5.5, subsidiary ANOVAs on the selection of lateral frontal and parietal sites revealed a stimulus type x location interaction for the same three latency regions. In the 300–600 ms latency region, the effect was due to a larger effect for pictures over frontal sites only, whereas for the following two latency regions the analysis confirmed a reversal of the magnitude difference from frontal to parietal sites. Over frontal sites the greater magnitude for the picture old/new effect continued, whereas over parietal sites words elicited the larger old/new effect (see Figure 5.5).

5.3.2.3. Topographic Analyses

Figure 5.6 shows topographic maps of the latency regions from 300-1200 ms. The 1200–1400 ms region is not shown, as no significant old/new effects were found for words in this latency region. As can be seen from these maps, words show a continued effect over left posterior sites, which, in the 900–1200 ms latency region, appears to be accompanied by a slight right-sided parietal effect. Pictures, however, show an initial widespread effect stretching over left frontal and parietal sites, which with time shifts to a right lateralised frontal effect.

Global ANOVAs resulted in a stimulus type x site effect for all three latency regions shown in figure 5.6 [300–600 ms: $F(3.6,54.4) = 3.27$, $p <.05$; 600–900: $F(3.2,47.8) = 2.89$, $p <.05$; 900–1200: $F(3.4,51.2) = 4.79$, $p < .005$]. Subsidiary analyses on the selection of lateral frontal and parietal sites revealed a reliable stimulus type x location interaction in each of these epochs [300–600: F(1,15) = 5.83, $p < .05$; 600–900: F(1,15) = 6.05, $p < .05$; 900–1200: F(1,15) = 10.68, $p < .01$], confirming the apparent differences in distribution evident from Figure 5.6.

5.3.2.4. Further Analyses

The starting point for this experiment was the question whether ERPs to correctly recognised pictures would elicit a more bilateral parietal old/new effect than words. The results of the analyses reported above seem to indicate the opposite (i.e., words showing the more bilaterally distributed ERP old/new effect than pictures). The reason for this might be that the chosen latency regions encompass the peak of the old/new effect for pictures better than they do for words. For this reason, further analyses were carried out on the two parietal sites. ERPs were quantified by measuring the mean amplitude of the 450-650 ms latency region for pictures, and the 530–730 ms latency region for words. These latency regions were chosen to encompass the peaks of the old/new effects for each stimulus class (see Figures 5.4 and 5.5). Separate ANOVAs were conducted for each stimulus type, employing the factors of response category (hit vs. correct rejection) and electrode site (LP vs. RP). For both pictures and words, the analyses revealed response category x hemisphere interactions [F(1,15) = 9.38, $p < .01$ and F(1,15) = 5.91, $p < .05$ respectively]. These results reflect the left-sided lateralisation of the effect in each case.

An across stimulus comparison of the lateral distribution of these effects was performed on the rescaled difference waveforms. This analyses, carried out to test for differences in the scalp distribution of the effect between the two stimulus types, employed the factors of stimulus type (words vs. pictures) and electrode site (LP vs. RP). ANOVA resulted in a main effect of electrode site [F(1,15) = 13.82, $p < .01$], but no effects involving the factor of stimulus type, thus confirming the left lateralisation of the ERP old/new effect for both types of stimulus (see Figure 5.8).

The analyses on the mean amplitude for pictures suggested that the lateral distribution of the frontal effect for pictures changed with time from a left to a more right-sided distribution. The reliability of this time-dependent change in the topography of the effect was assessed by comparing the scalp distribution of the effects over frontal sites in the 300–600 and 1200–1400 ms latency regions. This analysis was carried out on the rescaled difference waveforms and employed the factors of epoch, hemisphere and electrode site. ANOVA resulted in a reliable epoch x hemisphere interaction [F(1,15) = 11.61, p < .01], confirming that the lateral distribution of the effect did indeed shift from left to right over time (see Figure 5.7)

Finally, Figures 5.3 and 5.5 suggest that the frontal old/new effect elicited by pictures onsets slightly earlier than the left parietal effect. To test the reliability of this impression, ANOVA was carried out on the mean amplitude measurements of consecutive 100 ms latency regions from 200–500 ms post stimulus. The analyses were carried out for two sites, LF and LP, and employed the factors of response category (hit vs. correct rejection) and location (anterior vs. posterior). Where appropriate, subsidiary analyses were carried out on the two sites separately. Analysis of the 300–400 ms latency region revealed a response category x location interaction [F(1,15) = 6.42, p < .05] indicating differences in the reliability of effects between anterior and posterior sites. Subsidiary analyses confirmed this results by revealing a reliable main effect of response category at the anterior site [F(1,15) = 7.47, p < .025], but not at the posterior site. No interaction between response category and location was found for the 400–500 ms latency region, confirming that the frontal effect shown by pictures indeed onsets about 100 ms earlier than the parietal old/new effect.

5.3.2.5. Summary of the Results

Both pictures and words show a left parietal ERP old/new effect. In addition, pictures also show a frontal effect, which onsets slightly earlier than the parietal effect and lasts throughout the recording epoch. This frontal effect consists of two temporally and topographically distinct components. Initially, it is largest over left frontal sites but with time shifts to right frontal maximum.

5.4. Discussion

The performance measures show that subjects could discriminate between studied and new items very accurately across both stimulus categories with a trend for better recognition of picture than word stimuli. This trend for better recognition of pictures did materialise in the RTs, which showed quicker responses for pictures than for words.

The experiment sought to determine whether the left parietal and the early and late frontal ERP old/new effects are material-specific (i.e., whether the effects vary according to the nature of the information that is retrieved). The within tasks analyses of the ERP waveforms showed that, for both stimulus categories, old items elicited more positive going ERPs than new items. Over parietal sites, this effect was lateralised to the left for both types of material. This result was somewhat unexpected given the neuropsychological evidence (see Introduction and Chapter 1, section 1.6) for an involvement of both hemispheres in the encoding and retrieval of pictorial material. One explanation for this finding could be that the two classes of item were treated equivalently by the medial temporal lobe memory system. The pictures used in this study were easily verbalisable and could therefore have been encoded and retrieved by the same processes as those engaged by the words. This explanation seems unlikely, however, in the light of the fact that there was evidence for the differential processing of the two classes of item at frontal electrode sites. On the assumption that pictures did indeed engage the medial temporal lobe memory system more bilaterally than words, the present findings suggest the need for modification of the proposal that the left parietal old/new effect reflects processing mediated by the lateralised engagement of the medial temporal lobe memory system. The same is true, if, as suggested by the neuropsychological findings reviewed above, the retrieval of verbal material under certain task demands engages the right medial temporal lobe memory system to the same extent as the encoding of pictorial information. The asymmetry of the parietal old/new effect could not reflect the lateralised engagement of the medial temporal lobe memory system. However, it has to be kept in mind that the absence of differences in the ERP correlates does not predicate an absence of processing differences for the two types of stimulus as only a fraction of the neural activity associated with their processing can be recorded at the scalp.

A notable difference in the ERPs to the two stimulus classes could be found later in the recording epoch. Across stimulus-type analyses revealed a late right frontal old/new effect for pictorial stimuli which was not present for verbal stimuli. This effect showed the same latency and distribution as the effect described by Wilding and Rugg (1996). The right frontal effect has been connected with recollective post-retrieval processing of information provided by the medial temporal lobe memory system (Donaldson & Rugg, 1998; Wilding & Rugg, 1996, 1997a,b). This suggests that pictorial stimuli induce post-retrieval processes that do not occur in words in simple study-test recognition paradigms such as the one presented here. An explanation of this kind would be plausible if evidence could be found that encoding and/or retrieval processes for pictures differ from those for words in a way that would facilitate later recollection. That this might indeed be the case is evident from studies investigating the picture superiority effect (Rajaram, 1996; Weldon & Coyote, 1996; see also Chapter 1). The results of these studies seem to suggest that it is the relatively greater distinctiveness of the visual sensory features of pictures that produce the better memory performance in comparison to words (see also Nelson, 1979). By this means, the more distinctive code in which pictures are represented might result in processing beyond the mere retrieval requirements of the task. Thus, the emergence of the right-frontal effect in this study might be related to the richness or amount of information that is retrieved in response to the test cue. By this argument, the post-retrieval processes reflected by this effect are obligatorily engaged whenever the amount of information retrieved from episodic memory exceeds some threshold. This means that post-retrieval processes may sometimes be engaged without the task demand to retrieve contextual information.

This hypothesis is supported by the results from two other studies which found right frontal effects in simple recognition memory tasks. Allan and Rugg (1997) found a small right frontal old/new effect in the ERPs to correctly identified old words in a recognition memory task in which accuracy was very high. The high recognition accuracy indicates that large quantities of information must have been retrieved which facilitated recognition greatly. Similarly, Donaldson and Rugg (1998) found a right frontal ERP effect in a simple recognition task using word pairs. They presented subjects with word pairs at study. At test subjects were shown word pairs which either maintained their pairing (same), were new pairings made up of words from the study phase (rearranged), or were completely new to the experiment (new). The task was simply to judge if the items had been seen before. ERPs elicited by same and rearranged pairs showed the expected left parietal old/new effect, but they also showed a right frontal effect which was unexpected. The magnitude of the effects was smaller for the rearranged than the same pairs. The information contained in word pairs is very rich, even more so in same than rearranged pairs. The magnitude difference in the ERP effects between the two types of pairings, also present for the left parietal effect, indicates that both effects are sensitive to the amount of information retrieved. This supports the conjecture that the neural correlates underlying the right frontal effect might be obligatorily engaged when rich information is available.

In addition to the right frontal effect, ERPs to pictorial stimuli show a second difference from ERPs to words. Pictorial stimuli also elicit an early left frontal effect with an onset at about 300 ms post-stimulus. Similar early frontal effects have been found in a number of other studies (Donaldson & Rugg, 1998, in press; Rugg et al., 1998; Tendolkar et al., 1997). Tendolkar et al. (1997) showed a left frontal effect, onsetting slightly earlier than the left parietal effect, in a study of retroactive interference. Similarly, Donaldson and Rugg (1998, in press) found a bilateral frontal effect in a study of associative recognition. All these studies observed an early left or bilateral frontal effect only in combination with the requirement to retrieve contextual information. The present study and the study by Rugg et al. (1998) are the only ones in which this effect was evoked by a simple recognition memory judgement. In the study by Rugg et al. (1998), a simple recognition judgment was required for items previously encoded using a shallow or a deep encoding task. The study revealed two interesting aspects with regard to this effect. Firstly, the effect was present in the absence of a later right frontal effect (see also Tendolkar et al., 1997 for similar result), thus indicating that the operation of the neural generators underlying the two effects is independent. Secondly, the effect was insensitive to the encoding manipulation (i.e., there was no difference in magnitude between correctly recognised items encoded shallowly and those encoded deeply). Rugg et al. (1998) suggested that the effect may reflect familiarity driven processing, as this basis of recognition memory is thought to be insensitive to levels of processing manipulations at encoding (but see Jacoby, 1996; Toth, 1996, and Chapter 1, section 1.5.2). The present study does not advance the suggestions made by Rugg et al. (1998) apart from the finding that the early left/bilateral old/new effect is material independent. It does however support the notion that the retrieval of contextual information is not a necessary condition for the emergence of the early frontal effect. Further research is needed to establish the boundary conditions under which the effect is elicited and to further investigate its functional significance.

One feature of the early left/bilateral frontal effect found in the present study is that it precedes the onset of the left parietal effect by more than 100 ms (see Tendolkar et al., 1997 for similar results). This result suggests that the left parietal old/new effect is possibly not the on-line signature of the earliest retrieval processes. It seems more likely that retrieval is initiated by (possibly frontal) neural activation, expressed in the early left/bilateral frontal effect which could be automatic and restricted to sensory-perceptual information. Once retrieval is initiated, the left temporal lobe memory system starts the more effortful attempt to retrieve episodic information. This hypothesis is supported by studies connecting the left parietal old/new effect to recollective, hence episodic, retrieval processes. Furthermore, it has been shown repeatedly that the left parietal old/new effect is sensitive to the amount of information retrieved (see Rugg, Schloerscheidt, Doyle, Cox & Patching, (1996); Wilding, Doyle & Rugg, 1995; Wilding & Rugg, 1996) which adds plausibility to the above hypothesis. Within this framework it would indeed be the pictorial stimuli which would produce the early bilateral frontal effect due to their richer perceptual representation in comparison to words (see Introduction). The richer perceptual code would facilitate early retrieval of these aspects of the stimuli which would then lead to the more effortful episodic retrieval processes as expressed in the left parietal old/new effect. That said, neither the present study nor any other provide unequivocal evidence for this suggestion and further research is needed to establish its plausibility.

5.5. Summary and Conclusions

ERPs to word and picture recognition are similar in that they both show the well-established left parietal old/new effect. The fact that the effect is also lateralised to the left in picture recognition might be a result of the verbal encoding of the pictorial stimuli. The ERPs do, however, differ in two respects. Firstly, ERPs to pictures recognised correctly, show a later right frontal effect. The occurrence of this effect might be based on recollective processes occurring in pictures but not in words, due to the more distinctive semantic-sensory code which leads to stronger memory representation for pictures. The effect might, however, be a retrieval effect per se which occurs for any class of stimuli which provides large amounts or very rich information. Secondly, ERPs to correctly recognised pictures show an early bilateral frontal effect whose functional significance has yet to be elucidated.

Table 5.1 Summary of ANOVA on the mean amplitude measures for correctly recognised and new items for pictures and words

	PICTURES	**WORDS**
300 – 600 ms		
LF/RF vs. LP/RP		
RC	F(1,15) = 18.60, p < .005	F(1,15) = 9.49, p < .01
RC x LC	n.s.	F(1,15) = 5.49, p < .05
RC x HM	n.s.	n.s.
RC x LC x HM	n.s.	n.s.
LP vs. RP		
RC	F(1,15) = 13.27, p < .005	F(1,15) = 20.92, p < .001
RC x HM	F(1,15) = 9.62, p < .01	n.s.
F7/LF/F3 vs. F8/RF/F4		
RC	F(1,15) = 14.02, p < .005	n.s.
RC x HM	n.s.	n.s.
RC x ST	F(1.2,17.4) = 13.27, p < .005	n.s.
RC x HM x ST	F(1.5, 21.9) = 4.58, p < .05	n.s.
600 – 900 ms		
LF/RF vs. LP/RP		
RC	F(1,15) = 10.44, p < .01	F(1,15) = 7.99, p < .05
RC x LC	n.s.	F(1,15) = 11.57, p < .005
RC x HM	n.s.	n.s.
RC x LC x HM	n.s.	n.s.
LP vs. RP		
RC	F(1,15) = 9.39, p < .01	F(1,15) = 14.78, p < .005
RC x HM	n.s.	F(1,15) = 4.35, p = .055
F7/LF/F3 vs. F8/RF/F4		
RC	F(1,15) = 8.36, p < .05	n.s.
RC x HM	n.s.	n.s.
RC x ST	F(1.1,16.4) = 5.42, p < .05	n.s.
RC x HM x ST	F(1.4,20.5) = 7.25, p < .01	n.s.

	PICTURES	WORDS
900 – 1200 ms		
LF/RF vs. LP/RP		
RC	n.s.	F(1,15) = 6.22, p < .05
RC x LC	n.s.	F(1,15) = 11.22, p < .01
RC x HM	n.s.	n.s.
RC x LC x HM	n.s.	n.s.
LP vs. RP		
RC	n.s.	F(1,15) = 13.39, p < .005
RC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RC	F(1,15) = 5.99, p < .05	n.s.
RC x HM	n.s.	n.s.
RC x ST	F(1.3,20.2) = 3.99, p < .05	F(1.2,17.5) = 4.78, p < .05
RC x HM x ST	n.s.	n.s.
1200 – 1400 ms		
LF/RF vs. LP/RP		
RC	n.s.	n.s.
RC x LC	n.s.	n.s.
RC x HM	n.s.	n.s.
RC x LC x HM	n.s.	n.s.
LP vs.RP		
RC	n.s.	n.s.
RC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RC	n.s.	n.s.
RC x HM	F(1,15) = 4.21, p = .058*	n.s.
RC x ST	n.s.	n.s.
RC x HM x ST	n.s.	n.s.

RC = Response Category, ST = Site, LC = Location, HM = Hemisphere, * = marginally significant

Table 5.2 Summary of ANOVA on the subtracted mean amplitudes for words (word hit – new) and pictures (picture hit – new) - Magnitude Analyses across stimulus type

300 – 600 ms		
LF/RF vs. LP/RP	STT x LC	$F(1,15) = 4.85, p < .05$
LP vs. RP	no significant effects	
F7/LF/F3 vs. F8/RF/F3	STT	$F(1,15) = 8.01, p < .05$
600 – 900 ms		
LF/RF vs. LP/RP	STT x LC	$F(1,15) = 6.58, p < .05$
LP vs. RP	no significant effects	
F7/LF/F3 vs. F8/RF/F3	no significant effects	
900 – 1200 ms		
LF/RF vs. LP/RP	STT x LC	$F(1,15) = 10.75, p < .01$
LP vs.RP	STT	$F(1,15) = 4.26, p = .057$*
F7/LF/F3 vs. F8/RF/F3	no significant effects	
1200 – 1400 ms	no significant effects in this latency region	

STT = Stimulus Type, LC = Location, * = marginally significant

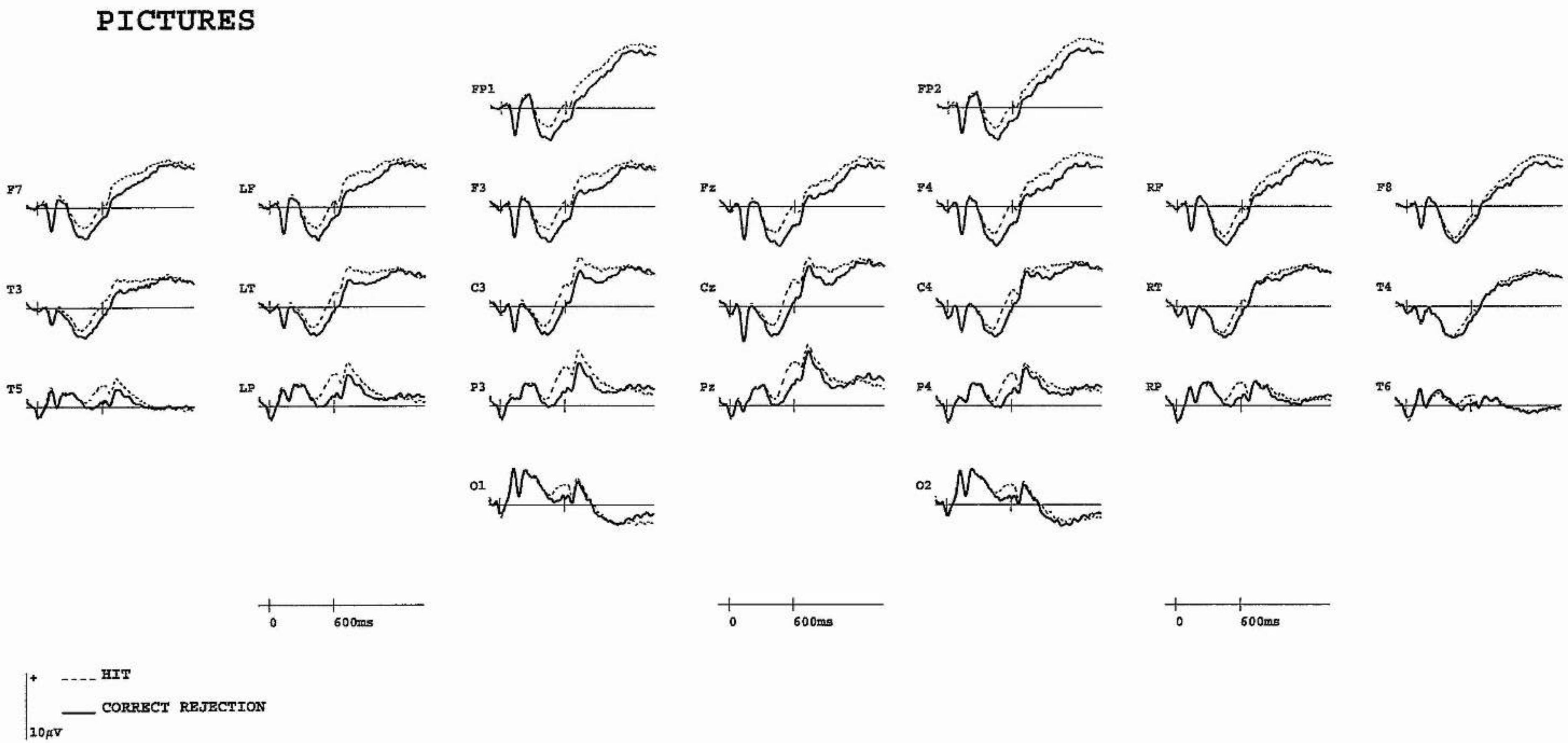


Figure 5.1: Grand average ERPs elicited by the hit and correct rejection response categories for picture stimuli. See Figure 4.1 for the description of the site labels.

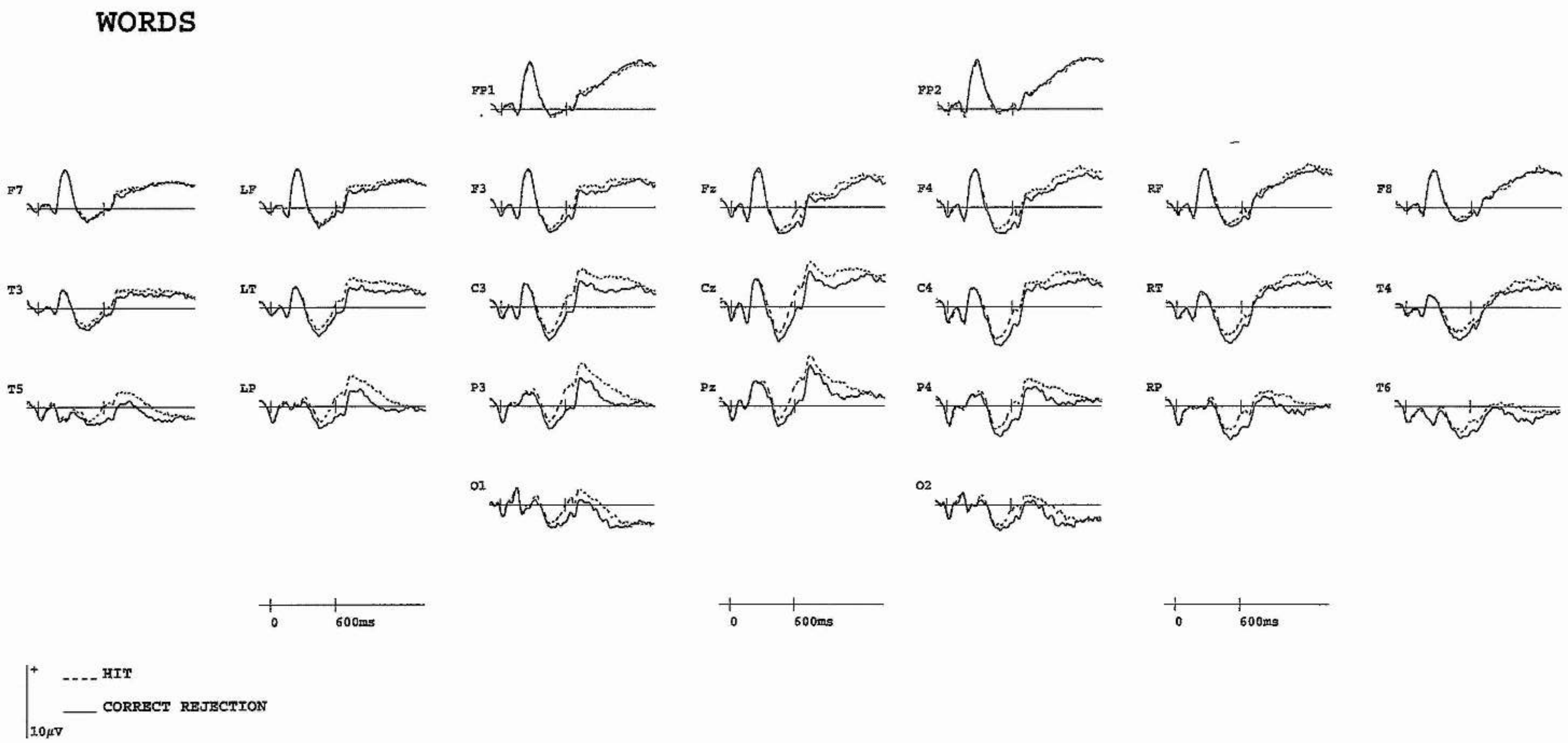


Figure 5.2: Grand average ERPs elicited by the hit and correct rejection response categories for word stimuli. Electrode sites as in Figure 5.1.

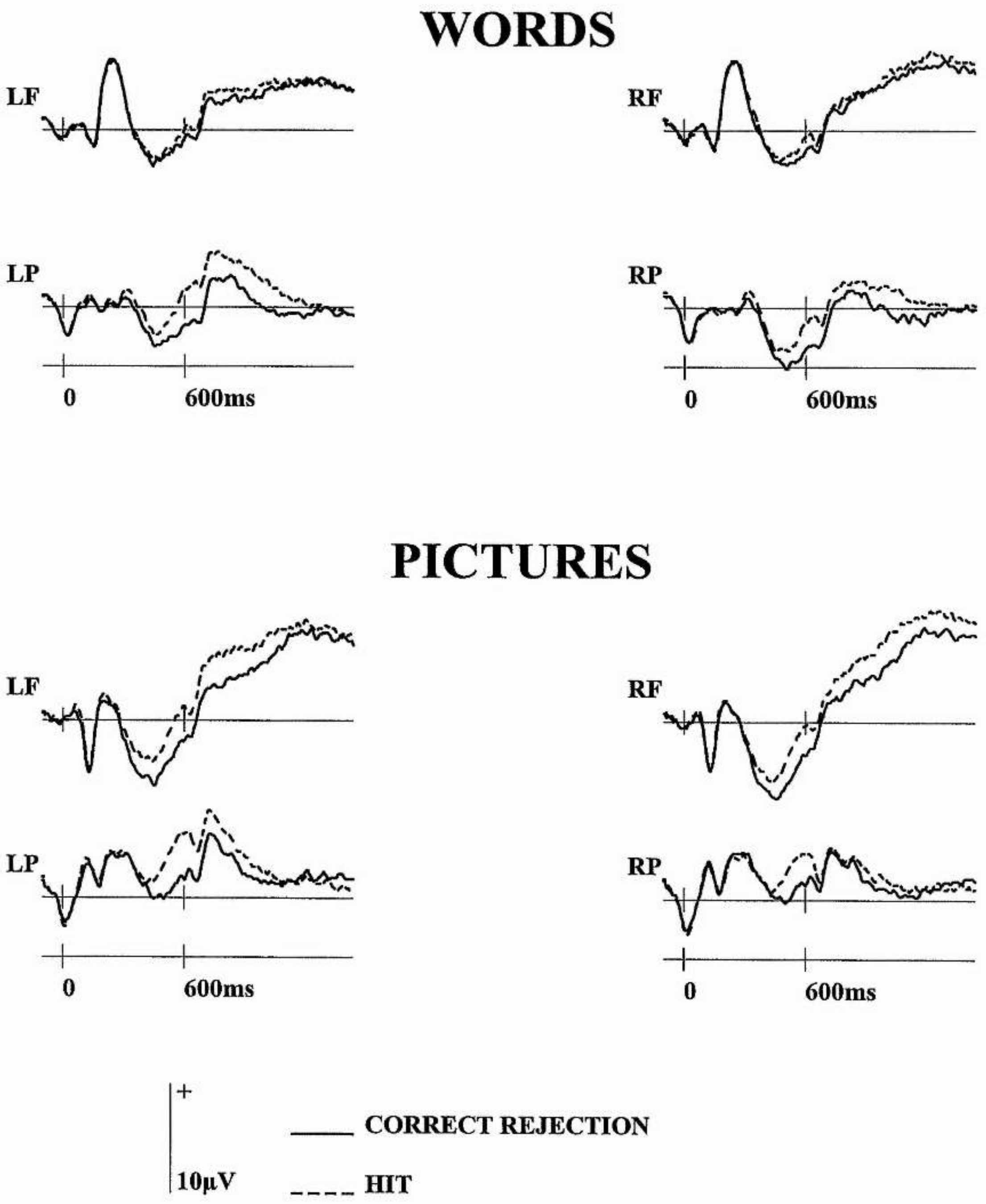


Figure 5.3: Grand average ERPs elicited by the hit and correct rejection response categories for picture and word stimuli at lateral frontal and parietal sites.

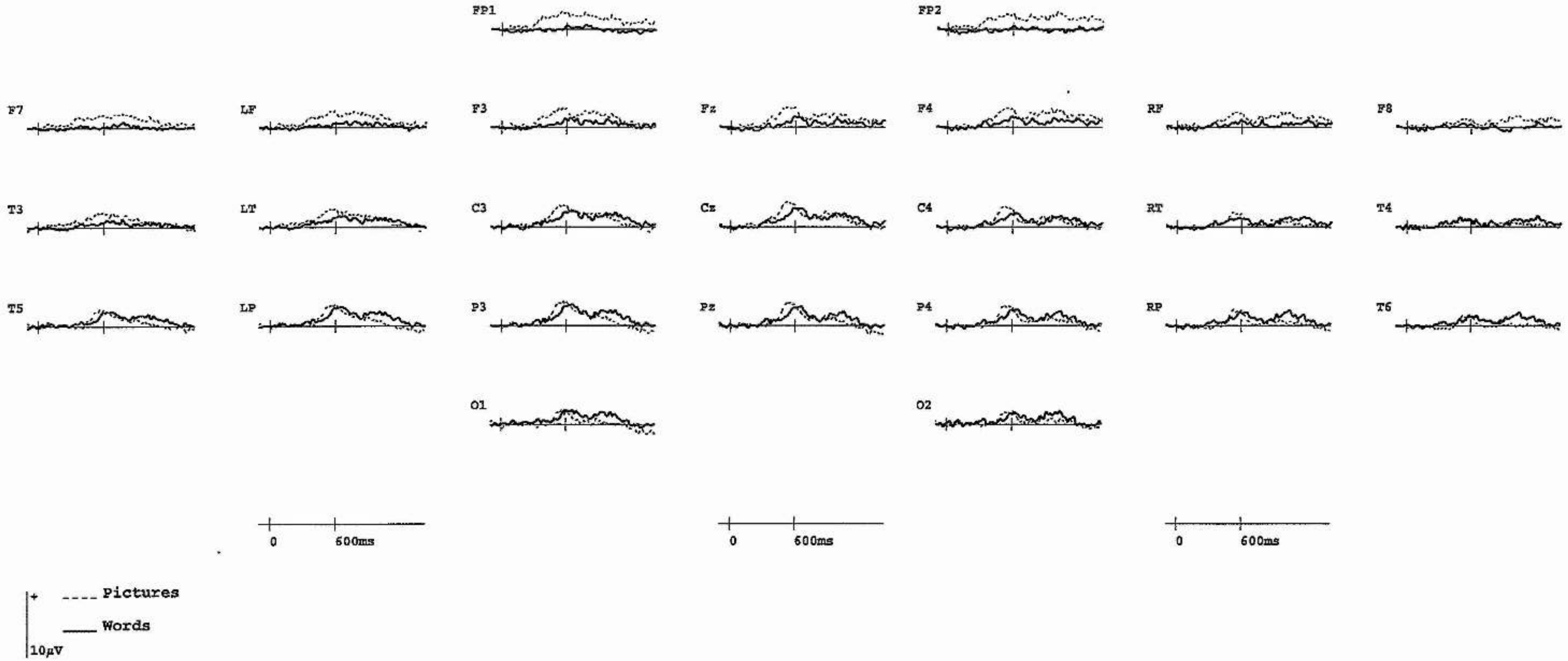


Figure 5.4: Subtraction waveforms (hit – correct rejection) for picture and word stimuli. Electrode sites as in Figure 5.1.

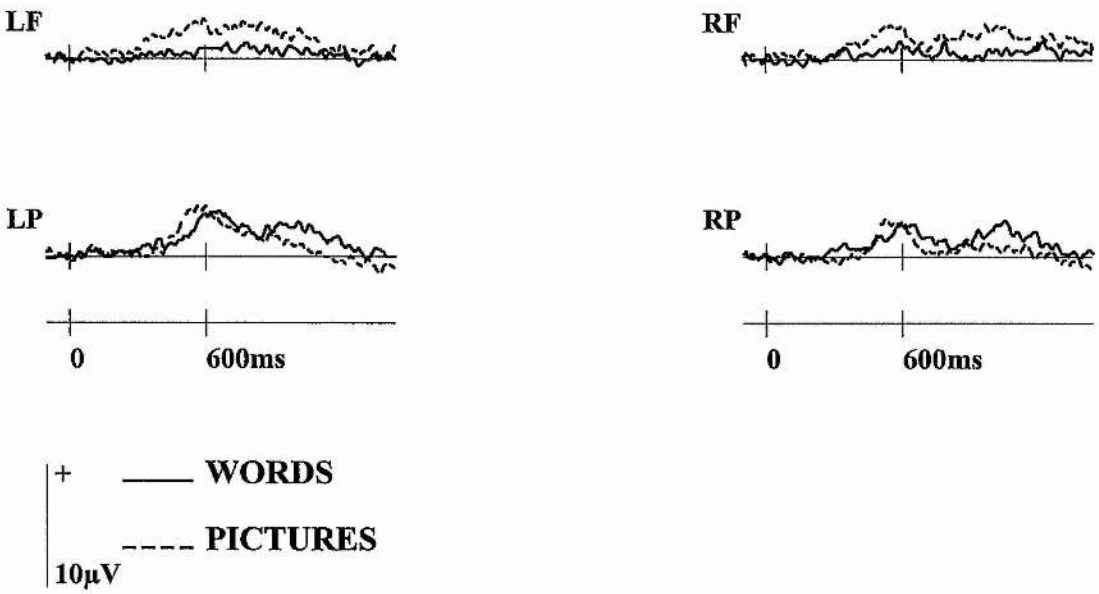


Figure 5.5: Subtraction waveforms (hit – correct rejection) for picture and word stimuli at lateral frontal and parietal electrode sites.

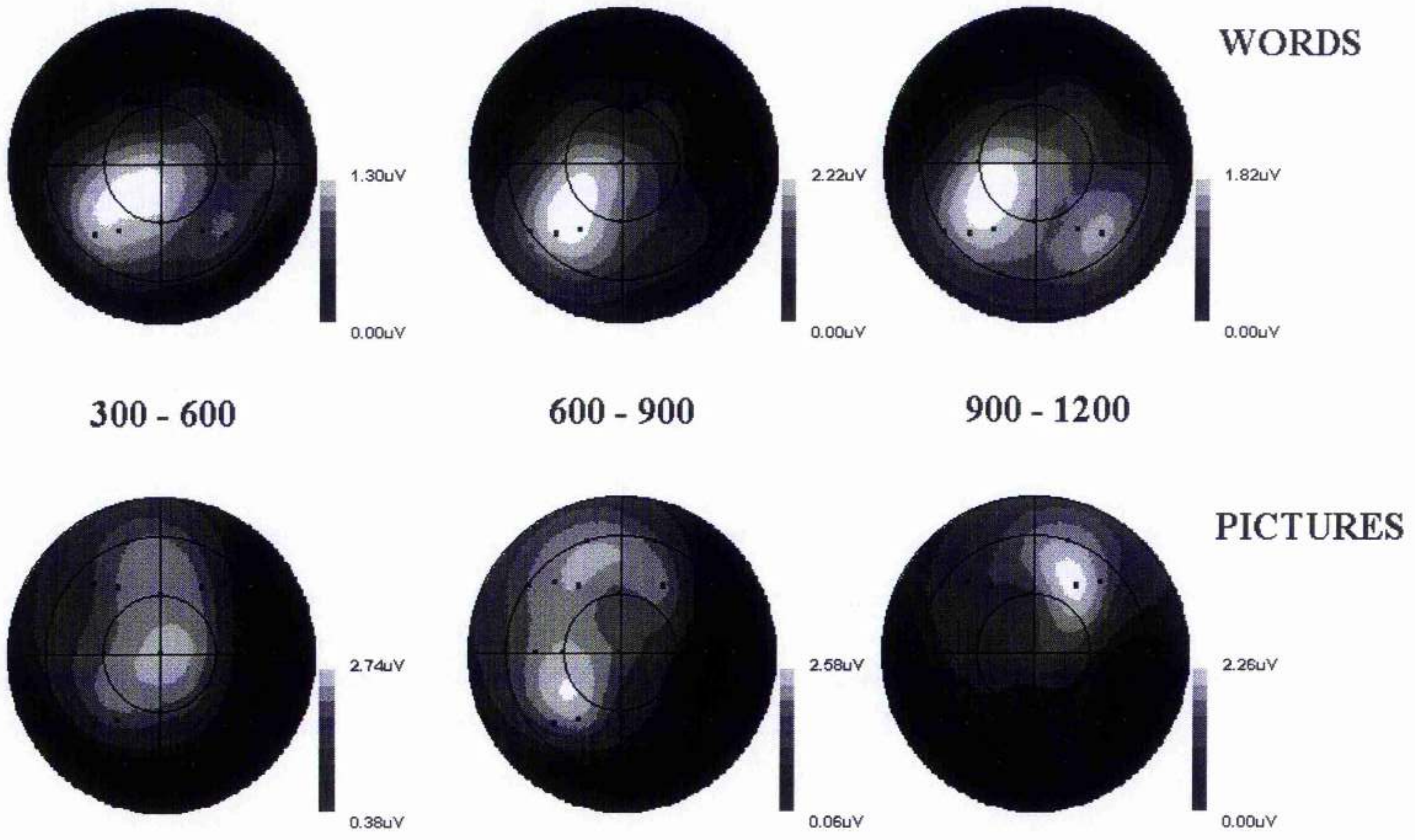


Figure 5.6: Topographic maps of the ERP old/new effects in the 300-600, 600-900, and 900-1200 ms latency regions for pictures and words, showing the relative amplitude of the differences between hit and correct rejection ERPs over all 25 electrode sites.

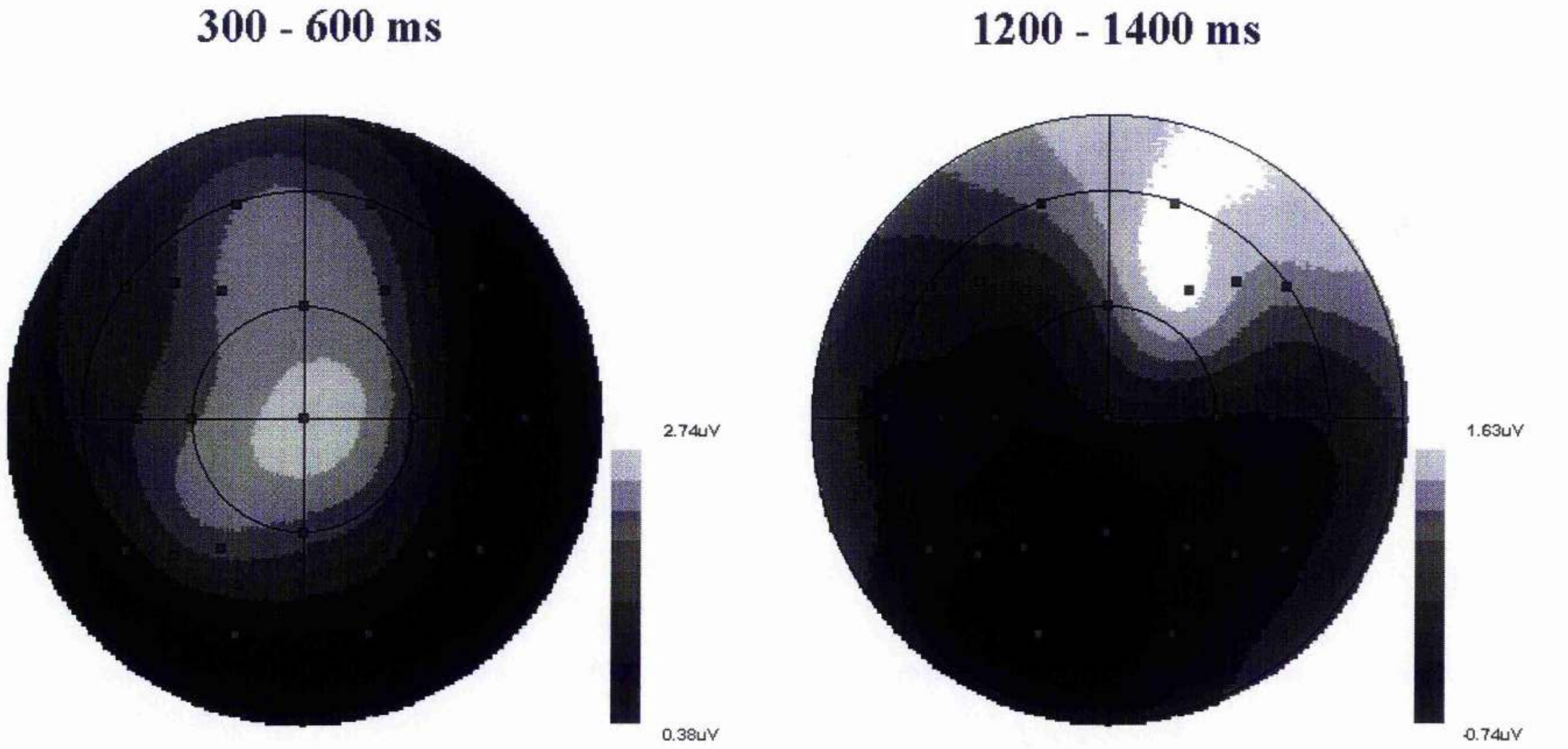


Figure 5.7: Topographic maps of the ERP old/new effects in the 300-600 and 1200-1400 ms latency regions for pictures, showing the relative amplitude of the differences between hit and correct rejection ERPs over all 25 electrode sites.

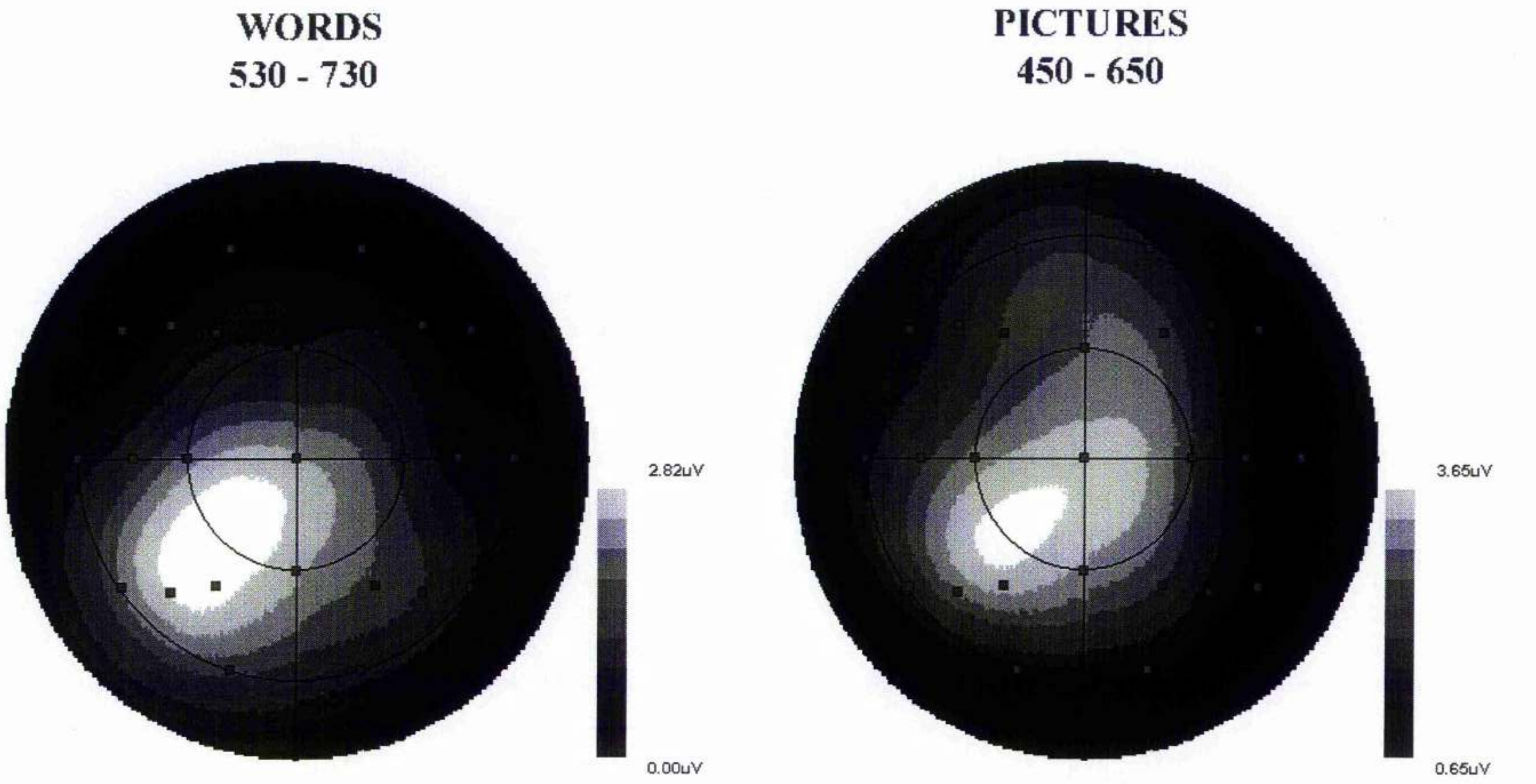


Figure 5.8: Topographic maps of the ERP old/new effects in the 530-730 ms latency region for words and the 450-650 ms latency region for pictures, showing the relative amplitude of the differences between hit and correct rejection ERPs over all 25 electrode sites.

CHAPTER 6

Experiment 2

6.1. Introduction

As demonstrated in Experiment 1 word and picture retrieval are associated with a left parietal old/new effect, which appears to be material independent. However, two temporally and topographically distinguishable frontal old/new effects were shown to be present only for the retrieval of pictures. It was suggested that these effects are triggered by perceptual and semantic features of pictures which automatically evoke processing not normally elicited by verbal stimuli. Thus, whilst processes mediating the left parietal old/new effect appear to show only quantitative differences (i.e., the effect is larger for the retrieval of pictures), processes mediating the early bilateral and late right frontal old/new effects show qualitative differences (i.e., they are present for picture, but not word retrieval).

The question addressed by the second experiment was whether the emergence of the two frontal effects in Experiment 1 is indeed a consequence of the processing of the richer perceptual and semantic code inherent in pictorial stimuli. To test this hypothesis, the exact replication of stimuli between study and test (within modality conditions replicated from experiment 1) was contrasted with two conditions in which the identity of the item was kept constant between study and test but the surface form was altered (across modality conditions). In these conditions, subjects studied pictures (e.g., a knife) and retrieved from word cues (e.g. KNIFE), or studied words and retrieved from pictures as cues. If it is indeed the relatively greater perceptual and semantic distinctiveness of pictures that automatically evokes processes indexed by the early left/bilateral and late right frontal ERP effects, it might be expected that these effects would only emerge in those conditions in which pictures were presented at encoding (i.e., pictures at study and test, or pictures at study then words at test). Consequently, as for Experiment 1, differences in retrieval processes due to differences in encoding operations for the two types of item could be reflected in qualitatively different patterns of ERP activity across the experimental conditions. These differences can be demonstrated by contrasting the scalp topography of ERP effects associated with each condition.

The study also addresses the question of whether the left parietal effect, thought to index recollection, is sensitive to surface changes between study and test. If the effect showed a reduction in magnitude in the across modality conditions as compared to the within modality conditions, it would indicate that recollection, as indexed by the left parietal old/new effect, is not solely mediated by conceptual processes (Gardiner & Java, 1993; Jacoby, 1983; Roediger & Blaxton, 1987). In this case there would be a strong indicationg that the effect was also mediated by data-driven processes (Jacoby, 1983) which rely on a perceptual match between study and test stimulus (Roediger et al., 1989).

6.2. Method

6.2.1. Subjects

The subjects were 42 students from St. Andrews University (mean age 21.7 years, ranging from 16–35 years). The data from 3 subjects were rejected because task performance was too poor to permit the formation of ERPs from an acceptable number of trials. The data from 2 subjects were rejected due to excessive noise in the signal and the data from one further subject was rejected due to excessive EOG artefact. Of the remaining 36 subjects who contributed to the study, 12 were female. All subjects were right-handed as defined by writing-hand and gave written consent prior to participating in the study.

6.2.2. Experimental Materials

The stimuli consisted of 126 digitised pictures of common objects and 126 words which were the names of these objects as determined by naming agreement between 5 native English speakers (see Chapter 4). The words were between 3 and 11 letters long and had a mean frequency of 28 occurrences per million (Francis & Kucera, 1982). For a complete listing of the stimuli used in this experiment see Appendix B.

The 120 critical items of each stimulus type (words + pictures) were randomly divided into 3 lists of 40 items, so that each word list had a corresponding picture list containing the same items. The remaining 6 items of each stimulus type were used as fillers. Two lists, one containing pictures and one containing words, were combined to form a study list. This was done for all possible combinations of word and picture lists not containing the same items, resulting in six study lists with 80 items in each list (40 pictures and 40 words). Each study list was preceded by three filler items.

All three lists of each stimulus type were then combined to form test lists containing 120 items. Three versions of each of these test lists were formed, differing only in the serial order of the items. Thus, there were three test lists per item type. Each of these test lists consisted of 80 items from the study phase and 40 new items. Of the 80 items seen at study, 40 had been seen as pictures and 40 as words. This way three different experimental conditions were created in the test lists: Old items seen across modality (pictures at study then word at test or words at study then pictures at test); old items seen within modality (words at study and test, pictures at study and test); and new items. By combining the three test lists of each item type with each of the six study lists, all items appeared equally often as a word and as a picture in different combinations at study and as an old item (across and within modality) and new item at test. The test lists were preceded by three filler items and padded with further filler items in positions 43 and 85 at which point a rest break occurred.

6.2.3. Procedure

The experiment was based on a between-subject design. One group of subjects was administered the mixed study lists but only those test lists containing pictures, the other group received the same mixed study lists but only those test lists containing words. The design and the resulting response categories are shown below.

	Retrieval:	***Retrieval:***
	Group1	Group 2
***Encoding** (mixed item lists)*	PICTURES	WORDS
PICTURES	Within Modality	Across Modality
WORDS	Across Modality	Within Modality
	New	New

For each group, the experiment consisted of a single study-test cycle. Before the start of the experiment, subjects were fitted with an ERP recording cap as described in Chapter 4. It was then explained that they were taking part in a memory experiment that consisted of a study and a test phase. They were asked not to use any strategies to enhance their memory performance, but to concentrate on the study task. The task was to decide whether the item on the screen (word or picture) was an essential household item or not. Responses were given verbally. Items were displayed until the subject responded, at which point the experimenter displayed the next item via a mouse-click.

The test-task followed the study phase after an interval of approximately 10 minutes, during which time the subject had to list as many countries of the earth as he/she could. Each test trial started with the display of a fixation character (!) for 2000 ms, followed by a second fixation character (+) for 500 ms. These fixation characters extended vertically to the same degree as the items which they preceded. There then followed a 172 ms blank period following which the test items were presented for a duration of 500 ms.

Subjects were instructed to make a speeded old/new judgement to each item by pressing one of two microswitch keys with the index finger of one or other hand. They were further instructed to make this judgement as quickly and accurately as possible after seeing the item on the screen. The mapping of keys to responses was counterbalanced across subjects. To reduce the number of trials containing artefacts, subjects were instructed to remain relaxed, maintain fixation, minimise body and eye movement and to blink only when the exclamation mark was present on the monitor.

ERPs were formed for the 3 critical response categories described above: correctly classified new items (*new*); correctly recognised items seen within modality (*within modality hits*); and correctly recognised items seen across modality (*across modality hits*).

6.3. Results

6.3.1. Behavioural Results

Accuracy and Reaction Time (RT) measures for both types of retrieval cue (corresponding to experimental group) are shown in Table 6.1. For the recognition decision a 2x2 ANOVA was conducted on the discrimination index 'P(hit) – P(false alarm)', employing the factors of retrieval cue at test (picture vs. word, between subjects) and response category (within vs. across modality). This revealed a reliable retrieval cue x response category interaction [$F(1,34) = 22.15$, $p < .001$]. Post-hoc Tukey tests indicated reliable differences in the following comparisons: Firstly, when pictures acted as retrieval cues, accuracy was greater for within than across modality hits. Secondly, within modality items were more easily recognised when pictures were the retrieval cues than words. Thirdly, across modality hits were more accurate when words acted as retrieval cues rather than pictures (see Table 6.1).

ANOVA of the Reaction Time data employing the same factors as above also revealed a retrieval cue x response category interaction [F(1,34) = 37.23, p < .001]. Post-hoc Tukey tests revealed revealed significant differences in the following comparisons: Firstly, for both types of retrieval cue subjects responded quicker to within modality hits than to across modality hits. Secondly, within modality hits attracted faster responses when pictures acted as retrieval cues and thirdly, across modality hits attracted faster responses when words were the retrieval cues (see Table 6.1).

6.3.2. Event-Related Potentials

The grand average ERP waveforms elicited by new and old items (within and across modality) are shown in Figures 6.1 (pictures) 6.2 (words). Figure 6.3 displays the same waveforms for a selection of lateral frontal and parietal sites. The mean number of trials contributed by each subject in each experimental condition were 31, 34, and 26 in the new, within modality hit and across modality hit conditions respectively for pictures as retrieval cues and 29, 28, and 29 for the same condition respectively for words as retrieval cues.

For both types of retrieval cue, correctly recognised items are more positive going than new items. When pictures act as retrieval cues these old/new effects are distributed widely over the scalp and are larger for those recognised items seen within modality (i.e., pictures at study, pictures as retrieval cues) than those seen across modality (i.e., words at study, pictures as retrieval cues). An early frontal effect is evident, onsetting around 250 ms post-stimulus, and a left parietal effect onsetting slightly later than the frontal effect. A slightly different pattern can be seen for words as retrieval cues where within modality hits (i.e., words at study, words as retrieval cues) elicit a larger old/new effect only over frontal sites. At posterior sites the two old/new effects start at equal amplitude with the across modality hits (i.e., pictures at study, words as retrieval cues) developing a larger ERP effect after 600 ms post-stimulus onset.

The following sets of analyses were carried out on the data:

(1) Within Group Analyses

Three subsets of these analyses were executed. Firstly, a global ANOVA was conducted on the mean amplitude measures, employing the factors of response category (new/within modality hit/across modality hit), and electrode site (all sites). The global ANOVA was followed up by planned subsidiary pairwise comparisons (within modality hits vs.

new/across modality hits vs. new) on a selection of sites (LF/RF vs. LP/RP, LP vs. RP, F7/LF/F3 vs. F8/RF/F4). These comparisons allowed the results of Experiments 1 and 2 to be compared directly.

The second subset of within group analyses compared the magnitude of the old/new effects directly. These analyses were performed on the subtraction waveforms (within modality hit – new / across modality hit – new) employing the factors of modality (within modality vs. across modality) and electrode site. The global ANOVAs were followed up with the same subsidiary planned comparisons as described above.

The third subset of within group analyses compared the topographic distribution of the old/new effects elicited by the two classes of hits. These analyses were performed on the subtraction waveforms which were rescaled to remove global differences due to magnitude (McCarthy & Wood, 1985). The global analyses employed the factors of modality (within modality vs. across modality) and electrode site. As before, the global ANOVA was followed up with subsidiary planned pairwise comparisons on a selection of lateral frontal and parietal sites as described above.

(2) Across Group Analyses

Firstly, in order to compare the magnitude of the old/new effects directly, across group (retrieval cue) comparisons were performed on the difference scores (hit – correct rejection) of the within and the across modality conditions respectively. These comparisons took the form of global ANOVAs employing the factors of retrieval cue (pictures vs. words), modality (within modality vs. across modality) and electrode site. The global ANOVAs were again complemented by a set of planned subsidiary pairwise comparisons (within modality pictures vs. within modality words / across modality pictures vs. across modality words) on the same selection of sites as described above.

Secondly, differences in the scalp topography of these effects were investigated by ANOVA after the subtraction data had been rescaled to remove global differences in magnitude (McCarthy & Wood, 1985). Global ANOVAs employing the factors of retrieval cue (pictures vs. words), modality (within modality vs. across modality) and electrode site were again followed up with planned subsidiary pairwise comparisons on the selection of lateral frontal and parietal sites.

6.3.2.1. Within-Group Analyses

6.3.2.1.1. Group 1 - Pictures as Retrieval Cue

(1) Analyses of the mean amplitudes

The global ANOVA resulted in reliable response category x site interactions in the 300–1200 ms latency regions [300–600: $F(5.4,92.1) = 5.90$, $p < .001$; 600–900: $F(6,102.3) = 6.76$, $p < .001$; 900–1200: $F(6.6,112.3) = 4.69$, $p < .001$] confirming the reliability of the observed positivity for correctly recognised items (see Figure 6.1). Table 6.2 gives the mean amplitude of the old/new effects (within modality hit-new and across modality hit-new) at lateral frontal and parietal sites for the four latency regions. Table 6.3 summarises the results of the planned pairwise comparisons conducted on the mean amplitude measurements of the waveforms elicited by old and new items. Selected results, addressing the issues outlined in the introduction, are described below.

Within Modality Hits vs. New: The distribution of the effects was elucidated through the planned pairwise comparisons. ANOVAs on the lateral parietal sites resulted in a response category x hemisphere interaction for the 300–600 and 600–900 ms latency regions, confirming the left lateralised distribution of the parietal old/new effect in this time period (see Figures 6.3 and 6.14a). Within modality hits also showed a reliable frontal positivity which was evident over bilateral sites early in the recording epoch. Later in the epoch the effect was larger over left frontal sites, as was confirmed by the results of ANOVA on the selection of frontal sites resulting in a response category x hemisphere x site interaction for the 600–900, 900–1200 and 1200–1400 ms latency regions (see Table 6.2). Planned analyses on the selection of lateral frontal and parietal sites resulted in a main effect of response category for all but the latest recording epoch. These results were qualified by a response category x location x hemisphere interaction in the 600–900 ms latency region. Post-hoc Tukey HSD tests revealed that during this time the old/new effects were significantly larger over the left than the right parietal site and over this hemisphere significantly larger over the parietal than the frontal site. This result supports the outcome of the other planned comparisons, indicating that the effects show a left hemisphere lateralisation, especially over temporo-parietal sites.

As in Experiment 1, it seems that the frontal ERP effect onsets slightly earlier than the parietal effect (see Figure 6.3). The analyses conducted to test this possibility took the form of ANOVA on LF and LP for consecutive 100 ms latency regions from 200–600 ms post-stimulus. ANOVA employed the factors of response category (hit vs. correct rejection) and location (anterior vs. posterior). Where a relevant response category x location interaction arose, subsidiary ANOVAs were conducted on each of the two sites separately, employing the factor of response category only. ANOVA resulted in a reliable response category x location interaction for the 200–300 ms latency region [F(1,17) = 13.34, p < .005] and the 300–400 ms region [F(1,17) = 9.38, p < .01]. For both of these latency regions subsidiary ANOVAs revealed a reliable effect of response category only for LF [200–300: F(1,17) = 5.59, p < .05; 300–400: F(1,17) = 12.57, p < .005], thus confirming that for the within modality condition the frontal effect onsets around 200 ms earlier than the left parietal ERP old/new effect.

Across Modality Hits vs. New: Planned subsidiary ANOVAs on the parietal sites revealed a reliable response category x hemisphere interaction for the 600–900 and 900–1200 ms latency regions, confirming a left lateralised distribution for the parietal old/new effect for this class of hits (see Figure 6.14a). Planned comparison on the selection of frontal sites resulted in reliable response category x site interactions for all four latency regions. These results indicated that a frontal EP old/new effect was present, though contrary to that for the within modality hits, the effect was bilateral all through the recording epoch and largest nearest the midline. Planned comparisons on the selection of lateral frontal and parietal sites resulted in a main effect of response category in the 300–1200 ms latency regions. These results were qualified by a reliable response category x location x hemisphere interaction for the 600-900 ms latency region. Tukey HSD tests revealed significant differences between the mean amplitudes of the two parietal sites (LP and RP). This, together with a marginally significant response category x hemisphere interaction in the 900–1200 ms latency region, supported the results of the planned comparison on the parietal sites, confirming the left lateralisation of the temporo-parietal ERP old/new effect.

Contrary to the within modality hits, it appears that for the across modality hits the parietal effect, which is initially bilateral, onsets earlier than the frontal effect (see Figure 6.3). This impression was confirmed by the subsidiary planned comparisons which revealed the existence of an ERP old/new effect over parietal but not frontal sites in the 300-600 ms latency region.

(2) Analyses of the subtracted mean amplitudes – Magnitude analyses

Table 6.4 summarises the results of the analyses carried out on the subtracted mean amplitude measurements for pictures as retrieval cues. Figures 6.4 and 6.6 depict the subtraction waveforms for the within and across modality conditions for all 25 sites and for a selection of lateral frontal and parietal sites respectively. As above, only selected results are described below.

Global ANOVA revealed significant modality x site interactions for the 300–1200 ms latency regions, confirming the reliability of the larger magnitude for within modality hits than for the across modality hits evident in Figures 6.4 and 6.6. Planned comparisons on the selection of lateral frontal and parietal sites resulted in main effects of modality for the 300–1200 ms latency regions, qualified by a modality x hemisphere interaction in the 900–1200 ms region. The interaction indicates that the differences between the two hit categories are larger over the right than the left hemisphere. This distribution is slightly different in the 1200–1400 ms latency region in which ANOVA on the lateral frontal and parietal sites revealed a modality x location x hemisphere interaction. Tukey HSD tests indicated significant differences in magnitude between the left and right parietal sites and the left frontal and the left parietal sites. The results show that for this latency region the magnitude difference between the two hit categories is largest over right parietal and left frontal sites (see Table 6.2). This was confirmed by planned comparisons on the parietal sites only which revealed a modality x hemisphere interaction for the 900–1200 and 1200–1400 ms latency regions, indicating that the difference between the two hit categories was largest over right parietal sites (see Table 6.2). Planned subsidiary ANOVAs on the selection of frontal sites confirmed the observed left lateralisation of the magnitude difference late in the recording epoch through a modality x hemisphere x site interaction in the 1200-1400 ms latency region (see Figure 6.6).

(3) Analyses of the rescaled subtracted mean amplitudes – Topographic analyses

Table 6.5 summarises the results of ANOVA on the rescaled subtracted mean amplitudes for pictures as retrieval cues. Figure 6.8 shows the topographic maps of the 600–1400 ms latency regions. The 300–600 ms region is not displayed as no differences in the distribution of the two hit conditions could be found for this latency. As can be seen from the maps. the within modality condition shows a widespread effect which lateralises slightly to right posterior areas late in the recording epoch. The across modality condition shows a prominent left parietal effect which over time shifts to right frontal sites.

Global ANOVA resulted in a modality x site effect only for the 900-1200 ms latency region. This general indication of a difference in topographic distribution was elucidated by subsidiary planned comparisons on the selection of lateral frontal and parietal sites which revealed a modality x location x hemisphere interaction for this latency region. As can be seen from Figure 6.8, the across modality condition shows a strong effect over left temporo-parietal sites. This effect was not found for the within modality condition, for which the effect was of a more central distribution. ANOVA of the same type for the 1200–1400 ms latency region also gave rise to a modality x location x hemisphere interaction. As can be seen from Figure 6.8 both conditions show a frontal maximum centered around the midline. At posterior sites however, the within modality condition reveals a right-hemisphere maximum whereas the across modality condition still shows a strong effect over left posterior sites.

To assess if, as in Experiment 1, the topographic distribution of the frontal ERP old/new effect shifts over time, an across epoch ANOVA was performed for each of the two hit categories. The analysis was performed on the rescaled subtracted mean amplitudes of two latency regions: 300–600 and 1200–1400 ms for the within modality condition and 600–900 and 1200–1400 ms for the across modality condition (see Figure 6.9). These latency regions were chosen to encompass the earliest region in which a frontal effect was evident from the mean amplitude analyses. The analyses employed the factors of epoch (300–600/600-900 vs. 1200–1400 ms), hemisphere (left vs. right) and site (F7/LF/F3 vs. F8/RF/F3). ANOVA of the within modality condition resulted in a epoch x hemisphere x site interaction [$F(1.5,25.4) = 6.03$, $p < .025$]. The same analysis of the across modality condition revealed an epoch x hemisphere interaction [$F(1,17) = 4.66$, $p < .05$]. The results indicate that for both conditions there is a topographic shift over time. Unexpectedly, however, for the within modality condition the shift is from an initial bilateral distribution to a left-sided distribution (see Figure 6.9). This result confirms the mean amplitude analyses on the frontal sites which also showed a lateralisation of the old/new effect to the left during the later recording epochs. The across modality condition, however, shows the expected shift from a bilateral to a late right frontal effect.

6.3.2.1.2. Group 2 - Words as Retrieval Cues

(1) Analyses of the mean amplitude

Figures 6.2 and 6.3 show the ERPs elicited by old and new items for all 25 sites and a selection of lateral frontal and parietal sites respectively.

Global ANOVA revealed a main effect of response category for the 300–600 ms latency region [$F(1.9,31.9) = 5.21$, $p < .05$] , and reliable response category x site interactions for the remaining latency regions [600–900: $F(3.7,63.5) = 4.33$, $p < .005$; 900–1200: $F(4.9,83.1) = 4.24$, $p < .005$; 1200–1400: $F(5.9,99.8) = 3.14$, $p < .01$]. These results confirmed a reliable positivity for hits over correct rejections for the entire recording epoch. Table 6.2 shows the mean amplitude of the old/new effects (within modality hits – new and across modality hits – new) at lateral frontal and parietal sites for all four latency regions. Table 6.6. summarises the results of the planned pairwise comparisons conducted on the mean amplitude measurements of the waveforms elicited by old and new items. As before, selected results are described below.

Within Modality Hits vs. New: Planned comparisons on the parietal sites revealed a marginal main effect of response category ($p=.054$) for the 600–900 ms latency region, but no significant effects for any of the other latency regions. ANOVA of the selection of frontal sites resulted in a main effect of response category for the 300–600 and 600–900 ms latency regions. This confirms the existence of an early onsetting frontal ERP old/new effect stretching over bilateral frontal sites. Later in the recording epoch the effect shows a lateralisation to right frontal sites as confirmed by a reliable response category x hemisphere interaction in the 1200–1400 ms latency region (see Table 6.2). Subsidiary ANOVA of the lateral frontal and parietal sites revealed main effects of response category for the 300–1200 ms latency regions and a response category x hemisphere interaction for the 1200–1400 ms region. This result confirms a shift of the frontal ERP old/new effect to the right hemisphere, given that no effects involving the factor of hemisphere were observed for the subsidiary analysis on the parietal sites (see Table 6.2).

The results reported above seem to indicate an absence of any parietal old/new effect. However, visual inspection of Figure 6.3 indicates that the chosen latency regions for analysis might not encompass the peak of the apparent effect. For this reason, a further ANOVA was conducted on the mean amplitude measures of the 600–800 ms latency regions for the lateral parietal sites only, employing the factors of response category (within modality hit vs. correct rejection) and hemisphere (left vs. right). This latency region was chosen to encompass the peak of the positivity apparent in the waveforms for the within modality hits. ANOVA revealed a reliable response category x hemisphere interaction [F(1,17) = 4.92, p < .05], confirming the existence of a left lateralised parietal ERP old/new effect for this latency region (see Figure 6.14b and Table 6.2).

As the subsidiary planned comparisons revealed the existence of an ERP old/new effect over frontal, but not over parietal sites in the 300–600 ms latency regions no further analyses were necessary to establish an earlier onset of the frontal effect.

Across Modality Hits vs. New: Subsidiary planned comparisons on the parietal sites revealed a main effect of response category for the 600–900 and 900–1200 ms region and a response category x hemisphere interaction for the 1200–1400 ms latency region. The results indicate that whereas no lateralisation was evident for the early part of the recording epoch, a maximum over the right hemisphere was apparent in the later part. Similar results were obtained for subsidiary ANOVA on the selection of frontal sites, which revealed a response category x site interaction for the 600–1400 ms regions. The result was qualified by a response category x hemisphere interaction for the 1200–1400 ms region, indicating a shift of the initially bilateral effect to the right hemisphere for this time region (see Table 6.2). Subsidiary ANOVA on the selection of lateral frontal and parietal sites confirmed these results. ANOVA revealed main effects of response category only for the 600–1400 ms latency region, indicating that there was no reliable difference between the effects over frontal and parietal sites.

As mentioned above, there was no reliable indication of a left lateralisation of the parietal old/new effect. Inspection of Figure 6.3 suggests, however, that the lateralisation of the effect might be present, but that the chosen latency region did not encompass the temporal extent of the effect well. Therefore, ANOVA was conducted on the mean amplitude of the left and right parietal site for the 600–800 ms latency region, employing the factors of response category (hit vs. correct rejection) and hemisphere (left vs. right). This region was chosen to encompass the peak of the effect evident in Figure 3. ANOVA resulted in a response category x hemisphere interaction [F(1,17) = 4.70, p < .05], thus confirming that there was indeed a left lateralisation of the effect (see Figure 6.14b).

As for the within modality hits, analyses were carried out to check for differences in onset latency between the left frontal and parietal sites for consecutive 100 ms latency regions from 200–600 ms post-stimulus (for more detailed description see section 6.3.2.1.1.). ANOVA failed to reveal any reliable response category x location interactions in any of the latency regions, thus indicating that there was no difference in effect onset between the frontal and the parietal sites.

(2) Analyses of the subtracted mean amplitudes – Magnitude analyses

Table 6.7 summarises the results of ANOVA on the subtracted mean amplitudes for words as retrieval cues. Figures 6.5 and 6.6 show the difference waveforms for all 25 sites and for a selection of lateral frontal and parietal sites respectively. Over frontal sites, within modality hits show a larger ERP effect than the across modality hits in the 600–1200 ms latency range. Over posterior sites, however, after an initial period of equal magnitude, across modality hits show the larger ERP effect from about 700 ms post-stimulus.

None of the analyses conducted revealed a significant effect for the 300–600 ms latency region. Global ANOVA of the remaining latency regions resulted in reliable modality x site interactions, confirming the existence of magnitude differences for this time period. Subsidiary planned comparisons on the selection of frontal sites confirmed the larger magnitude of the within modality effect with a main effect of modality in the 600–900 ms latency region. Subsidiary ANOVA on the parietal sites also confirmed the reliability of the larger magnitude for the across modality condition, resulting in main effects of modality in the 900–1200 and 1200–1400 ms latency regions. ANOVA of the lateral frontal and parietal sites confirmed these results with reliable modality x location interactions, revealing the reliability of the reversal in magnitude difference from anterior to posterior sites (see Table 6.2).

(3) Analyses of the rescaled subtracted mean amplitudes – Topographic analyses

Table 6.8 summarises the results of the topographic analyses on the rescaled subtracted mean amplitudes for words as retrieval cues. Figure 6.10 shows the topographic maps of the effects for the 600-1400 ms latency regions. The 300–600 ms latency region is not depicted since no significant ERP effects were observed in the across modality condition for this time period. As is evident from the maps, the within modality condition shows a prominent frontally located effect which shifts from the left to the right hemisphere over time. The across modality condition, however, shows a more posterior effect, which also shifts from left to right over time.

Global ANOVA revealed significant modality x site interactions for the 600–1400 ms latency regions indicating differences in scalp distribution between the two response categories in this time region. Subsidiary ANOVA on the selection of lateral frontal and parietal sites revealed reliable modality x location interactions for the same three latency regions. The results confirm the reliability of the topographic differences evident from Figure 6.10.

As for the picture retrieval cues, analyses were undertaken to determine whether the topographic distribution of the frontal ERP old/new effect did indeed shift from an early left to a late right distribution. For this purpose an across epoch ANOVA was performed on the rescaled subtracted mean amplitudes of two latency regions. For within modality hits the regions from 300–600 and 1200–1400 ms (see Figure 6.11) were used, for across modality hits the epochs from 600–900 and 1200–1400 ms. The analyses employed the factors of epoch (300–600/600-900 vs. 1200–1400 ms), hemisphere (left vs. right) and site (F7/LF/F3 vs. F8/RF/F4). ANOVA of the within modality condition resulted in an epoch x hemisphere interaction [$F(1,17) = 11.41$, $p < .005$], indicating that for the within modality condition there is a clear shift from an early bilateral to a late right distribution of the frontal ERP effect. The same interaction was obtained for the across modality hits [$F(1,17) = 9.09$, $p < .01$] indicating that the shift from bilateral to right evident from Figure 6.11 is reliable.

6.3.2.2. Across Group Analyses

6.3.2.2.1. Magnitude Analyses

Figure 6.7 shows the subtraction waveforms for within and across modality conditions for a selection of lateral frontal and parietal sites, compared across retrieval cues. As can be seen from Figure 6.7, pictures show a larger effect than words for the within modality conditions over all depicted sites. In the across modality conditions, both retrieval cues show largely the same magnitude, apart from late in the recording epoch where words show a larger effect over right hemisphere sites.

Global ANOVA revealed a retrieval cue x modality interaction for the 300–600 ms latency region [$F(1,34) = 11.56$, $p < .005$], and reliable retrieval cue x modality x site interactions for the remaining latency regions [600–900: $F(4,136.2) = 7.23$, $p < .001$; 900–1200: $F(4.5,153.3) = 5.93$, $p < .001$; 1200–1400: $F(4.4,150.9) = 2.79$, $p < .05$]. The results indicate reliable differences in magnitude between the hit categories of the two subject groups. The distribution of these differences are elucidated in the subsidiary pairwise comparisons reported below.

Table 6.9 summarises the results of the subsidiary pairwise comparisons conducted on the subtracted mean amplitudes to compare the magnitude of the hit categories across retrieval cues. Selected results are reported below.

(1) Within Modality Conditions

Subsidiary planned comparisons on the parietal sites revealed a main effect of retrieval cue for the 300–1200 ms latency regions, confirming the larger effect for pictures than for words over parietal sites (see Table 6.2). Subsidiary comparisons on the selection of frontal sites resulted in a retrieval cue x site interaction for the 300–600 and 600–900 ms latency regions, and a retrieval cue x hemisphere interaction for the 1200–1400 ms region. The results indicate that, over frontal sites, pictures show a reliably larger effect than words for more than half of the recording epoch. Later on, however, this advantage for pictures is restricted to the left hemisphere, while over the right hemisphere words show the larger effect. Subsidiary ANOVA on the selection of lateral frontal and parietal sites revealed a main effect of retrieval cue for the 300–600 and 600–900 ms latency region and also a marginally significant retrieval cue x location effect for the 600–900 ms latency region. The results confirm the reliability of magnitude difference between pictures and words and also indicate a trend for this difference to be larger over posterior than anterior sites (see Figure 6.7 and Table 6.2).

(2) Across Modality Conditions

As expected from inspection of Figure 6.7, almost no reliable differences in the magnitude of the across modality conditions could be detected. ANOVA of the lateral frontal and parietal sites revealed a significant retrieval cue x hemisphere interaction in the 900–1200 ms latency region and a marginally significant interaction of the same kind in the 1200–1400 ms region. The results indicate that words do show a reliably larger effect over the right hemisphere late in the recording epoch, and that there is no difference for this magnitude difference between anterior and posterior sites.

6.3.2.2.2. Topographic Analyses

Figures 6.12 and 6.13 show the topographic maps for the within and across modality conditions respectively, each figure displaying the conditions for both types of retrieval cue.

The maps for the 300–600 ms latency regions are not displayed as no significant differences were found for any of the comparisons in this time period.

Global ANOVA revealed reliable retrieval cue x modality x site interactions for the 600–900 [F(5.1,175.1) = 4.36, p < .005] and 900–1200 [F(4.8,164.4) = 4.57, p < .005] ms latency regions, indicating reliable differences in the topographies of the hit conditions for the two types of retrieval cue.

Subsidiary planned comparison on the lateral frontal and parietal sites for the within modality conditions revealed a significant retrieval cue x location interaction for the 600–900 ms latency region [F(1,34) = 4.37, p < .05]. A marginally significant interaction of the same type emerged for the 900–1200 ms region [F(1,34) = 3.40, p = .074]. These results reflect the more frontal distribution of the within modality ERP old/new effect for words in comparison to a more centro-posterior distribution of the effect for pictures during these latency regions (see Figure 6.12).

The pairwise comparison on the lateral frontal and parietal sites for the across modality hit conditions resulted in a reliable retrieval cue x hemisphere interaction for the 900–1200 ms latency region [F(1,34) = 5.22, p < .05]. The result reflects the difference in lateralisation of the effects for pictures and words in this condition. Pictures show a left sided maximum whereas for words the maximum is lateralised to the right hemisphere (see Figure 6.13).

6.3.2.3. Summary of the Results

For pictures as retrieval cues, both within and across modality hit conditions show a pronounced left parietal effect which onsets earlier for the within than the across modality condition. Both hit conditions also show an early bilateral frontal effect which over time changes its topographic distribution. For the within modality condition this effect onsets about 200 ms earlier than the left parietal effect and is initially bilateral in distribution but shifts to the left hemisphere over time. The across modality condition also shows a bilateral frontal effect which, over time, shows a trend to shift to a right hemisphere maximum. Other than in the within modality condition, this bilateral frontal effect onsets later than the left parietal effect. During the whole recording epoch, the within modality ERP effects show a larger magnitude than the across modality ERP effects.

For words as retrieval cues both conditions show a left parietal effect, onsetting around 600 ms post-stimulus. For the across modality condition this effect shifts to the right hemisphere later in the recording epoch. In addition to the left parietal effect, the within modality condition also shows an early bilateral frontal effect which, over time, shifts to a right hemisphere maximum. As for the picture stimuli this effect onsets about 200 ms earlier than the left parietal effect. The across modality condition also shows a bilateral frontal effect which changes its topographic distribution over time from a bilateral to a late right frontal maximum. In contrast to the within modality condition there is no reliable onset difference between the parietal and the frontal ERP effects. Differences in magnitude of the ERP effects show a reversal from anterior to posterior scalp sites. Over frontal sites, within modality hits show a reliably larger effect than across modality hits from about 600–1200 ms, whereas over posterior sites across modality hits display the larger effect from about 900 ms onwards.

In magnitude comparisons across stimulus types, picture retrieval cues show a larger effect for the within modality hit conditions over nearly the whole recording epoch. This difference is larger over posterior than anterior sites. In the across modality conditions, both retrieval cues show largely the same magnitude, apart from late in the recording epoch where words show a larger effect over right hemisphere sites.

The topographic distribution of the effects compared across stimulus types revealed that, for the within modality conditions, words show a more frontal maximum whereas pictures show a more central distribution of the effects from about 600–1200 ms post-stimulus. For the across modality conditions, differences only emerged later in the recording epoch where pictures show a centrally distributed maximum whereas words show the largest effect over the right hemisphere.

6.4. Discussion

The recognition accuracy scores demonstrate a picture superiority effect in the within modality conditions. Comparison of the across modality conditions revealed that when pictures were encoded stimuli (words at retrieval) performance was significantly better than for words as encoding stimuli (pictures at retrieval). These results indicate that the picture superiority effect is most probably due to encoding rather than retrieval conditions. The performance results were mirrored by the RT results. Responses were significantly faster for pictures than for words in the within modality conditions. They were also reliably faster in the across modality condition when pictures were the encoding stimuli (words at retrieval) rather than words (pictures at retrieval). Thus, the picture superiority effect is not only evident in accuracy measures, but also in RT measures (for similar results see Stenberg, Radeborg & Hedman, 1995).

The aim of the present study was to determine whether the emergence of the two frontal effects in experiment 1 was an outcome of the encoding of the richer perceptual and semantic code inherent in the picture stimuli. To this extent the present study considered whether any of the old/new effects observed in Experiment 1 were sensitive to changes in the surface form between study and test items, and in how far the encoding of qualitatively different items would lead to qualitatively different ERP correlates of retrieval. Before addressing the latter question, each old/new effect will be discussed in turn with respect to its sensitivity to changes in surface form between study and test.

6.4.1. The Left Parietal Old/New Effect

Replicating the results from Experiment 1, all four conditions showed a left lateralised parietal old/new effect (see Figure 6.14 a,b). The picture within modality condition revealed the earliest onset for this effect, around 400 ms, all other conditions showed a much later onset (around 600 ms). Interestingly, the picture within modality condition and the word across modality condition both also revealed effects over right parietal sites (see Figures 6.3, 6.6, 6.8 and 6.9). For the picture within modality condition this effect onset around the same time as the left parietal effect and carried on until the end of the recording epoch. For the word across modality condition the effect onset late in the recording epoch and coincided with a strong right frontal effect, suggesting the possibility of propagation of the activity from anterior to posterior sites. Inspection of Table 6.2 reveals that for both those conditions the mean amplitude of the ERPs is larger over the lateral parietal than frontal sites, suggesting that volume conduction would not have occurred from anterior to posterior sites, but rather the reverse. Given this possibility, it is notable that the positive shift over right parietal sites was present for the two conditions in which pictures were the encoding stimuli. This would suggest that information encoded from pictorial stimuli does engage additional neural generators at retrieval that are not engaged for items that were encoded from words. However, replication of the observed pattern of effects is needed to justify any further investigation.

The magnitude analyses revealed the more interesting results, addressing the point as to whether the left parietal effect is in any way sensitive to the lack of perceptual overlap between study and test in the across modality conditions. It emerged that for picture retrieval cues the within modality condition showed a significantly larger effect than the across modality condition. However, for words as retrieval cues the effects for the two conditions were of equal magnitude until about 800 ms post-stimulus from which point onwards the across modality condition elicited the significantly larger effect. From these results, it appears that the left parietal old/new effect was largest when pictures were the encoding stimuli but that this retrieval advantage onset later in time under conditions of surface change between study and test. A systematic magnitude difference occurring between the within and across modality conditions, independent of type of encoding stimulus, would have indicated that the left parietal effect is indeed sensitive to perceptual overlap between study and test and thus, at least partially, elicited by data-driven processes. However, the fact that the magnitude of the effect varies with the type of encoding stimulus (i.e., it is larger when pictures were encoded rather than words), suggests that the effect indexes recollecion mediated by conceptually-driven processes (Rajaram, 1996; Roediger & Blaxton, 1987).

6.4.2. The Early Bilateral Frontal Effect

As well as a left parietal effect, all conditions in this study displayed an early bilateral frontal effect. For the two within modality conditions, this effect onset prior to the left parietal effect, around 250ms post-stimulus for pictures and around 400 ms post-stimulus for words. In addition to the onset difference of the effect for the two types of retrieval cue, it also displayed a magnitude difference. The effect showed a larger amplitude for pictures than for words (see Figure 6.7). In the across modality conditions the effect onset much later, around the same time or even later than the left parietal effect. Thus, for the across modality conditions, it is possible that the bilateral frontal effect is due to propagation of activity from the posterior to the anterior sites. Inspection of Table 6.2 reveals that the mean amplitude of the ERPs is larger over the left lateral parietal than the left lateral frontal electrode site for both across modality conditions. This suggests that the bilateral frontal effect might indeed be the result of volume conduction rather than a real old/new effect. Taken together, these findings suggest that the early bilateral effect, first observed in Experiment 1, is indeed sensitive to the perceptual overlap between study and test. Furthermore, the earlier onset of the effect for the picture than the word within modality condition and its larger magnitude for the former condition suggests that it might also be sensitive to the factors responsible for the memory advantage of pictorial stimuli. There is strong evidence that it is the more distinctive perceptual information inherent in pictorial stimuli that is responsible for the picture superiority effect (Nelson, 1979; Nelson, Reed & McEvoy, 1977; Weldon & Coyote, 1997). Thus, it could be argued that the bilateral frontal effect is functionally correlated to perceptual, data-driven processes (Jacoby, 1983; Roediger et al., 1989), which predominantly occur under conditions of perceptual overlap between study and test items.

This interpretation finds support in the results of a study by Wilding and Rugg (1997b). In their study, subjects were presented visually with words they were asked to read out loud, or were presented with words auditorily. At test subjects were required to make an initial old/new judgement to the items from the study phase and an equal amount of new items. For those items judged old they were required to make a subsequent source judgement (heard or spoken at study). They found an early bilateral effect which was larger for those items which were presented in the same modality at study and test (i.e., visually) than for those which were presented in different modalities (i.e., auditorily at study – visually at test). Unfortunately, Wilding and Rugg did not analyse possible differences in onset time between the bilateral frontal and the left parietal effect. However, the results obtained in their study provide further evidence that the early bilateral frontal effect is sensitive to perceptual overlap between study and test.

The present experiment provides further evidence for the independence of the early bilateral frontal effect from tasks requiring the recollection of contextual information as it is present for a simple recognition memory judgement only. A recent study by Rugg et al., (1998) supports these results. In their study, they manipulated memory encoding by cueing subjects to perform either a 'shallow' or a 'deep' encoding task (Craik & Lockhard, 1972). At test subjects performed a simple old/new recognition memory judgement which, for correctly recognised old items, elicited an early bilateral frontal component in the 300–500 ms latency region. Given its distribution and latency region, this component is most likely to be equivalent to the early bilateral component found in the present study. Interestingly, the bilateral frontal effect in the Rugg et al. (1998) study was not sensitive to the levels of processing manipulation implemented at study. Rugg et al. (1998) argued that the depth of processing manipulation employed at study would enhance recollection, but would not influence data-driven processes. The insensitivity of the early bilateral frontal effect to depth of processing led Rugg et al. (1998) to suggest that the component may reflect familiarity-driven recognition processes, thought to be insensitive to depth of processing manipulations at study (c.f. Jacoby, 1996; Toth, 1996). Given the suggested involvement of data-driven processes in familiarity-driven recognition (Jacoby, 1996; Jacoby & Dallas, 1981) it could be suggested that the early bilateral frontal component reflects familiarity-driven recognition which is sensitive to successful data-driven processing of the stimulus. However, this conclusion can at best be regarded as tentative and further research is needed to establish this component as the correlate of familiarity-driven recognition.

The emergence of the early frontal effect for the two within modality conditions, rather than just those in which pictures were the encoding stimuli, is somewhat unexpected as in Experiment 1 the effect was only present in the picture condition. One possible explanation for this unexpected occurrence could lie in the test format in which items were presented in the present study. All test items were presented randomly, independent of which experimental condition they belonged to. This randomised presentation might make a shift between retrieval processes or strategies for the different types of items difficult, if not impossible (Johnson, Nolde, Mather, Kounios, Schacter & Curran, 1997). This possibility will be addressed in Experiment 3.

6.4.3. The Late Right Frontal Effect

Results regarding the late right frontal effect were mixed. The two conditions which showed a clear right frontal effect were the word within and word across modality condition (see Figures 6.3 and 6.11). The picture within modality condition, rather than showing a right lateralised effect, resulted in a late effect maximal over left frontal sites. The picture across modality condition, however, showed a bilateral distribution over frontal sites which later shifted to a right-sided maximum (see Figures 6.3 and 6.10).

The results do not support the initial expectation, that a late right frontal effect would most likely emerge for those conditions in which pictures were the encoded stimuli. This pattern could have been expected if the stronger perceptual representation of pictures was the cause for the frontal effects observed in Experiment 1. Rather surprisingly, the picture within modality condition did not show a right lateralised frontal effect but revealed a lateralisation to left frontal sites instead. An explanation for this result is not readily available. However, inspection of Figure 6.8 reveals that whilst the maximum of the effect was centered around the midline, the effect stretched further towards inferior sites over the left hemisphere than over the right. This pattern could explain the finding of a left-hemisphere maximum over frontal sites, though it is not at all clear why this should happen. The word across modality condition did, however, result in a late right frontal effect, which was coincidental with a later right hemisphere shift over temporo-parietal sites. The negative gradient in mean amplitude from posterior to anterior sites, evident from Table 6.2, suggests the possibility that the frontal effect was, at least partly, the result of a conduction artifact from parietal sites. Thus, caution is necessary in the interpretation of this finding. Speculating, however, that the possible volume conduction merely enhanced the frontal effect, it is interesting to note that the right frontal effect did emerge in a condition in which pictures were the encoding stimuli, but words the retrieval cues. Such a result would support the suggestion made in Experiment 1 that the emergence of the right frontal effect might be related to the richness or amount of information that is retrieved in response to the test cue, rather than the requirement to retrieve contextual information. However, given the possibility of a conduction artifact, the support for the results from Experiment 1 can only be very tentative.

Rather unexpectedly, the two conditions in which words were the encoding stimuli (i.e., the word within and picture across modality conditions) elicited a late right frontal effect. For the word within modality condition a possible explanation could lie in the high recognition rate achieved by the experimental subjects (see Table 6.1). Allan and Rugg (1997) found a late right frontal effect in a simple recognition memory task using verbal stimuli under similar conditions. However, comparing the recognition rates from Experiment 1 and 2, it appears that performance is very similar for the word condition in Experiment 1 and the word within modality condition in the present study (87.5% and 87.1% hits respectively). This comparison makes an explanation in terms of a high recognition performance unlikely. More parsimoniously, and similarly to the unexpected occurrence of the early left/bilateral old/new effect discussed above, it could be suggested that the right frontal effect occurs as a result of the randomised presentation of test items.

The comparison of the magnitude of the effect for the within and across modality conditions for each of the two types of retrieval cue would address the question of the sensitivity of the effect to changes in surface form between study and test. In the present study this comparison could only be made for the word conditions, as the picture within modality condition displayed a rather unexpected left-sided maximum over frontal sites late in the recording epoch. For the word retrieval cue conditions, ANOVA did not reveal any differences in magnitude between the two conditions during this time (1200–1400 ms post-stimulus) indicating that the right frontal effect may not be sensitive to changes in surface form. Such a finding would support earlier conjectures (Donaldson & Rugg, 1998; Wilding & Rugg 1997a) that the functional locus of this effect is one of post-retrieval processes, operating on the outcome of the actual retrieval process. However, the interpretation of this result is hampered by two issues. Firstly, the right frontal effect occurs simultaneously with a right hemisphere maximum over temporo-parietal sites (see Figure 6.6). The magnitude of the frontal effect could thus be boosted by propagation of activity from posterior sites. Secondly, if it is indeed the case that the randomised presentation of the test items at retrieval is a pertinent factor in eliciting the right frontal effect in those conditions in which words are the retrieval cues, then comparison of the two conditions is meaningless and renders the results uninterpretable. These issues will be addressed in Experiment 3.

6.4.4. Topographic Comparisons

One issue, addressed by the current study, is whether the encoding of items as different as words and pictures results in qualitatively different ERP patterns at retrieval, as suggested by the results of Experiment 1. Such qualitative differences can be demonstrated by contrasting the scalp topography of ERP effects associated with the conditions in question. In cases where reliable differences in the topography emerge they can reflect changes in either the loci of the neural generators of the effect, or the relative levels of activation of multiple neural generators common to each condition.

From the topographic comparisons of the within and across modality conditions it appears that for both types of retrieval cue the within modality conditions showed the more anterior maximum, whereas the across modality conditions revealed a more posterior distribution of effects. This was evident especially for words as retrieval cues, for which ANOVA revealed reliable response category x location interactions from 600 ms onwards. For the 1200–1400 ms latency region this interaction probably arose due to a strong right parietal maximum, co-occurring with an equally strong right frontal effect. Thus, late in the recording epoch the difference was most likely not due to an absence of frontal effects in the across modality condition, but the presence of a (unexpected) right parietal maximum. Picture retrieval cues did not show reliable differences in distribution until 900 ms post-stimulus, from which point on a similar pattern arose as for words. Again, topographic differences between the two conditions in the 1200–1400ms latency region were probably due to a different hemispheric distribution over posterior sites whilst both conditions showed strong frontal effects.

The direct comparison of within and across modality conditions across type of retrieval cue supports this suggestion. No major topographic differences were found for the across modality conditions, apart from that of a retrieval cue x hemisphere interaction in the 900–1200 ms latency region which resulted from a bilaterally distributed parietal effect for words in comparison to a left lateralised parietal effect for pictures. Similarly, comparison of the within modality conditions only resulted in a retrieval cue x location interaction for the 600–900 ms latency region. This interaction arose from a more central maximum for pictures in comparison to a very pronounced frontal maximum for words. The more central maximum for pictures rather than words probably arose due to a very strong left parietal effect cooccuring with the frontal effects. Interestingly, the latter comparisons did not show any topographic differences for the 1200–1400 ms latency region, suggesting that the frontal effects, evident for this latency region in all conditions, are independent of type of encoding stimulus and type of presentation at test.

As discussed above, the strong frontal components evident for those conditions in which words were the encoding stimuli are unexpected. A possible reason for this state of affairs could be the randomised presentation of test items, an issue which will be addressed in the following study.

6.5 Summary and Conclusions

All experimental conditions showed a left parietal old/new effect which did not appear to be sensitive to changes in surface form between study and test items. However, the effects appeared to be sensitive to the type of information that was retrieved in that it was largest for the retrieval of those items which were most easily recollected (i.e., pictures). In addition, all experimental conditions showed an early bilateral frontal effect which, contrary to the left parietal old/new effect, appeared to be sensitive to perceptual overlap between study and test. The occurrence of this effect for all conditions was somewhat surprising and it was suggested that the randomised presentation of the test items might make a switch between retrieval strategies normally employed for the different types of items difficult. The same explanation was offered for the unexpected occurrence of a reliable late right frontal effect in those conditions in which words were the encoding stimuli. The conditions in which the emergence of a late right frontal effect was expected rendered mixed results. A left rather than right frontal maximum was evident in the picture within modality condition. The word across modality condition showed the expected component but it coincided with a late right positivity over posterior sites which made any interpretation of the result difficult. Topographic differences were independent of type of encoding stimulus but varied systematically with the presence or absence of modality change between study and test. Whereas within modality conditions showed the more frontally distributed effects, across modality conditions revealed a consistent maximum over more posterior scalp regions. This pattern was consistently evident up to 1200 ms post-stimulus, after which all conditions resulted in frontally distributed effects. No topographic differences where evident in this time region when comparing within and across modality conditions across retrieval cues.

Table 6.1 Summary of Accuracy and Reaction Time results for Experiment 2

	Retrieval **Picture (Group1)**			***Retrieval*** **Word (Group 2)**		
Encoding	P(Hit)	p(Hit) – p(FA)	CR	p(Hit)	p(Hit) – p(FA)	CR
Accuracy:						
Within Modality	97.3 (4.1)	81.7 (12.4)	84.4 (10.6)	87.1 (8.5)	74.7 (8.9)	87.1 (6.4)
Across modality	73.5 (10.1)	57.8 (12.9)	84.4 (10.6)	85.3 (5.1)	72.9 (12.3)	87.1 (6.4)
Reaction Time						
Within Modality	844 (187)		1215 (286)	961 (254)		1134 (264)
Across Modality	1088 (274)		1215 (286)	1025 (255)		1134 (264)

Table 6.2 Mean amplitude of the ERP effects (within modality hit – new and across modality hit – new) at lateral frontal and parietal sites for the 300-600, 600-900, 900-1200 and 1200-1400 ms latency regions for pictures and words as retrieval cue.

	Within Modality				**Across Modality**			
	LF	RF	LP	RP	LF	RF	LP	RP
PICTURES								
300 – 600 ms	3.42	2.91	2.82	1.55	1.23	0.89	0.89	0.21
600 – 900 ms	4.36	3.93	5.55	3.62	1.45	1.07	2.62	0.52
900 – 1200 ms	2.17	2.38	2.97	2.92	0.86	0.40	2.65	0.85
1200 – 1400 ms	1.81	0.79	1.15	1.83	-0.29	0.40	1.18	0.59
WORDS								
300 – 600 ms	1.56	1.16	0.93	0.57	0.78	0.80	0.69	0.64
600 – 900 ms	3.09	2.95	1.56	0.50	1.09	1.06	1.99	1.18
900 – 1200 ms	1.78	2.70	0.79	0.81	0.81	1.79	2.28	2.50
1200 – 140 ms	0.31	1.84	0.18	0.68	0.33	1.98	1.27	2.46

Table 6.3 Summary of ANOVA on the mean amplitude measures for correctly recognised and new items for pictures as retrieval cue (Group 1)

	Within Modality vs. New	**Across Modality vs.New**
300 – 600 ms		
LF/RF vs. LP/RP		
RC	F(1,17) = 44.68, p < .001	F(1,17) = 17.78, p < .005
RC x LC	n.s.	n.s.
RC x HM	n.s.	n.s.
RC x LC x HM	n.s.	n.s.
LP vs. RP		
RC	n.s.	F(1,17) = 4.79, p < .05
RC x HM	F(1,17) = 7.54, p < .05	n.s.
F7/LF/F3 vs. F8/RF/F4		
RC	F(1,17) = 36.70, p < .001	n.s.
RC x HM	n.s.	n.s.
RC x ST	F(1.2,20.2) = 24.37, p < .001	n.s.
RC x HM x ST	n.s.	n.s.
600 – 900 ms		
LF/RF vs. LP/RP		
RC	F(1,17) = 53.63, p < .001	F(1,17) = 21.16, p < .001
RC x LC	n.s.	n.s.
RC x HM	n.s.	n.s.
RC x LC x HM	F(1,17) = 5.65, p < .05	F(1,17) = 5.33, p < .05
LP vs. RP		
RC	F(1,17) = 65.79, p < .001	F(1,17) = 12.27, p < .005
RC x HM	F(1,17) = 5.66, p < .05	F(1,17) = 8.95, p < .01
F7/LF/F3 vs. F8/RF/F4		
RC	F(1,17) = 27.45, p < .001	F(1,17) = 13.10, p < .005
RC x HM	n.s.	n.s.
RC x ST	F(1.2,21) = 32.20, p < .001	F(1.4,24) = 10.99, p < .005
RC x HM x ST	F(1.8,30.1) = 5.49, p < .05	n.s.

	Within Modality vs. New	**Across Modality vs. New**
900 – 1200 ms		
LF/RF vs. LP/RP		
RC	F(1,17) = 15.40, p < .005	F(1,17) = 22.23, p < .001
RC x LC	n.s.	n.s.
RC x HM	n.s.	F(1,17) = 4.35, p = .053*
RC x LC x HM	n.s.	n.s.
LP vs. RP		
RC	F(1,17) = 25.83, p < .001	F(1,17) = 19.34, p < .001
RC x HM	n.s.	F(1,17) = 5.93, p < .05
F7/LF/F3 vs. F8/RF/F4		
RC	F(1,17) = 6.94, p < .05	n.s.
RC x HM	n.s.	n.s.
RC x ST	F(1.1,18.4) = 12.51, p < .005	F(1.3,23.1) = 13.65, p < .005
RC x HM x ST	F(1.2,21.2) = 4.26, p < .05	n.s.
1200 – 1400 ms		
LF/RF vs. LP/RP		
RC	n.s.	n.s.
RC x LC	n.s.	n.s.
RC x HM	n.s.	n.s.
RC x LC x HM	n.s.	n.s.
LP vs.RP		
RC	F(1,17) = 6.20, p < .05	F(1,17) = 4.64, p < .05
RC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RC	n.s.	n.s.
RC x HM	n.s.	n.s.
RC x ST	F(1.2,19.6) = 4.99, p < .05	F(1.3,22.5) = 6.72, p < .05
RC x HM x ST	F(1.4,24.1) = 10.50, p < .005	n.s.

RC = Response Category (hit vs. correct rejection), ST = Site, LC = Location (anterior vs. posterior), HM = Hemisphere (right vs. left), * = marginally significant

Table 6.4 Summary of ANOVA on the subtracted mean amplitude measures for pictures as retrieval cue (Magnitude Analyses – Group 1)

300 – 600 ms		
Global ANOVA	MD	F(1,17) = 34.03, p < .001
	MD x ST	F(4.1,69.3) = 6.46, p < .001
LF/RF vs. LP/RP	MD	F(1,17) = 25.31, p < .001
LP vs. RP	MD	F(1,17) = 21.33, p < .001
F7/LF/F3 vs. F8/RF/F4	MD	F(1,17) = 22.61, p < .001
	MD x ST	F(1.4,24.21) = 18.27, p < .001
600 – 900 ms		
Global ANOVA	MD	F(1,17) = 51.53, p < .001
	MD x ST	F(5.3,90.7) = 6.77, p < .001
LF/RF vs. LP/RP	MD	F(1,17) = 48.01, p = .001
LP vs. RP	MD	F(1,17) = 71.70, p < .001
F7/LF/F3 vs. F8/RF/F4	MD	F(1,17) = 25.94, p < .001
	MD x ST	F(1.4,24.6) = 24.69, p < .001
900 – 1200 ms		
Global ANOVA	MD	F(1,17) = 8.45, p < .05
	MD x ST	F(5.6,90.7) = 4.74, p < .001
LF/RF vs. LP/RP	MD	F(1,17) = 6.22, p < .05
	MD x HM	F(1,17) = 8.78, p < .01
LP vs.RP	MD	F(1,17) = 5.04, p < .05
	MD x HM	F(1,17) = 13.58, p < .01
F7/LF/F3 vs. F8/RF/F4	MD	F(1,17) = 5.92, p < .05
1200 – 1400 ms		
Global ANOVA	no significant effects	
LF/RF vs. LP/RP	MD x LC x HM	F(1,17) = 10.16, p < .01
LP vs.RP	MD x HM	F(1,17) = 4.81, p < .05
F7/LF/F3 vs. F8/RF/F4	MD x HM	F(1,17) = 5.28, p < .05
	MD x HM x ST	F(1.9,32.2) = 6.44, p < .01

MD = Modality (within vs. across), ST = Site, LC = Location (anterior vs. posterior), HM = Hemisphere (right vs. left), * = marginally significant

Table 6.5 Summary of ANOVA on the rescaled subtracted mean amplitude measures for pictures as retrieval cue (Topographic Analyses – Group 1)

300 – 600 ms	no significant results for this latency region	
600 – 900 ms	no significant results for this latency region	
900 – 1200 ms		
Global ANOVA	MD x ST	F(5.4,91.1) = 3.19, p < .01
LF/RF vs. LP/RP	MD x LC x HM	F(1,17) = 5.11, p < .05
1200 – 1400 ms		
Global ANOVA	no significant effects	
LF/RF vs. LP/RP	MD x LC x HM	F(1,17) = 11.41, p < .01

MD = Modality (within vs. across), ST = Site, LC = Location (anterior vs. posterior), HM = Hemisphere (right vs. left)

Table 6.6 Summary of the results of ANOVA on the mean amplitude measures for correctly recognised and new items for words as retrieval cue (Group 2)

	Within Modality vs. New	**Across Modality vs.New**
300 – 600 ms		
LF/RF vs. LP/RP		
RC	F(1,17) = 9.48, p < .01	n.s.
RC x LC	n.s.	n.s.
RC x HM	n.s.	n.s.
RC x LC x HM	n.s.	n.s.
LP vs. RP		
RC	n.s.	n.s.
RC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RC	F(1,17) = 6.48, p < .05	n.s.
RC x HM	n.s.	n.s.
RC x ST	n.s.	n.s.
RC x HM x ST	n.s.	n.s.
600 – 900 ms		
LF/RF vs. LP/RP		
RC	F(1,17) = 15.16, p < .005	F(1,17) = 10.23, p < .01
RC x LC	F(1,17) = 4.38, p = .052	n.s.
RC x HM	n.s.	n.s.
RC x LC x HM	n.s.	n.s.
LP vs. RP		
RC	F(1,17) = 4.19, p = .054	F(1,17) = 12.88, p < .005
RC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RC	F(1,17) = 11.84, p < .005	n.s.
RC x HM	n.s.	n.s.
RC x ST	n.s.	F(1.2,21) = 8.26, p < .01
RC x HM x ST	n.s.	n.s.

	Within Modality vs. New	**Across Modality vs. New**
900 – 1200 ms		
LF/RF vs. LP/RP		
RC	$F(1,17) = 8.93, p < .01$	$F(1,17) = 13.90, p < .005$
RC x LC	n.s.	$F(1,17) = 4.34, p = .053$*
RC x HM	n.s.	n.s.
RC x LC x HM	n.s.	n.s.
LP vs. RP		
RC	n.s.	$F(1,17) = 19.19, p < .001$
RC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RC	$F(1,17) = 7.72, p < .05$	$F(1,17) = 4.84, p < .05$
RC x HM	n.s.	n..s
RC x ST	$F(1.3,22.9) = 4.88, p < .05$	$F(1.3,22.5) = 9.78, p < .005$
RC x HM x ST	n.s.	n.s.
1200 – 1400 ms		
LF/RF vs. LP/RP		
RC	n.s.	$F(1,17) = 6.20, p < .01$
RC x LC	n.s.	n.s.
RC x HM	$F(1,17) = 5.17, p < .05$	$F(1,17) = 9.46, p < .01$
RC x LC x HM	n.s.	n.s.
LP vs.RP		
RC	n.s.	$F(1,17) = 8.17, p < .05$
RC x HM	n.s.	$F(1,17) = 4.59, p < .05$
F7/LF/F3 vs. F8/RF/F4		
RC	n.s.	n.s.
RC x HM	$F(1,17) = 5.06, p < .05$.	$F(1,17) = 9.01, p < .01$
RC x ST	$F(1.5,25.2) = 5.46, p < .01$	$F(1.2,20.9) = 6.08, p < .05$
RC x HM x ST	n.s.	n.s.

RC = Response Category (hit vs. correct rejection), ST = Site, LC = Location (anterior vs. posterior), HM = Hemisphere (right vs. left), * = marginally significant

Table 6.7 Summary of ANOVA on the subtracted mean amplitude measures for words as retrieval cue (Magnitude Analyses – Group 2)

300 – 600 ms	no significant effects for this latency region	
600 – 900 ms		
Global ANOVA	MD x ST	F(7.2,46.6) = 6.71, p < .005
LF/RF vs. LP/RP	MD x LC	F(1,17) = 12.89, p < .005
LP vs. RP	no significant effects	
F7/LF/F3 vs. F8/RF/F4	MD	F(1,17) = 8.02, p < .01
900 – 1200 ms		
Global ANOVA	MD x ST	F(3,50.7) = 6.42, p < .005
LF/RF vs. LP/RP	MD x LC	F(1,17) = 12.85, p < .005
LP vs.RP	MD	F(1,17) = 10.04, p < .01
F7/LF/F3 vs. F8/RF/F4	no significant effects	
1200 – 1400 ms		
Global ANOVA	MD x ST	F(3,50.9) = 3.41, p < .05
LF/RF vs. LP/RP	MD x LC	F(1,17) = 5.58, p < .05
LP vs. RP	MD	F(1,17) = 6.76, p < .05
F7/LF/F3 vs. F8/RF/F4	no significant effects	

MD = Modality (within vs. across), ST = Site, LC = Location (anterior vs. posterior), HM = Hemisphere (right vs. left), * = marginally significant

Table 6.8 Summary of ANOVA on the rescaled subtracted mean amplitude measures for words as retrieval cue (Topographic Analyses – Group 2)

300 – 600 ms	no comparisons could be performed due to too much noise in the across modality condition	
600 – 900 ms		
Global ANOVA	MD x ST	F(4.4,75.1) = 4.99, p < .005
LF/RF vs. LP/RP	MD x LC	F(1,17) = 12.99, p < .005
900 – 1200 ms		
Global ANOVA	MD x ST	F(3.4,57.1) = 6.73, p < .001
LF/RF vs. LP/RP	MD x LC	F(1,17) = 14.98, p < .005
1200 – 1400 ms		
Global ANOVA	MD x ST	F(2.9,50) = 2.91, p < .05
LF/RF vs. LP/RP	MD x LC	F(1,17) = 4.35, p =.053*

MD = Modality (within vs. across), ST = Site, LC = Location (anterior vs. posterior), HM = Hemisphere (right vs. left), * = marginally significant

Table 6.9 Summary of results of ANOVA on subtracted mean amplitudes comparing within and across modality hit categories across retrieval cues (Magnitude Analyses across retrieval cues)

	Within Modality	**Across Modality**
300 – 600 ms		
LF/RF vs. LP/RP		
RTC	F(1,34) = 9.42, p < .005	F(1,34) = 17.78, p < .005
RTC x LC	n.s.	n.s.
RTC x HM	n.s.	n.s.
RTC x LC x HM	n.s.	n.s.
LP vs. RP		
RTC	F(1,34) = 6.34, p < .05	n.s.
RTC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RTC	F(1,34) = 6.62, p < .05	n.s.
RTC x HM	n.s.	n.s.
RTC x ST	F(1.2,42) = 6.09, p < .05	n.s.
RTC x HM x ST	n.s.	n.s.
600 – 900 ms		
LF/RF vs. LP/RP		
RTC	F(1,34) = 8.77, p < ..01	n.s.
RTC x LC	n.s.	n.s.
RTC x HM	F(1,34) = 3.95, p = .055*	n.s.
RTC x LC x HM	n.s.	n.s.
LP vs. RP		
RTC	F(1,34) = 22.21, p < .001	n.s.
RTC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RTC	n.s.	n.s.
RTC x HM	n.s.	n.s.
RTC x ST	F(1.2,41.5) = 13.2, p < .001	n.s.
RTC x HM x ST	n.s.	n.s.

	Within Modality vs. New	**Across Modality vs. New**
900 – 1200 ms		
LF/RF vs. LP/RP		
RTC	n.s.	n.s.
RTC x LC	n.s.	n.s.
RTC x HM	n.s.	F(1,34) = 5.25, $p < .05$
RTC x LC x HM	n.s.	n.s.
LP vs. RP		
RTC	F(1,34) = 7.50, $p < .05$	n.s.
RTC x HM	n.s.	F(1,34) = 3.89, $p = .057$*
F7/LF/F3 vs. F8/RF/F4		
RTC	n.s.	n.s.
RTC x HM	n.s.	n.s.
RTC x ST	n.s.	n.s.
RTC x HM x ST	n.s.	n.s.
1200 – 1400 ms		
LF/RF vs. LP/RP		
RTC	n.s.	n.s.
RTC x LC	n.s.	n.s.
RTC x HM	n.s.	F(1,34) = 3.86, $p = .058$*
RTC x LC x HM	n.s.	n.s.
LP vs.RP		
RTC	n.s.	n.s.
RTC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RTC	n.s.	n.s.
RTC x HM	F(1,34) = 6.29, $p < .05$.	n.s.
RTC x ST	n.s.	n.s.
RTC x HM x ST	n.s.	n.s

RTC = Retrieval Cue (pictures vs. words), ST = Site, LC = Location (anterior vs. posterior), HM = Hemisphere (right vs. left), * = marginally significant

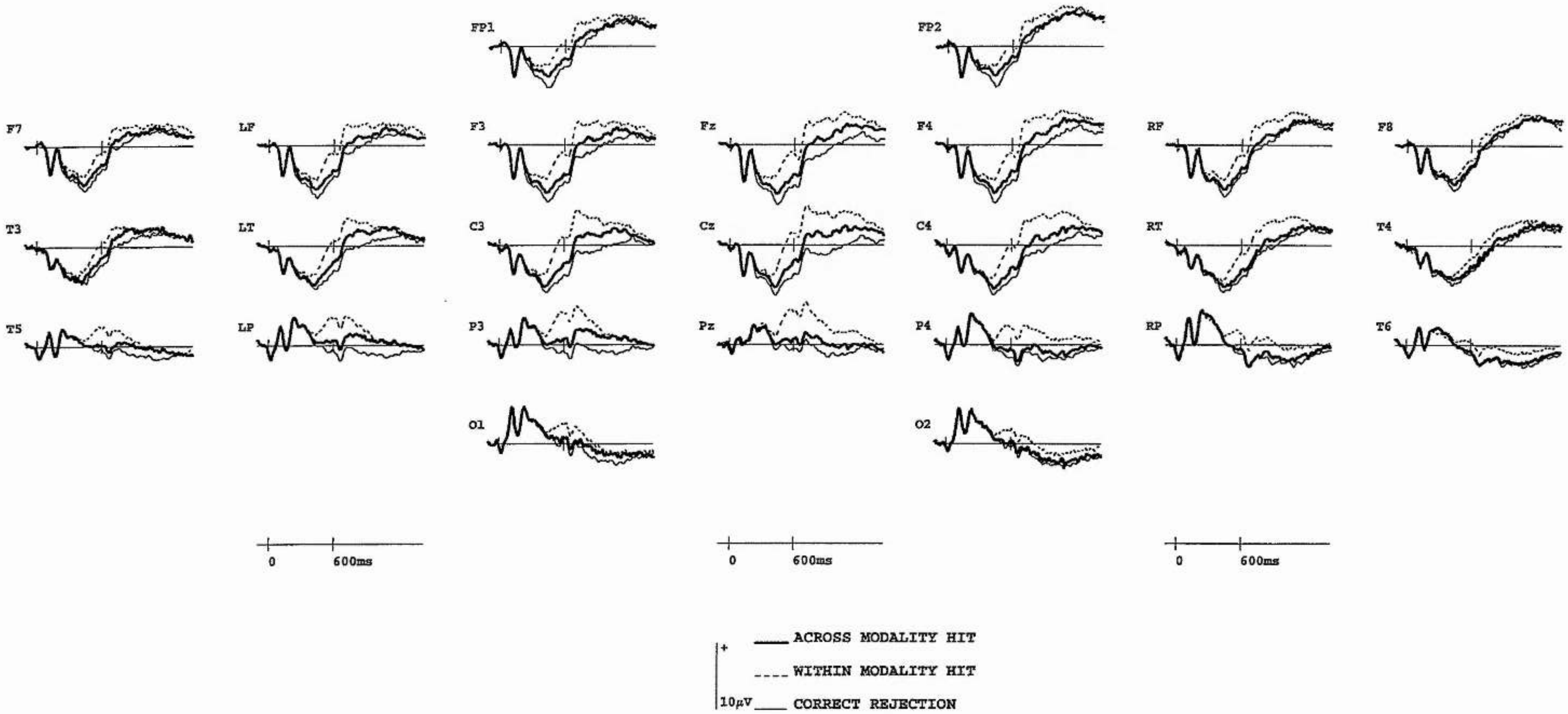


Figure 6.1: Grand average ERPs elicited by correctly recognised old items in the within modality condition (*within modality hits*) and the across modality condition (*across modality hits*) and by correctly rejected new items (*correct rejections*) for pictures as retrieval cues. See Figure 4.1 for a description of the site labels.

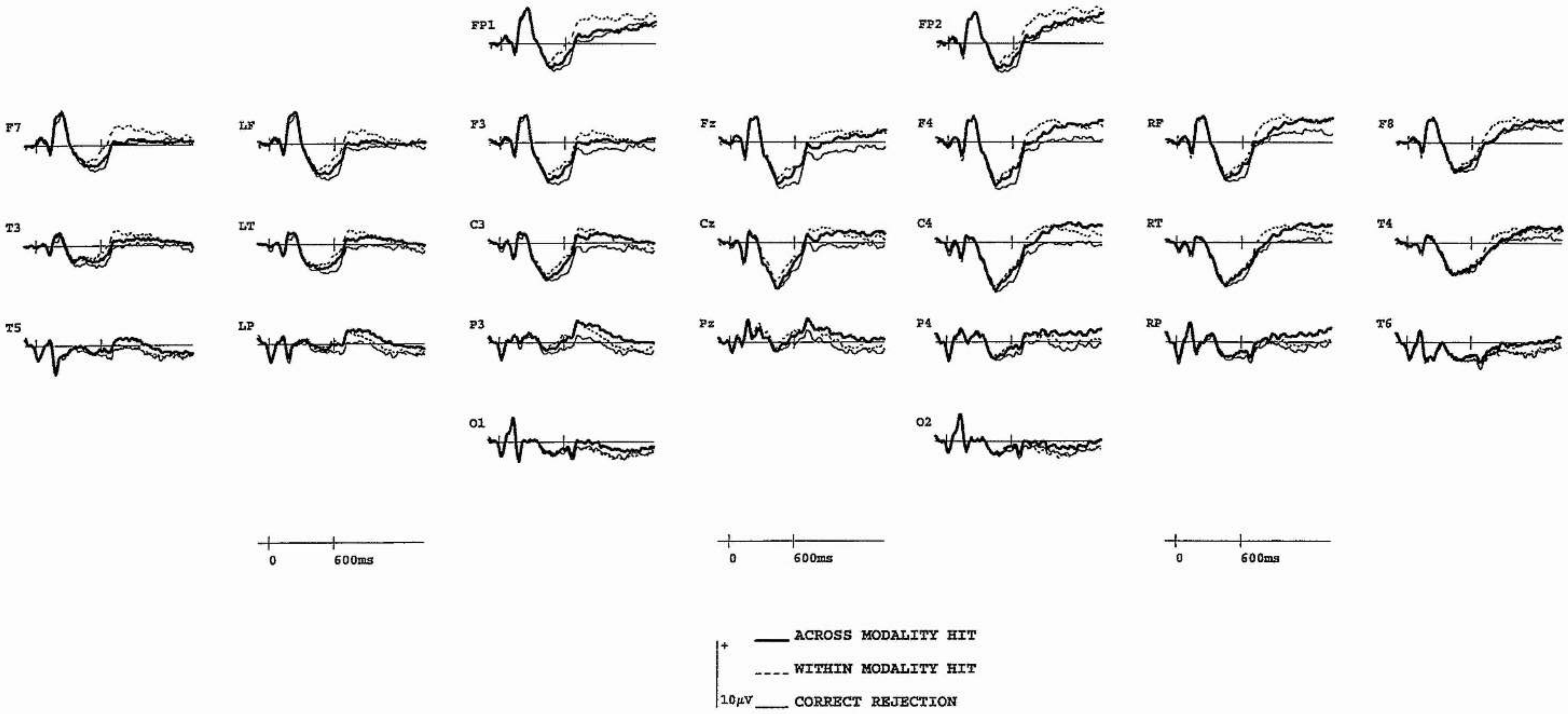


Figure 6.2: Grand average ERPs elicited by correctly recognised old items in the within modality condition (*within modality hits*) and the across modality condition (*across modality hits*) and by correctly rejected new items (*correct rejections*) for words as retrieval cues. Electrode sites as in Figure 6.1.

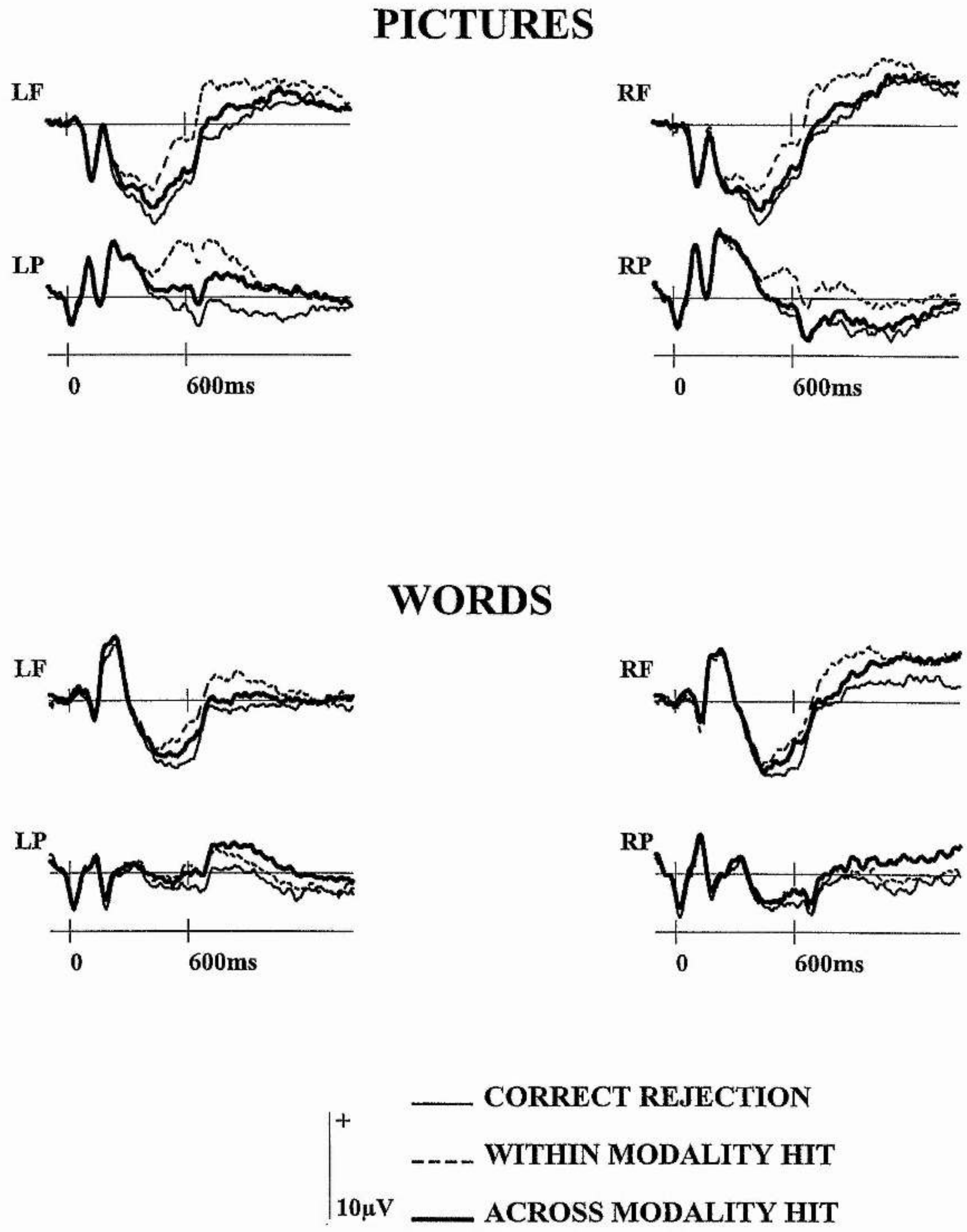


Figure 6.3: Grand average ERPs elicited by the within modality hit, across modality hit and correct rejection response categories for picture and word retrieval cues at lateral frontal and parietal sites.

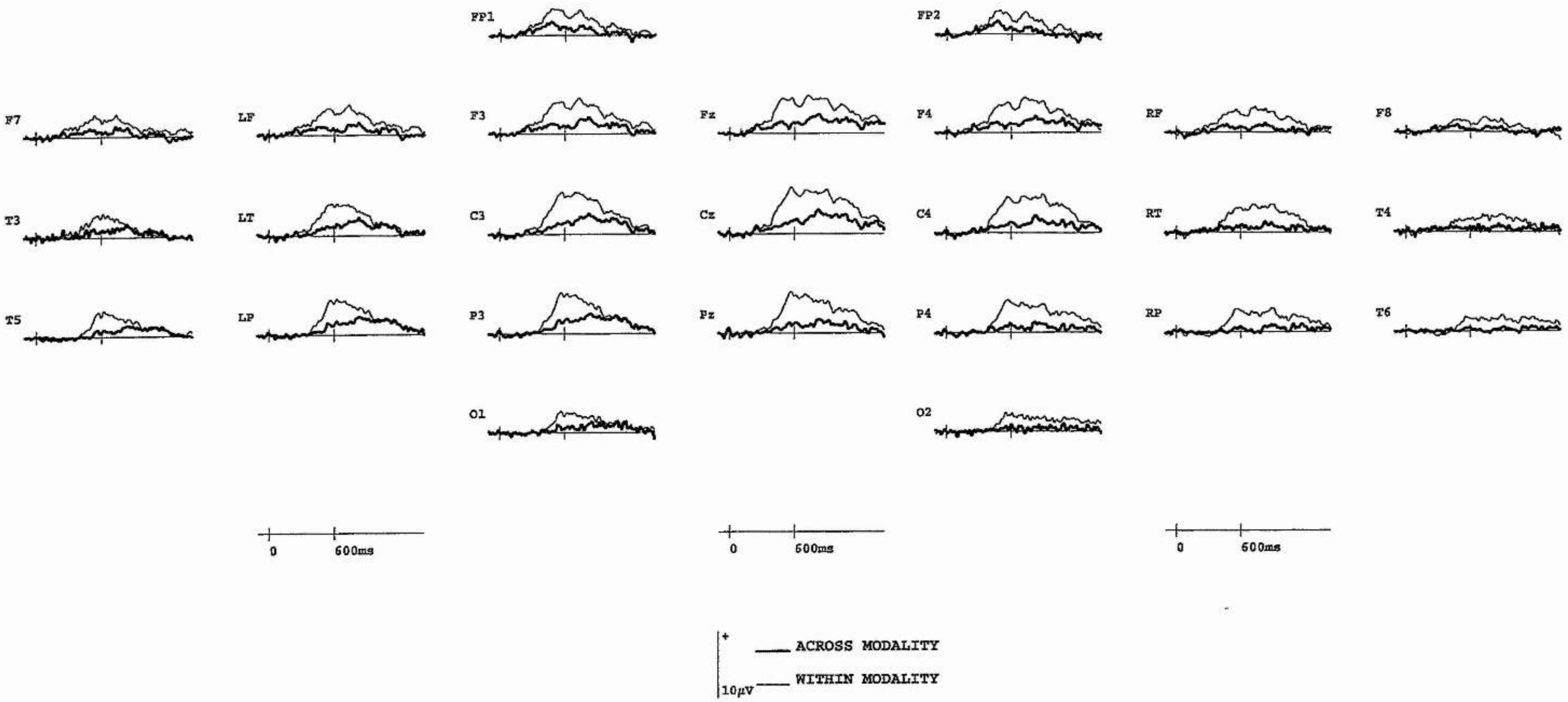


Figure 6.4: Subtraction waveforms (hit – correct rejection) for the within and across modality condition for pictures as retrieval cues. Electrode sites as described in Figure 4.1.

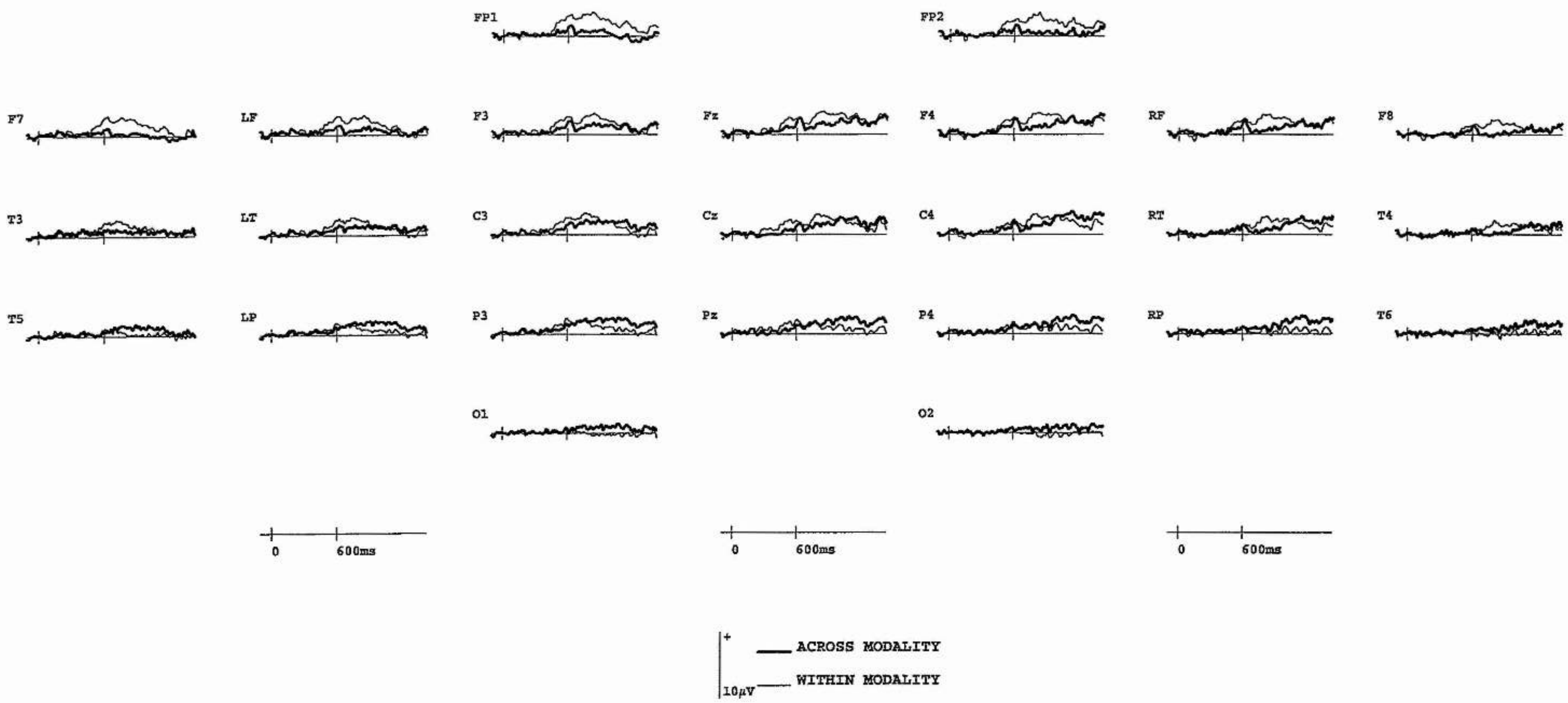


Figure 6.5: Subtraction waveforms (hit – correct rejection) for the within and across modality condition for words as retrieval cues. Electrode sites as described in Figure 4.1.

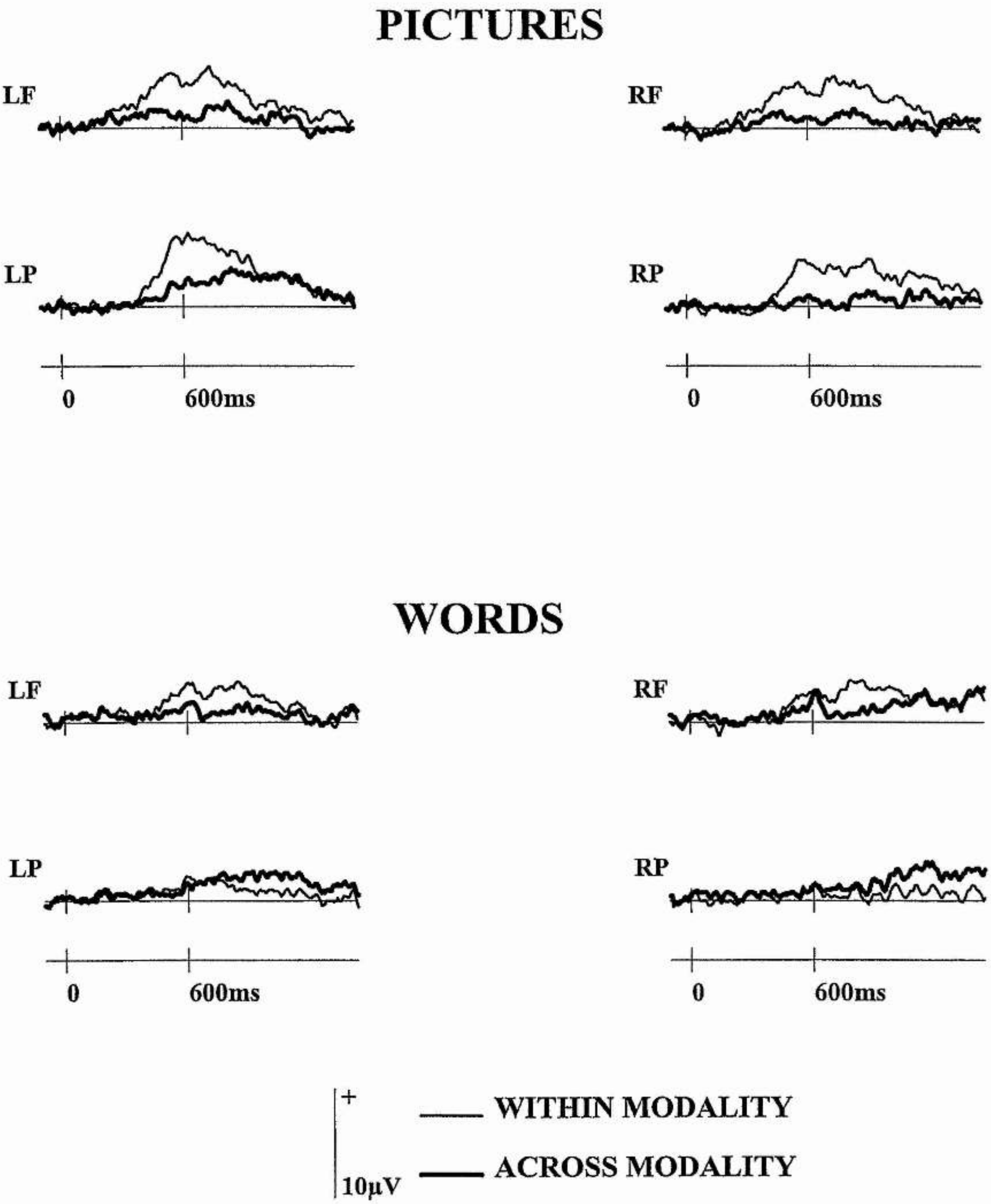
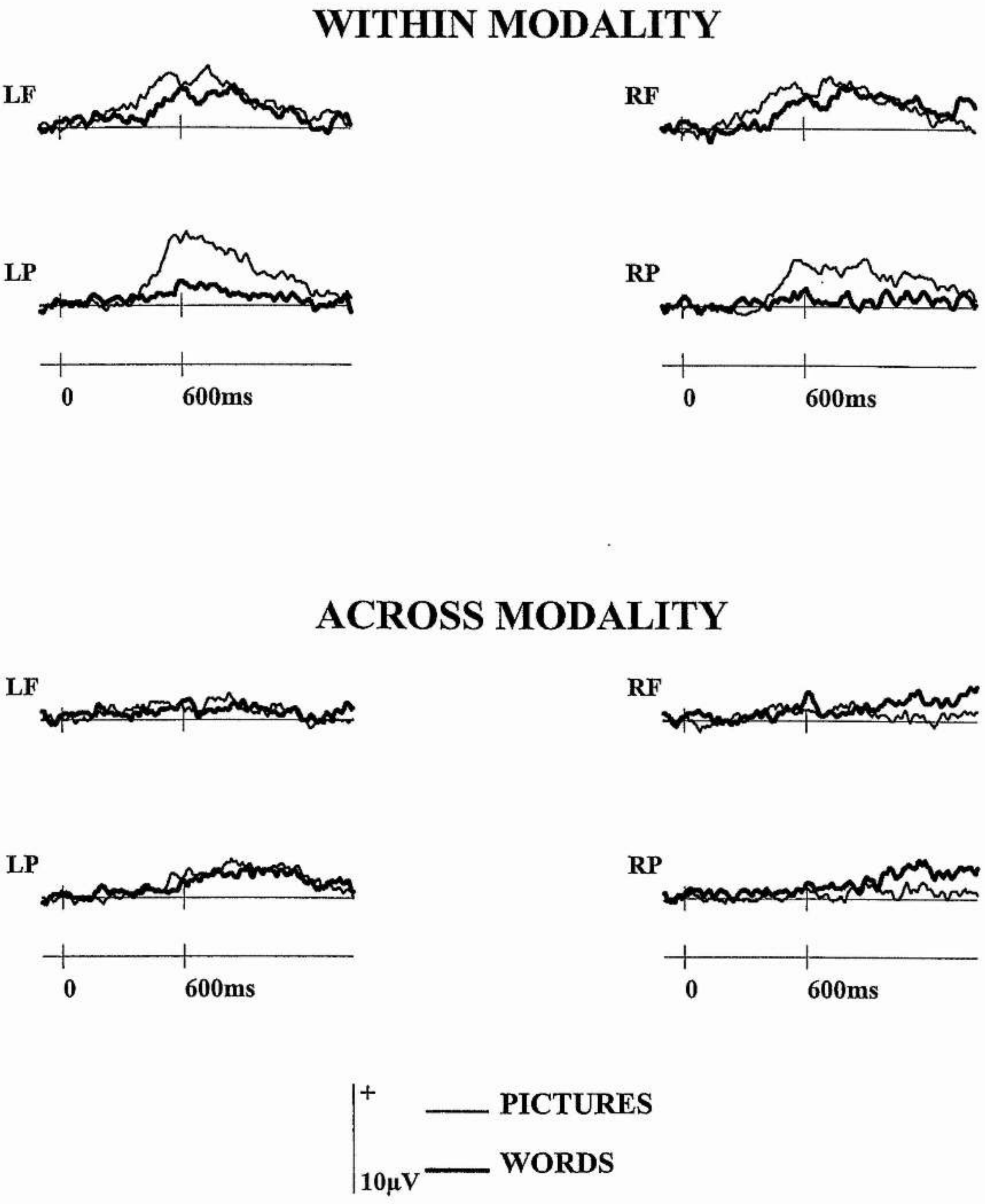


Figure 6.6: Subtraction waveforms (hit – correct rejection) for the within and across modality conditions for pictures and words as retrieval cues, shown at lateral frontal and parietal electrode sites.



WITHIN MODALITY

ACROSS MODALITY

Figure 6.7: Subtraction waveforms (hit – correct rejection) for the within and across modality conditions compared across retrieval cues, shown at lateral frontal and parietal sites.

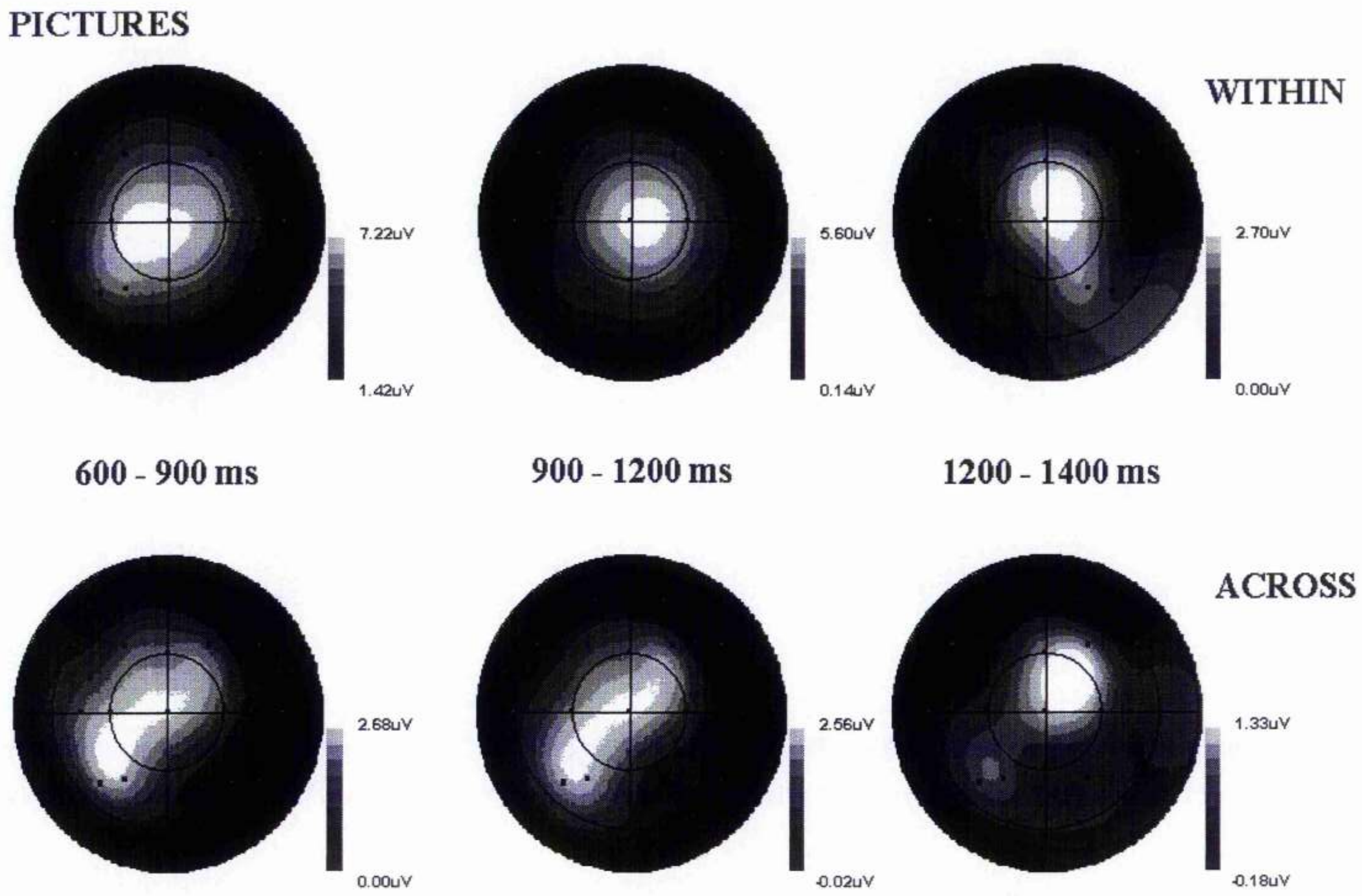


Figure 6.8: Topographic maps of the ERP old/new effects in the 600-900, 900-1200, and 1200-1400ms latency regions for the picture within and the picture across modality conditions, showing the relative amplitudes of the differences between hit and correct rejection ERPs over all 25 electrode sites.

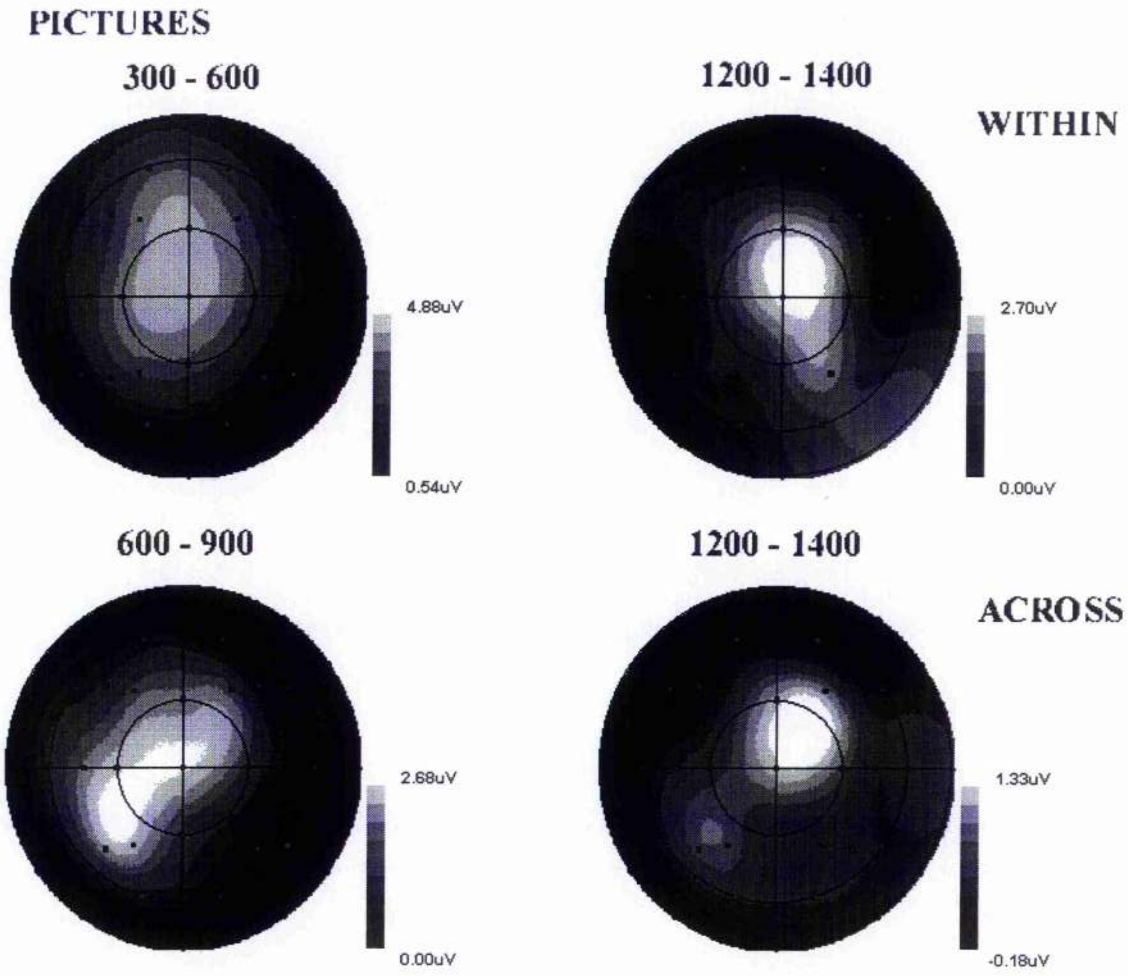


Figure 6.9: Topographic maps of the ERP old/new effects in the 300-600 and 1200-1400ms latency regions for the picture within modality condition and in the 600-900 and 1200-1400 ms latency regions for the picture across modality condition. The maps display the relative amplitudes of the differences between hit and correct rejection ERPs over all 25 electrode sites.

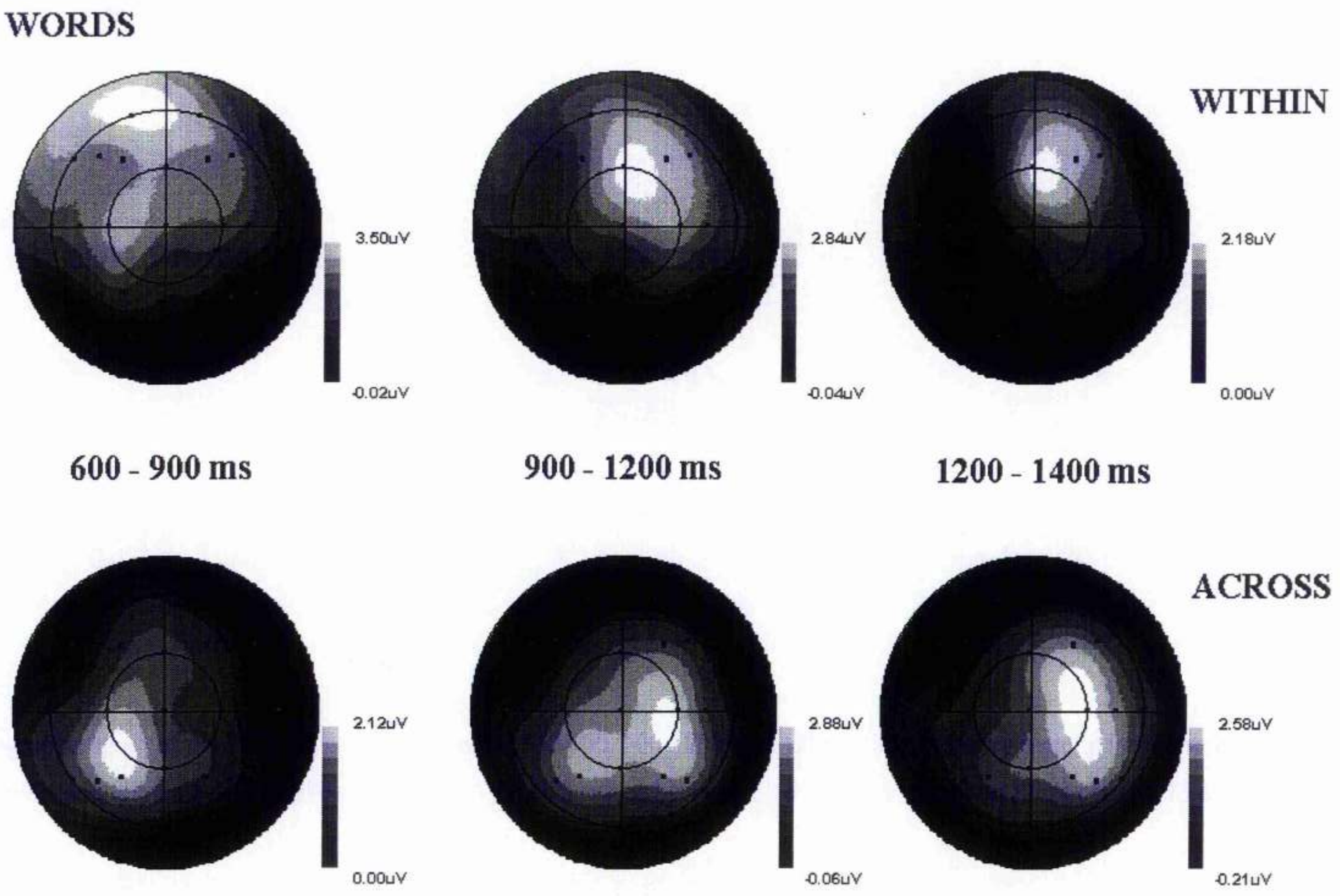


Figure 6.10: Topographic maps of the ERP old/new effects in the 600-900, 900-1200, and 1200-1400ms latency regions for the word within and the word across modality conditions, showing the relative amplitudes of the differences between hit and correct rejection ERPs over all 25 electrode sites.

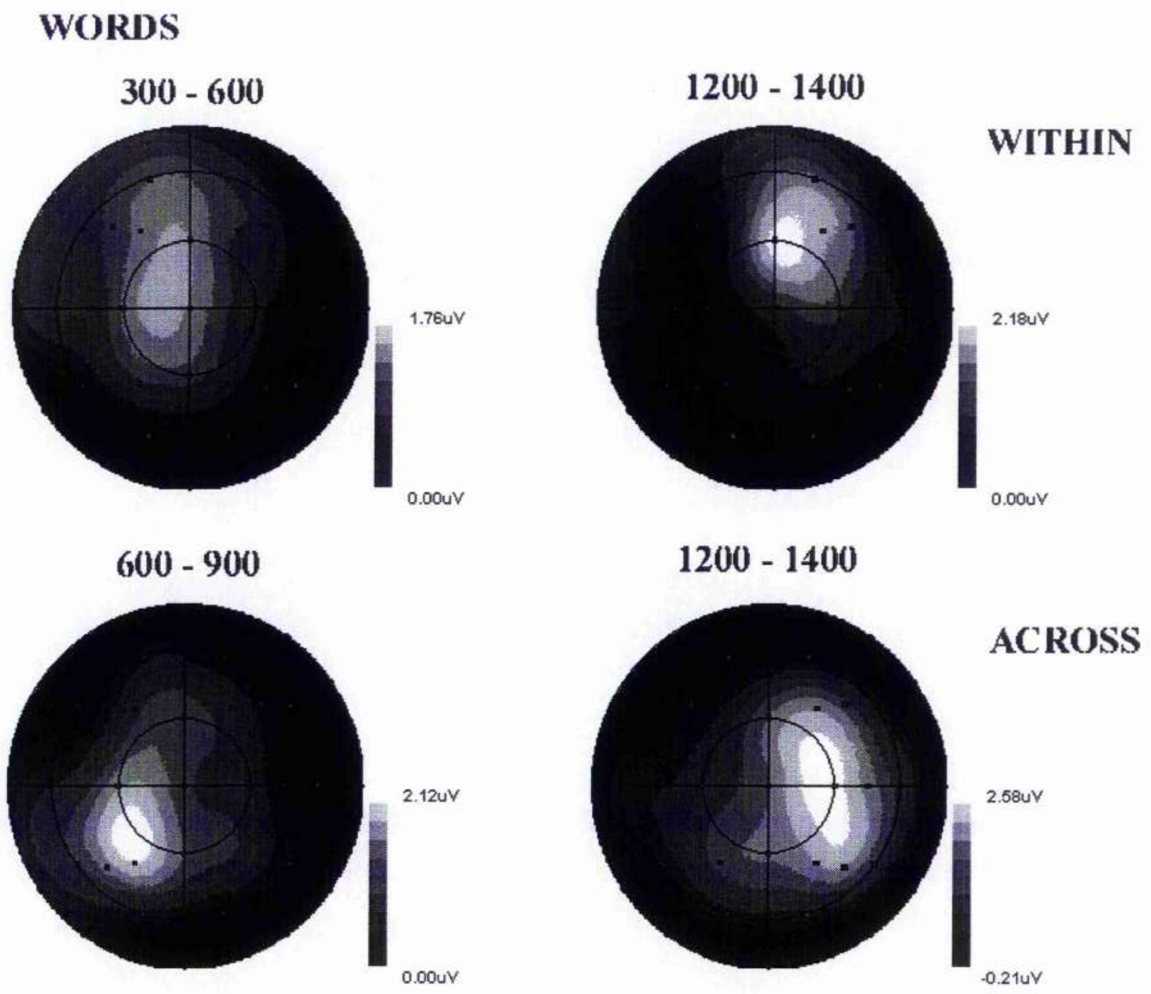


Figure 6.11: Topographic maps of the ERP old/new effects in the 300-600 and 1200-1400ms latency regions for the word within modality condition and in the 600-900 and 1200-1400 ms latency regions for the word across modality condition. The maps display the relative amplitudes of the differences between hit and correct rejection ERPs over all 25 electrode sites.

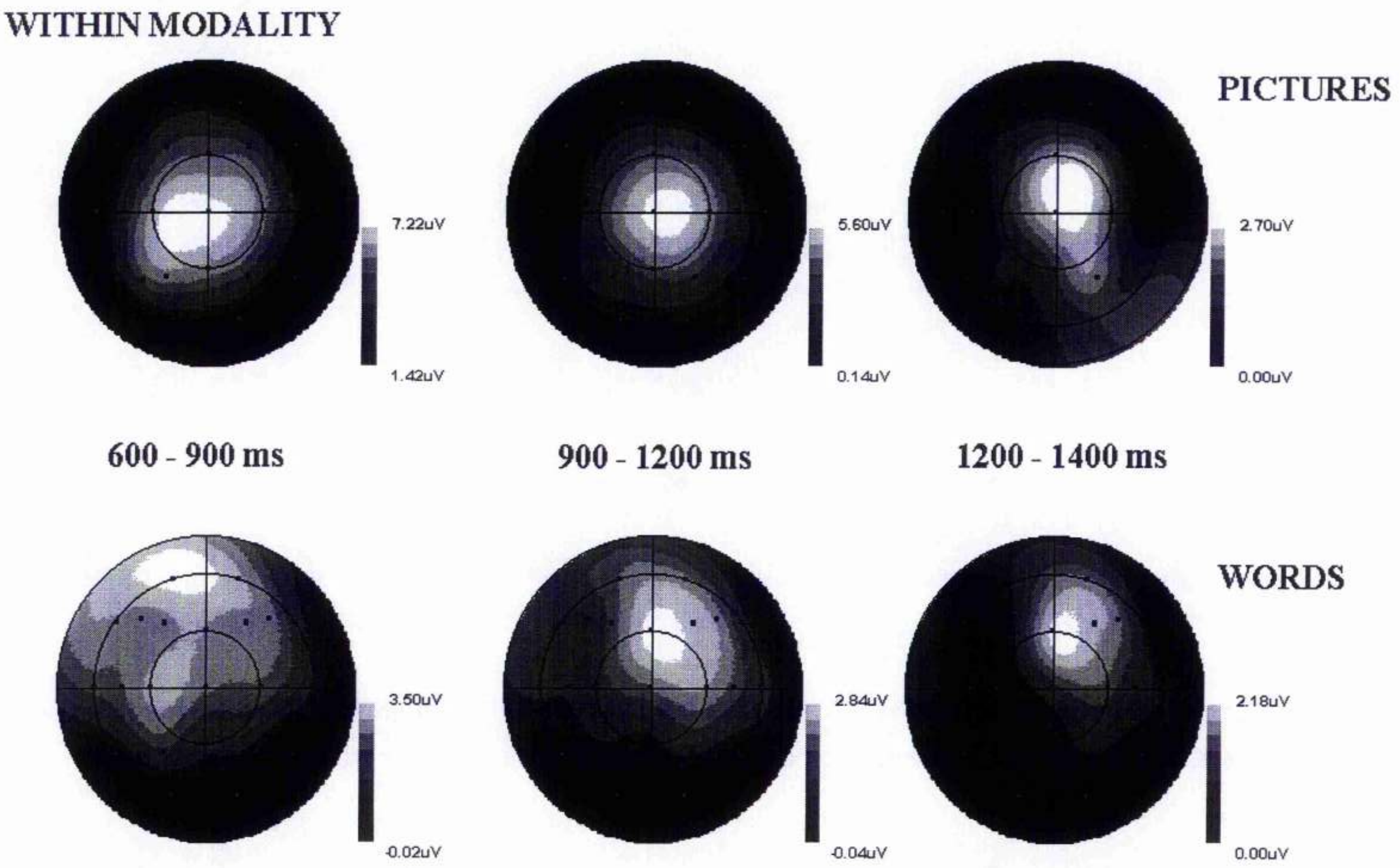


Figure 6.12: Topographic maps of the ERP old/new effects in the 600-900, 900-1200, and 1200-1400ms latency regions for the picture within and the word within modality conditions, showing the relative amplitudes of the differences between hit and correct rejection ERPs over all 25 electrode sites.

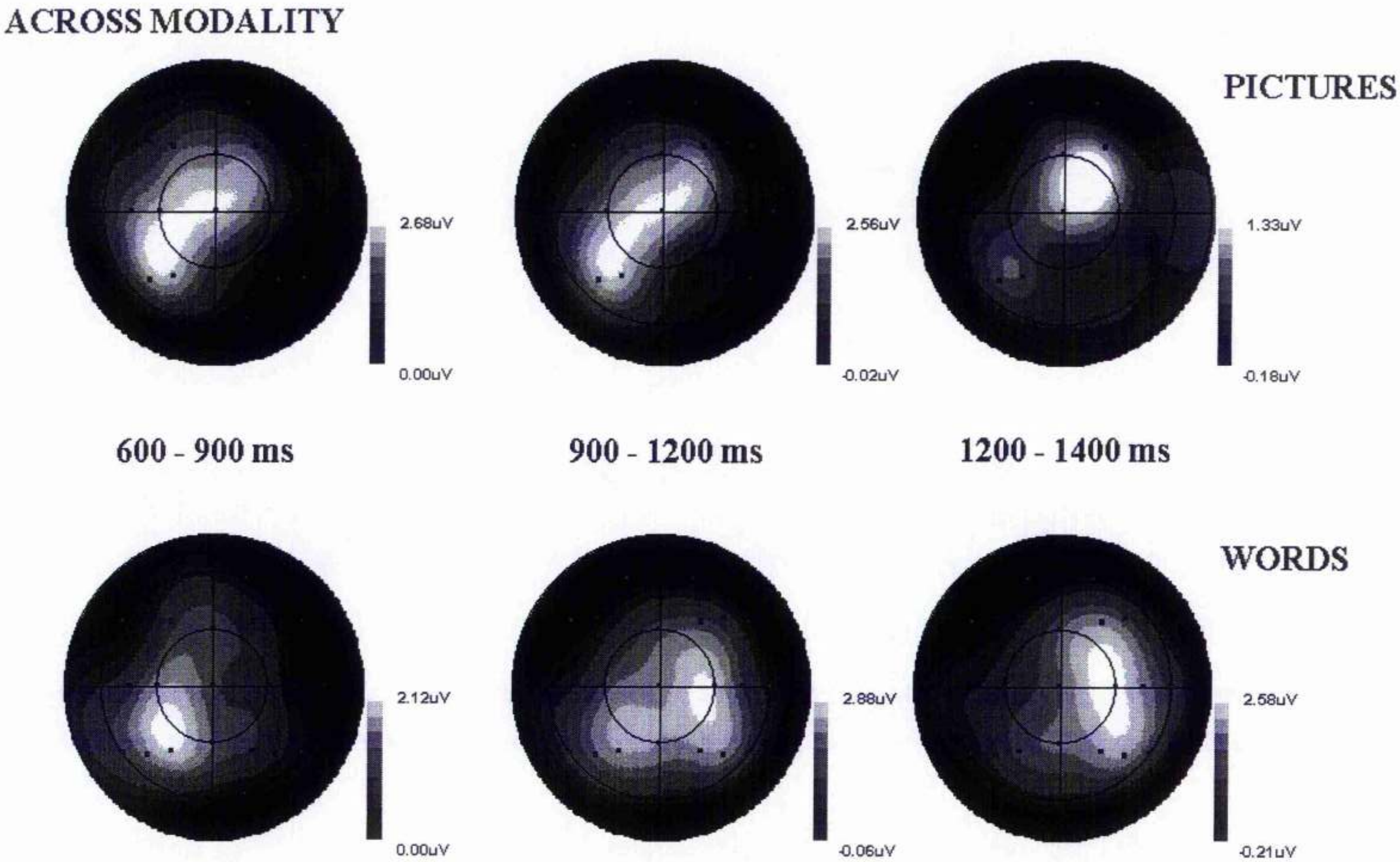
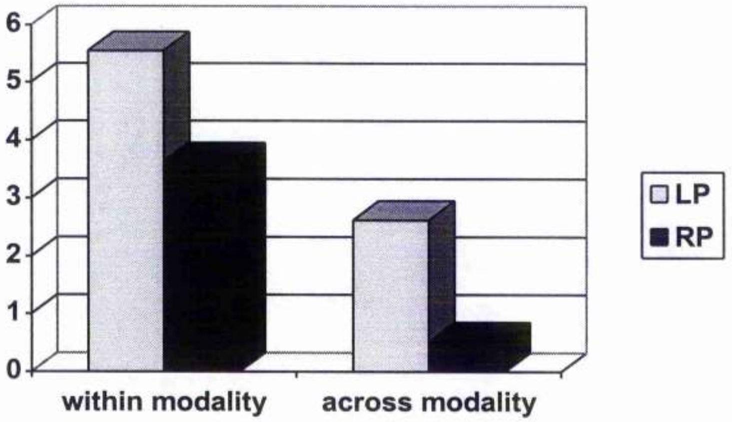


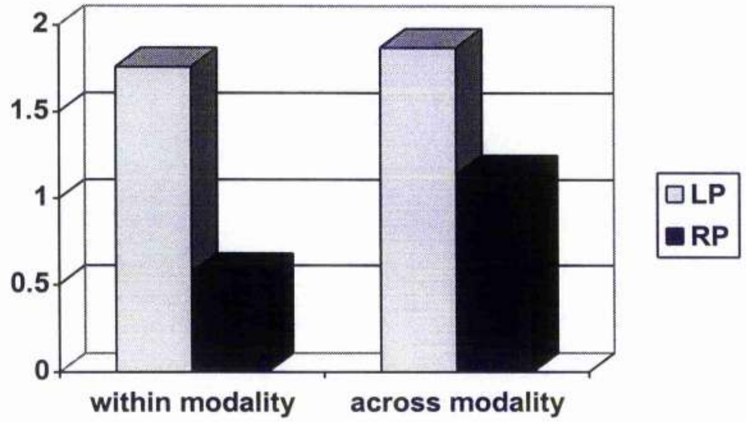
Figure 6.13: Topographic maps of the ERP old/new effects in the 600-900, 900-1200, and 1200-1400ms latency regions for the picture across and the word across modality conditions, showing the relative amplitudes of the differences between hit and correct rejection ERPs over all 25 electrode sites.

Figure 6.14: Mean amplitudes for the difference between the respective hit and correct rejection ERPs at the left and right parietal sites.

a) PICTURES: 600 – 900 ms post-stimulus



b) WORDS: 600 – 800 ms post-stimulus



CHAPTER 7

Experiment 3

7.1. Introduction

The results of Experiment 2 are clearly discordant with those of Experiment 1, in that frontally distributed old/new effects were found for the very condition (word within modality) in which no such effects were observed in the first study. Furthermore, those conditions hypothesised to be most likely to show the frontally distributed effects as a result of automatically activated retrieval processes (i.e., those conditions in which pictures were the encoded stimuli) elicited unexpected and ambiguous results. One possible reason for this state of affairs could be that the frontally distributed old/new effects are sensitive to the overall experimental 'context' in which the task was performed. In Experiment 1, all test trials in each block belonged to the same experimental condition. In Experiment 2, however, subjects were required to retrieve items belonging to different experimental conditions in a randomised and rapid manner. For this reason, quick switches in retrieval strategy might not be possible, resulting in similar retrieval processes for all items, independent of stimulus type and task requirements.

A study by Johnson et al. (1997) directly addressed the issue of frontal ERP old/new effects in randomised and blocked experimental designs. They compared the ERP effects for correctly recognised previously presented items and false recognition of associatively related, nonpresented lures. When the test items were presented blocked by test type (new, old, lure), waveforms for old and lure items differed over frontal sites. When the test format randomly intermixed the types of items, however, there was no difference between waveforms for correctly recognised old items and false alarms to lures at those sites. On the basis of these results, they concluded that different test formats affect the type of processing subjects engage in and that these differences in processing are reflected in differences in the ERPs to the two types of item. They argued that in the randomised presentation condition, subjects were making old-new judgements mainly on the basis of "an overall feeling of semantic familiarity" (p.256), whereas in the blocked condition the strong similarity of the test items resulted in extensive evaluation of the perceptual and contextual qualities of the retrieved information. Thus, they argued that in the blocked condition contextual information is retrieved in order to facilitate the evaluation of item's status.

However, taking into account the current ideas about the functional significance of the late right frontal effect, this suggestion seems rather counterintuitive. So far the effect has predominantly been shown to be elicited under conditions in which the retrieval of contextual information was a task requirement, or in which the retrieval of this information was necessary to guide behaviour according to task requirements (Senkfor & Van Petten, 1998; Wilding & Rugg, 1996, 1997a,). This led to the suggestion that the effect may be functionally correlated with post-retrieval evaluative processes, thought to be instantiated by the prefrontal cortex (see Chapter 3, section 3.4 for further discussion). Given that these are the very processes proposed by Johnson et al. (1997) to be engaged in the blocked test format, it seems reasonable to suggest that significant frontal effects could be expected for this condition and for both types of item. By the same argument, the proposed absence of these processes in the randomised test presentation should have resulted in an absence of frontal effects in this condition. However, even in light of these interpretative difficulties, it seems that the late frontal effect could be sensitive to test format. Unfortunately, the latency regions chosen for analysis by Johnson et al. (1997) did not allow an evaluation of this issue for the early frontal effect, which nevertheless appears to be evident in their data (Figure 1, p.253).

The present experiment was designed to investigate whether the frontally distributed old/new effects, which occurred unexpectedly in Experiment 2, resulted from the randomised presentation of the experimental conditions. To this end, the experimental design was modified so that experimental conditions were presented blocked rather than randomised as in Experiment 2 (see below, section 7.2.2.). Accordingly, each subject received two study-test blocks, one for the within modality condition and one for the across modality condition. This way, across subject groups, the within modality conditions replicated the two conditions from Experiment 1. Assuming that it was indeed the randomised presentation of experimental conditions which evoked the unexpected frontal effects in Experiment 2, it could be expected that these effects should be absent for those conditions in which words were the encoding stimuli in the present experiment. Thus, the within modality conditions in the present experiment should replicate the findings observed in Experiment 1.

7.2. Method

7.2.1. Subjects

The subjects were 41 students from St. Andrews University (mean age 20.9 years, ranging from 18–32 years). The data from 4 subjects were rejected because of a baseline artifact. The data from 1 further subject were rejected due to excessive EOG artifact. Of the remaining 36 subjects who contributed to the study, 25 were female. All subjects were right-handed and gave written consent prior to participating in the study.

7.2.2. Experimental Design

As in Experiment 2, three different experimental conditions were the focus of this experiment: old items seen within modality (i.e., pictures at study and test, words at study and test), old items seen across modality (i.e., pictures at study then words at test, words at study then pictures at test), and new items. As before, the experiment was based on a between-subject design with one group receiving test lists containing pictures and the other group receiving those containing words. In the current experiment, however, each subject group received two study-test cycles (in comparison to the one study-test cycle in Experiment 2). Each cycle contained only one type of old items (i.e. within or across modality items) thus administering these experimental conditions in a blocked rathern than randomised fashion (Experiment 2).

The design and the resulting experimental conditions are outlined below:

	Retrieval Group1 PICTURES	***Retrieval*** Group 2 WORDS
Encoding (Blocked)		
PICTURES	Within Modality	Across Modality
WORDS	Across Modality	Within Modality
	New	New

7.2.3. Experimental Material

The stimuli used in this experiment were the same as those employed in Experiment 2 [see Appendix B]. The 120 critical items of each stimulus type (pictures and words) underwent a randomisation procedure as follows: The critical items of each stimulus type were randomly assigned to two lists of 40 items and 2 lists of 20 items, so that each word list had a corresponding picture list containing the same items. The remaining 6 items of each stimulus type were used as fillers. Each of the lists containing 40 items was used as a study list. Thus 4 study lists were created, 2 containing pictures and 2 containing the corresponding words. Each study list was preceded by three filler items.

Test lists were created by combining the 2 study lists of each item type with one of the 20 item lists of the same stimulus type. This way 4 test lists were created, 2 containing pictures and 2 containing the corresponding words, each with a length of 60 items. The 2 picture lists were formed in 2 different serial orders of old and new items, the corresponding word lists had the same serial orders as the picture lists. Thus, of the 4 test lists, 2 contained the same items in different stimulus types in the same serial order. The test lists were preceded by three filler items and padded with a further filler item at position 34, at which point a rest break occurred.

The random assignment of items to lists was carried out three times over, each procedure resulting in 4 study lists (2 containing pictures, 2 containing the corresponding words) and 4 test lists (2 containing pictures and 2 containing the corresponding words). For each randomisation procedure 2 different serial orders of old and new items were used, one for one picture test list and the corresponding word test list, and one for the other picture and word test lists.

Each subject was administered the study and test lists from one of the three randomisation procedures. Of the two study lists, one was administered as pictures and one as words, with the two lists containing different items. The study lists were paired with the appropriate test lists so as to create the within modality test condition (i.e., pictures at study and test, words at study and test) and the across modality test condition (i.e., pictures at study and words at test, words at study and pictures at test). Each subject saw the two test lists in two different serial orders of old and new items.

7.2.4. Procedure

The lists from each randomisation procedure were administered to 6 subjects each: three of which saw the within modality condition first, the other the across modality condition.

Task instructions were identical to those in Experiment 2. The interval between the study and test phase was approximately 10 minutes, as was the interval between the two study-test cycles.

ERPs were formed for the 3 critical response categories described above: correctly classified new items (*new*); correctly recognised items seen within modality (*within modality hits*); and correctly recognised items seen across modality (*across modality hits*).

7.3. Results

7.3.1. Behavioural Results

Accuracy and RT measures for both types of retrieval cue are shown in Table 7.1. For the recognition decision a 2x2 ANOVA was conducted on the discrimination index 'p(hit) – p(false alarm)' employing the factors of retrieval cue at test (picture vs. word, between subjects) and response category (within vs. across modality). This ANOVA revealed a reliable retrieval cue x response category interaction [$F(1,34) = 11.69$, $p < .005$]. Post-hoc Tukey tests indicated the following significant differences: Firstly, for picture stimuli within modality hits showed the greater accuracy score than across modality hits. Secondly, across modality hits showed greater accuracy scores when words acted as retrieval cues rather than pictures (see Table 7.1).

ANOVA of the Reaction Time data also revealed a retrieval cue x response category interaction [$F(1,34) = 32.57$, $p < .001$]. Post-hoc Tukey tests indicated the following significant differences: Firstly, when pictures were the retrieval cue within modality hits showed the quicker reaction time than across modality hits. Secondly, across modality hits were responded to faster when words acted as retrieval cues and thirdly, within modality hits attracted faster response times when pictures were the retrieval cues (see Table 7.1).

7.3.2. Event-Related Potentials

The grand average ERP waveforms elicited by new and old items (within and across modality) are shown in Figure 7.1 for pictures as retrieval cues and Figure 7.2 for words. Figure 7.3 displays the same waveforms for a selection of lateral frontal and parietal sites. For both types of retrieval cue, correctly recognised items show more positive going ERP waveforms than new items. When pictures are the retrieval cues, the effects are widely distributed over the scalp and are larger for those items seen within modality up to about 600 ms post-stimulus. An early frontal ERP effect is visible for the within modality hits only. Across modality hits also show a frontal effect. However, this effect as a considerably later onset. A parietal effect is also evident which is larger over the left than the right for the across modality hits, but seems to be of bilateral distribution for the within modality hits.

Words as retrieval cues show a slightly different pattern, in that within modality hits show a larger effect than across modality hits only over frontal sites. At posterior sites, both types of hit elicit ERP effects of the same magnitude. As for the picture retrieval cues, within modality hits show an early onsetting frontal effect. Across modality hits also reveal a frontal positivity which is very late in onset and most pronounced over right frontal sites. Similar to the picture retrieval cues, a parietal effect is also evident which is larger over left than right parietal sites for the across modality hits and of bilateral distribution for the within modality hits.

The mean number of trials contributed by each subject in each experimental condition were 29, 31, and 27 in the new, within modality hit, and across modality hit conditions respectively for pictures as retrieval cues; and 33, 35, and 34 for the same conditions respectively for words as retrieval cues. The same sets of analyses were carried out on the data as described in Chapter 6.

7.3.2.1. Within-Group Analyses

7.3.2.1.1. Group 1- Pictures as Retrieval Cues

(1) Analyses of the mean amplitudes

The global ANOVA resulted in reliable response category x site interactions for the 300–600 [$F(5.4,91.8) = 2.67$, $p < .05$], 900–1200 [$F(6.5,111.3) = 3.16$, $p < .01$] and 1200–1400

[F(6.2,105.2) = 2.91, p < .05] ms latency region. The 600–900 ms latency region revealed a reliable main effect of response category [F(1.7, 28.8) = 9.58, p < .005]. The results confirmed the reliability of the observed positivity of correctly recognised items (see Figure7.1). Table 7.2 gives the mean amplitudes of the differences between hits and correct rejections at lateral frontal and parietal sites. Table 6.3 summarises the results of the planned pairwise comparisons conducted on the mean amplitude measurements of the waveforms elicited by old and new items. Selected results of interest are reported below.

Within Modality Hits vs. New: Planned pairwise comparisons on the lateral parietal sites revealed a main effect of response category throughout the recording epoch, confirming the existence of an ERP effect over posterior sites. Within modality hits also showed a reliable frontal positivity, which was largest nearest the midline. This was confirmed by the results of planned comparisons on the selected frontal sites which revealed reliable response category x site interactions for all latency regions. Planned comparisons on the selection of lateral frontal and parietal sites resulted in main effects of response category from 300–1200 ms and a response category x location interaction for the 1200–1400 ms latency region. As is evident from Figure 7.3, this interaction arose due to a positivity for within modality hits over new items which was evident over posterior but not anterior sites (see Table 7.2).

From the analyses reported above, it appears that the temporo-parietal ERP effect is not lateralised to the left as would be expected. However, inspection of Figure 7.3 indicates that the chosen latency regions for analysis might not encompass the peak of the apparent effect. For this reason, a further ANOVA was conducted on the mean amplitude measures of the 500–700 ms latency region for the lateral parietal sites only, employing the factors of response category (within modality hit. vs. correct rejection) and hemisphere (left vs. right). This latency region was chosen to encompass the peak of the positivity apparent in the waveforms. ANOVA did not reveal a reliable response category x hemisphere interaction, thus indicating that the temporo-parietal ERP old/new effect is indeed of bilateral distribution (see Figure 7.4 a).

As in Experiments 1 and 2, it appears that the frontal ERP effect onsets slightly earlier than the parietal effect (see Figure 7.3). This was investigated using ANOVA for consecutive 100 ms latency regions from 200-600 ms post-stimulus. ANOVA was conducted on two sites, LF and LP, employing the factors of response category and location (anterior vs. posterior). Where appropriate, subsidiary analyses employing only the factor of response category were carried out on each of the two sites separately. ANOVA failed to reveal a reliable response category x location interaction in any of the latency regions, indicating that the frontal effect does not onset reliably earlier than the parietal effect for this experimental condition.

Across Modality Hits vs. New: Planned subsidiary comparisons on the parietal sites revealed a response category x hemisphere interaction in the 600–900 ms latency region, confirming the lateralisation of this effect to the left hemisphere for this experimental condition (Figure 7.4 a). Planned comparisons on the selection of frontal sites resulted in reliable response category x site interactions for the 600–1400 ms latency regions. The results confirm the presence of a frontal ERP effect for the across modality hits which is largest nearest the midline. These results were qualified by a marginally significant response category x hemisphere interaction in the 900–1200 ms region, indicating a tendency for the effect to be larger over the right hemisphere during this time period. Planned comparisons on the selection of lateral frontal and parietal sites resulted in main effects of response category for the 300–1200 ms regions. ANOVA of the 1200–1400 ms latency region resulted in a reliable category x location x hemisphere interaction. Tukey HSD tests indicated significant differences between the mean amplitudes of the two anterior sites and the right anterior and posterior sites with the right anterior site showing the largest old/new difference (see Table 7.2).

Unlike for the within modality hits, it appears that for the across modality hits the parietal ERP old/new effect onsets slightly earlier than the frontal effect. This was tested using the same analyses as described for the within modality condition. However, ANOVA failed to reveal any reliable response category x location interaction, thus indicating that there was no reliable onset difference between frontal and parietal sites.

(2) Analyses of the subtracted mean amplitudes – Magnitude analyses

Figures 7.5 and 7.7 depict the subtraction waveforms for both response categories (within modality and across modality) for all 25 sites and for a selection of lateral frontal and parietal sites, respectively. It appears that between 300 and 900 ms post stimulus within modality hits show effects that are of a larger magnitude than those elicited by across modality hits. This magnitude difference appears to be largest nearest the midline. Table 7.4 summarises the results of the analyses carried out on the subtracted mean amplitude measurements for pictures as retrieval cue. Selected results of interest are reported below.

Global ANOVA resulted in a main effect of modality for the 300–600 ms latency region and a modality x site interaction in the 1200–1400 ms region, confirming magnitude differences between the two hit categories for these latency regions. Planned comparisons on the selection of lateral frontal and parietal sites resulted in a reliable main effect of modality for the 300–600 ms latency region, indicating that within modality hits showed a reliably larger effect than across modality hits over anterior and posterior sites (see Table 7.2). A reliable modality x location x hemisphere interaction emerged for the 900–1400 ms latency regions. Tukey HSD tests revealed that the interaction in the 900–1200 ms region arose due to a reversal in magnitude differences between the frontal and parietal sites of the right hemisphere. At the frontal site, the effects for across modality hits were significantly larger than those for within modality hits, whereas at the right posterior site within modality hits showed a larger magnitude than across modality hits (see Table 7.2). Tukey HSD test for the 1200–1400 ms latency regions revealed the same pattern of results. These results were confirmed by planned comparisons on the parietal sites, which revealed modality x hemisphere interactions for the 600–1400 ms latency regions, indicating a larger magnitude for within modality than across modality hits over the right parietal site. Planned comparisons on the selection of frontal sites also confirmed the above result, revealing a modality x hemisphere interaction in the 1200–1400 ms latency region, showing the reliably larger magnitude for across than within modality hits over right frontal sites (see Figure 7.7).

(3) Analyses of the rescaled subtracted mean amplitudes – Topographic analyses

Figure 7.9 shows the topographic maps of the 600–1400 ms latency regions for both categories of hits. The 300–600 ms latency region is not displayed, as no topographic differences emerged from the analyses of this latency region. As can be seen from these maps, the within modality condition shows a widespread effect which lateralises to right posterior regions later in the recording epoch. The across modality condition, however, shows a more frontal distribution of the effect which over time seems to shift from left to right. Table 7.5 summarises the results of ANOVA on the rescaled subtracted mean amplitudes.

Global ANOVA resulted in a modality x site interaction for the 1200–1400 ms latency region only. The planned comparison on the selection of lateral frontal and parietal sites, however, revealed more specific differences, resulting in modality x location x hemisphere interactions for the 600–1400 ms latency regions. As can be seen from Figure 7.9, in the 600–900 ms latency region the within modality condition shows a more bilateral distribution over posterior sites than the across modality condition, whereas the across modality condition reveals a more frontally distributed maximum than the within modality condition. For the 900–1400 ms latency regions, the within modality condition shows a right posteriorly distributed effect whereas the across modality condition shows a more right frontal oriented maximum. The results from the planned comparisons confirm the reliability of the differences evident for these three latency regions.

To determine whether the topographic distribution of the frontal ERP old/new effect shifts over time, an across epoch ANOVA was performed for each of the two old/new effects (i.e., within modality hits – new and across modality hits – new). For the within modality condition the analysis was performed on the rescaled subtracted mean amplitudes of two latency regions: 300–600 and 1200–1400 ms post stimulus. For the across modality condition analysis was performed on the 600–900 and 1200–1400 ms regions as no effect was found for the 300–600 ms region in the initial mean amplitude analysis. Figure 7.10 displays the topographic maps for the early and late latency regions involved in the analyses. ANOVA employed the factors of epoch (early vs. late), hemisphere (lefts vs. right), and site (F7/LF/F3 vs. F8/RF/F4) and did not reveal any significant results involving the factor of epoch for the within modality condition. Analysis of the across modality condition resulted in a reliable epoch x hemisphere interaction [$F(1,17) = 7.05$, $p < .05$], indicating that the frontal effect did indeed shift to the right hemisphere over time (see Figure 7.10).

7.3.2.1.2. Words as Retrieval Cues

(1) Analyses of the mean amplitude

Figures 7.2 and 7.3 show the ERPs elicited by old and new items for all 25 sites and a selection of lateral frontal and parietal sites, respectively.

Global ANOVA revealed reliable response category x site interactions for all four latency regions [300 – 600: $F(4,68.7) = 2.53$, $p < .05$; 600 –900: $F(5.8,98.8) = 10.05$, $p < .001$; 900 – 1200: $F(6.3,107.8) = 4.51$, $p < .001$; 1200 –1400: $F(5.4,91.5) = 2.66$, $p < .05$]. These results confirmed the reliable positivity for correctly recognised old items over new items. Table 7.2 gives the mean amplitudes of the difference between hit and correct rejection ERPs for lateral frontal and parietal sites for all 4 latency regions. Table 7.6 summarises the results of the planned pairwise comparisons conducted on the mean amplitude measurements of the waveforms elicited by old and new items. Selected results are described below.

Within Modality Hits vs. New: Planned comparisons on the parietal sites revealed main effects of response category for all four latency regions, confirming the presence of a parietal old/new effect. ANOVA on the selection of frontal sites resulted in reliable response category x site interactions also for all four latency regions, confirming the presence of a frontal ERP old/new effect which is largest nearest the midline. The results were qualified by a response category x hemisphere interaction in the 1200–1400 ms latency region, indicating a late lateralisation of this frontal effect to the right hemisphere. Planned comparisons on the selection of lateral frontal and parietal sites resulted in reliable response category x location interactions for the 300–600 and 600–900 ms regions. These results indicated that the ERPs to hits were more positive going than correct rejections, but that the difference in mean amplitude was larger over frontal than parietal sites. ANOVA of the 1200–1400 ms latency region revealed a response category x hemisphere interaction, confirming the lateralisation of the mean amplitude differences to the right hemisphere, as indicated by the results of ANOVA on the selection of frontal sites (see Table 7.2).

The results reported above indicate an absence of a left lateralisation for the parietal old/new effect. Inspection of Figure 7.3 indicates, however, that the latency regions chosen for the anlyses reported above might not encompass the peak of the effect. For this reason, a further ANOVA was conducted on the mean amplitude measures of the 500–700 ms latency regions for the lateral parietal sites only, employing the factors of response category (within modality vs. new) and hemisphere (left vs. right). The latency region was chosen to encompass the peak of the effect evident in Figure 7.3. ANOVA did not reveal a reliable effect involving the factor of hemisphere, thereby confirming that the parietal effect is of bilateral distribution (Figure 7.4 b).

As for pictures as retrieval cues, analyses were performed to establish the possibility of an earlier onset of the frontal ERP effect than the parietal effect. These again took the form of ANOVA on LF and RF for consecutive 100 ms latency regions from 200–600 ms post-stimulus, employing the factors of response category and location. ANOVA resulted in a reliable response category x location interaction for the 400–500 ms latency region [$F(1,17) = 6.172$, $p < .05$] but not any later regions. Subsidiary analyses on each of the two sites revealed that for this region LF showed a main effect of response category [$F(1,17) = 8.50$, $p < .05$, whereas LP did not show this effect. These results indicate that the frontal effect does indeed onset about 100 ms earlier than the parietal effect.

Across Modality Hits vs. New: Planned pairwise comparisons on the lateral parietal sites resulted in main effects of response category for the 600–1400 ms latency regions, thus confirming the existence of a temporo-parietal old/new effect. ANOVA on the selection of frontal sites revealed response category x site interactions for the 600–900 ms latency region, resulting from a negativity of the across modality condition in comparison to new items. For the 900–1400 ms latency regions, ANOVA resulted in reliable response category x hemisphere interactions. These results indicate the existence of a greater positivity for old than new items which is largest nearest the midline and greater over the right than the left hemisphere. Planned comparisons on the selection of lateral frontal and parietal sites resulted in response category x location interactions for the 600–900 and 900–1200 ms latency regions indicating that differences in mean amplitude between old and new items were larger over posterior than anterior sites. ANOVA of the 1200–1400 ms latency region resulted in a response category x hemisphere interaction, indicating that the ERP effects evident from the selective analyses of frontal and parietal sites are largest over right hemisphere sites (see Table 7.2).

The results above indicate that the parietal effect is of bilateral distribution and not lateralised to the left as might be expected. However, the latency regions chosen for analyses might not encompass the peak of the parietal effect evident in Figure 7.3. Therefore, ANOVA was conducted on the mean amplitude measures of the 500–700 ms latency region, employing the factors of response category and hemisphere. This latency region was chosen to encompass the peak of the effect as evident in Figure 7.3. ANOVA resulted in a response category x hemisphere interaction [$F(1,17) = 5.63$, $p < .05$], thus confirming that the parietal ERP effect is indeed bigger over the left than the right hemisphere (Figure 7.4 b).

Inspection of Figure 7.3 indicates that for the across modality condition the parietal effect onsets earlier than the frontal effect. This was tested with ANOVA on LF and LP for consecutive 100 ms latency regions from 300-600 ms post-stimulus. The ANOVA revealed a reliable response category x location interaction for the 500–600 ms latency region [$F(1,17) = 7.69$, $p < .05$]. Subsidiary ANOVAs showed that for this latency region, LP showed a main effect of response category [$F(1,17) = 17.02$, $p < .005$], whereas ANOVA on LF did not reveal this effect. The results confirm that for the across modality condition the parietal effect onsets earlier than the frontal effect.

(2) Analyses of the subtracted mean amplitudes – Magnitude analyses

Figures 7.6 and 7.7 show the difference waveforms for all 25 sites and for a selection of lateral frontal and parietal sites, respectively. Over frontal sites, the ERP old/new effect elicited by the within modality condition shows a considerably larger ERP effect than the across modality effect over nearly the whole recording epoch. At posterior sites, the ERP effects to both conditions are mostly of equal magnitude. The exception is a limited period around 600 ms during which the within modality effect shows a slightly larger magnitude than the across modality effect over right parietal sites whereas over left parietal sites the reverse pattern is evident. Table 7.7 summarises the results of the analyses carried out on the subtracted mean amplitude measurements for words as retrieval cues. Selected results of interest are reported below.

None of the analyses conducted revealed a significant effect for the 1200–1400 ms latency region. Global ANOVA of the remaining regions resulted in a main effect of modality for the 300–600 ms region and reliable modality x site interactions for the 600–900 and 900–1200 ms regions, thus confirming the existence of magnitude differences for these time periods. Subsidiary planned comparisons on the selection of frontal sites resulted in a reliable modality x site interaction for the 300–600 ms latency region and main effects of modality for the 600–1200 ms regions. These results confirmed the reliability of the magnitude differences over frontal sites evident from Figure 7.6. Subsidiary ANOVA on the lateral parietal sites resulted in a modality x hemisphere interaction for the 600–900 ms latency region, indicating a difference in magnitude distribution over the two hemispheres at posterior sites. Over left parietal sites, across modality hits show a larger magnitude than within modality hits, whereas over right parietal sites this pattern is reversed. Planned comparisons on the selection of lateral frontal and parietal sites revealed a reliable modality x location interaction. This was qualified, however, by a marginally significant interaction between modality, location and hemisphere. Together these interactions indicate the validity of the subsidiary planned comparisons on the frontal and parietal sites of a larger magnitude for within modality hits over frontal sites and a hemispheric reversal of the same magnitude difference from right to left posterior sites (see Table 7.2).

(3) Analyses of the rescaled subtracted mean amplitudes – Topographic analyses

Figure 7.11 displays the topographic maps for the 600-1400 ms latency regions. The maps for the 300-600 ms region are not displayed as there was no reliable old/new effect for the across modality condition in the initial mean amplitude analyses. As is evident from the maps, the within modality condition shows a prominent frontally located effect which shifts from the left to the right hemisphere with time. The across modality condition shows an initially more posterior effect which shifts from the left posterior sites to right frontal sites over time. Table 7.8 summarises the results of the topographic analyses on the rescaled subtracted mean amplitudes.

Global ANOVA revealed significant modality x site interactions for the 600–900 and 900–1200 ms latency regions, indicating differences in scalp distribution between the two categories of hits in these time regions. Subsidiary planned comparisons on the selection of lateral frontal and parietal sites resulted in a modality x location interaction for both latency regions, confirming the differences in the anterior and posterior distribution for the two hit categories evident in Figure 7.11.

As for the picture retrieval cues, analyses were performed to determine whether the topographic distribution of the frontal ERP old/new effect shifted over time. Figure 7.12 displays the topographic maps for the early and late latency regions for the within and across modality hits. For this purpose, the same across epoch analyses were performed as described in section 7.3.2.1.1. This time, however, only for the within modality hits, as no frontal effect was evident in the across modality condition until late in the recording epoch (see Figures 7.3 and 7.12). ANOVA of the within modality condition resulted in a reliable epoch x hemisphere interaction [$F(1,17) = 8.50$, $p < .05$], confirming a shift of the frontal effect from the left to the right hemisphere over time as (see Figure 7.12).

7.3.2.2. Across Group Analyses

7.3.2.2.1. Magnitude Analyses

Figure 7.8 shows the subtraction waveforms for the within and across modality conditions for a selection of lateral frontal and parietal sites, compared across retrieval cues. As can be seen from this figure, for the within modality conditions words show a larger effect than pictures over frontal sites. This magnitude difference is reversed over parietal sites, where pictures show a larger effect than words. For the across modality condition, the pattern is reversed with pictures showing a larger effect over frontal sites, especially over the right hemisphere, and words displaying an effect of larger magnitude over posterior sites.

Global ANOVA resulted in retrieval cue x modality x site interactions for the 600–1400 ms latency regions [600–900: $F(4.3,145.7) = 10.03$, $p < .001$; 900–1200: $F(4.7,159.5) = 5.63$, $p < .001$; 1200–1400: $F(4.2,143) = 3.65$, $p < .01$], confirming the existence of reliable magnitude differences between the ERP effects of the two subject groups.

Table 7.9 summarises the results of the subsidiary planned pairwise comparisons conducted on the subtracted mean amplitudes to compare the magnitude of the effects across retrieval cues. Selected results are reported below.

(1) Within Modality Conditions

Subsidiary planned comparisons on the selection of lateral frontal and parietal sites revealed reliable retrieval cue x location interactions for the 600–1400 ms latency regions and a marginally significant interaction of the same kind for the 300–600 ms region. The results confirm the pattern of differences evident in Figure 7.8. Over frontal sites, words show a reliably larger effect than pictures, whereas over posterior sites it is pictures which show the reliably larger effect than words (see Table 7.2). Planned comparisons on the lateral parietal sites revealed a main effect of retrieval cue for the 300–600 ms latency region, confirming the larger effect for pictures than words for this latency region. ANOVA on the selection of frontal sites resulted in a retrieval cue x hemisphere x site interaction for the 1200–1400 ms latency region, indicating differences in the distribution of the magnitude differences over frontal sites. For this latency region, magnitude differences are larger over the right than the left hemisphere, and largest over the more inferior sites.

(2) Across Modality Conditions

Planned comparisons on the selection of lateral frontal and parietal sites revealed a retrieval cue x location interaction for the 600–900 ms latency region, confirming the pattern of differences evident in Figure 7.8. Frontally, pictures show a larger effect than words, whereas over posterior sites words show a larger effect than pictures (see Table 7.2). Subsidiary planned comparisons on the lateral parietal sites resulted in a retrieval cue x hemisphere interaction in the 1200–1400 ms latency region, indicating that the observed differences in magnitude over posterior sites were restricted to the right hemisphere. ANOVA on the selection of frontal sites revealed main effects of retrieval cue for the 600–900 and 900–1200 ms latency regions. These results confirmed the outcome of ANOVA on the lateral frontal and parietal sites which indicated that pictures show a larger effect over frontal sites than words.

7.3.2.2.2. Topographic Analyses

Figures 7.13 and 7.14 show the topographic maps for the within and across modality conditions respectively, each figure displaying the conditions for both types of retrieval cue. For the across modality conditions, maps of the 300–600 ms latency regions are not displayed as the rescaling of the difference waveforms for words resulted mainly in noise. As can be seen from the maps, the within modality conditions show differences in the distribution of the effects depending on retrieval cue. Pictures show a slightly more posterior distribution of the effects which, over time, lateralise to the right hemisphere. Words, however, show a frontal maximum, which also shifts to right hemisphere sites over time. The across modality conditions show the reverse pattern. Picture retrieval cues show a frontal maximum, whereas words show an initial posterior maximum which over time shift to right frontal sites.

Global ANOVA revealed reliable retrieval cue x modality x site interactions for the 600–1400 ms latency regions [600–900: $F(4,136,3) = 7.33$, $p < .001$; 900–1200: $F(4.6,156.6) = 4.87$, $p < .005$; 1200–1400: $F(3.9,134.2) = 2.74$, $p < .05$], confirming the existence of reliable topographic differences between the hit conditions for the two types of retrieval cue.

Subsidiary planned comparisons on the lateral frontal and parietal sites for the within modality conditions revealed reliable retrieval cue x location interactions for all four latency regions [300–600: $F(1,34) = 4.79$, $p < .05$; 600–900: $F(1,34) = 10.64$, $p < .005$; 900–1200: $F(1,34) = 7.36$, $p < .05$; 1200–1400: $F(1,34) = 13.21$, $p < .005$], confirming the more frontal distribution of the effects for the word retrieval cues as opposed to the more posterior distribution of effects for the picture retrieval cues. ANOVA on the lateral frontal and parietal sites for the across modality conditions resulted in a retrieval cue x location interaction in the 600–900 ms latency region only [$F(1,34) = 6.06$, $p < .05$]. This result confirms the difference in topographic distribution between the two retrieval cues for this time interval, with pictures having a more frontal distribution than words (see Figure 7.14)

7.3.2.3. Summary of the Results

For pictures as retrieval cues, within modality hits show a long-lasting bilateral temporo-parietal ERP old/new effect, whereas across modality hits show the expected left lateralised effect. Both types of hits show a reliable frontal positivity which onsets earlier for the within than the across modality condition. Whereas the frontal effect for the across modality condition shows a shift in its topographic distribution from left to right frontal sites over time, that for the within modality hits centres around the midline throughout the recording epoch. Both types of hits show effects of the same magnitude up to 600 ms post-stimulus. Later during the recording epoch, differences are mainly found over right hemisphere sites, with across modality hits showing effects of larger magnitude over frontal sites, whereas within modality hits are larger over posterior sites. Across the whole recording epoch within modality hits show a reliably more posterior distribution than across modality hits which show a maximum over anterior sites.

For words as retrieval cues within modality hits also show a bilateral temporo-parietal ERP old/new effect whereas across modality hits show a left lateralised effect for a short time-period between 500 and 700 ms post-stimulus. Both type of hits show a late frontal effect which is larger over the right than the left hemisphere; within modality hits, however, also show an early bilateral effect, onsetting about 100 ms before the parietal effect. For across modality hits this pattern of onset difference is reversed with the parietal effect onsetting at least 100 ms earlier than the frontal effect. Magnitude differences are pronounced over frontal sites, where within modality hits show a larger effect than across modality hits throughout the recording epoch. Over posterior sites, differences in magnitude are confined to a short period between 500 and 900 ms post-stimulus during which time across modality hits are larger than within modality hits over left temporo-parietal sites and vice versa over right temporo-parietal sites. Differences in the topographic distribution between within and across modality hits only emerged for the time between 600 and 1200 ms post-stimulus. During this time within modality hits show a reliably more anterior distribution than across modality hits, which show a maximum in effect size over posterior sites.

In confirmation of the analyses carried out for each of the stimulus types separately, comparisons across stimulus type show reversals in magnitude differences from anterior to posterior sites. For within modality hits, words show a larger effect than pictures over frontal sites, whereas over posterior sites pictures show the reliably larger effect than words. For across modality hits, a reversal in magnitude differences is also evident, this time however it is pictures which show the reliably larger effect over anterior sites, whereas words have the larger effect size over posterior sites. This reversal in magnitude differences is confined to a relatively short latency region between 600 and 900 ms post-stimulus, but differences in effect size are apparent before and after this time period over frontal and parietal sites when analysed selectively.

Analyses on the subtracted mean amplitudes, comparing the topographic distribution of the ERP effects, show that for the within modality condition words have a reliably more anterior distribution than pictures which show maximum effect size over posterior sites. This difference is reliable nearly throughout the whole recording epoch. In the across modality conditions, topographic differences are only evident in the 600–900 ms latency region, in which pictures show the more anterior distribution of effects than words. No topographic differences between any of the experimental conditions were found for the 1200–1400 ms latency region in which both types of stimuli show a right frontal maximum.

7.4. Discussion

In the present experiment, analyses of recognition accuracy did not reveal a picture superiority effect in the within modality conditions. This mirrors the results of Experiment 1, in which there was also only a trend towards a picture superiority effect in the accuracy data. Both experiments were run under blocked test conditions, suggesting that under these conditions recognition accuracy for words, at least for highly imageable items, can be elevated to the same level as recognition accuracy for pictures. However, for the across modality conditions there was a reliable recognition advantage for pictures as encoding stimuli (words at retrieval) over words as encoding stimuli (pictures at retrieval), suggesting the high recognition performance for verbally encoded stimuli depends on perceptual overlap between study and test stimuli. The RT data mirrored the results of Experiment 2 in that responses were significantly faster for pictures than for words in the within modality conditions. They were also reliably faster in the across modality condition when pictures were the encoding stimuli (words at retrieval) rather than words (pictures at retrieval). Thus, a picture superiority effect was evident in the RT data, even if not to the same extent in the accuracy data.

The aim of the present experiment was to establish whether the early bilateral and late right frontal effects are sensitive to the format in which the memory test is conducted. To this end, experimental conditions were presented in blocked format in contrast to the randomised format in which they were presented in Experiment 2. The impact of the test format, as well as any other considerations arising from the results, will be considered for each of the old/new effects in turn.

7.4.1. The Left Parietal Old/New Effect

A left lateralised temporo-parietal old/new effect was evident for correctly recognised old items in both across modality conditions. However, within modality conditions revealed a slightly different pattern with a bilaterally distributed temporo-parietal effect which even for very targeted analyses (100 ms sweeps from 400 – 800 ms post-stimulus on LP and RP) did not show any sign of a lateralisation to the left hemisphere (see Figure 7.4a). For all experimental conditions, the effect was very long-lasting (well towards the end of the recording epoch) and of bilateral distribution late in the recording epoch (see Figure 7.3).

Considering the relatively strong lateralisation of the effect observed in Experiment 1 and 2, the present results are somewhat unexpected. The within modality conditions in the present experiment constitute replications of the two experimental conditions from Experiment 1 in which subjects performed a study-test recognition test on one block of words and one block of pictures. In this experiment, ERPs to correctly recognised old items revealed a left lateralised temporo-parietal effect independent of stimulus type. It is therefore somewhat puzzling that in the present study, which closely replicates the test format of Experiment 1, both within modality conditions should reveal bilateral parietal effects, a pattern most likely to be expected for picture stimuli (see Introduction, Chapter 5 and section 1.6.3, Chapter 1). Given the discrepancies between the results of these two experiments, it seems reasonable to suggest that it is not necessarily the test format that influences the occurrence or lateralisation of the parietal old/new effect. It seems more likely that other factors like stimuli and encoding instructions (size judgement based on imaged referent vs. function judgement), which varied slightly between the two experiments, might be responsible. Further research will have to test this possibility using the materials of Experiment 1 under the test instructions of the present study.

Considering the results of the current experiment, it is interesting to note that it is the within modality conditions that elicit the bilaterally distributed effect, whereas the across modality conditions result in a lateralisation of the effect to the left hemisphere. This result contradicts the hypothesis first stated in Chapter 5, that it is pictures which should produce a bilaterally distributed effect due to engagement of the medial temporal lobe memory systems in the left and right hemisphere. However, this contradiction could be more apparent than real. A possible explanation for the present pattern of results could be that due to the high imageability of the words (picture names) and the easily verbalisable nature of the pictures both types of information are used to retrieve items in the within modality conditions. This would result in engagement of the medial temporal lobe memory systems bilaterally, resulting in a bilaterally distributed parietal old/new effect. In the across modality conditions, however, it might be the semantic information (i.e., the name of the objects) which is primarily used to retrieve information, thus resulting in predominant activation of the left medial temporal lobe memory system. Test format might have caused this difference to appear for the present experiment only, as the randomised presentation in Experiment 2 might have resulted in predominant use of semantic information for retrieval in all conditions. Contrary to the proposal made with respect to the results of Experiment 1, this explanation would support the notion that the left parietal effect reflects processing mediated by the lateralised engagement of the medial temporal lobe memory system. Further research will have to establish if such a lateralisation could also be shown for the right medial temporal lobe memory system, possibly through the use of non-nameable pictorial stimuli. The success of such a demonstration would provide a further line of evidence in support of the laterality hypothesis.

In the present experiment, no right greater than left late posterior positivity was observed over parietal sites for those experimental conditions in which pictures were the encoding stimuli. Such a late right lateralisation of the parietal old/new effect had been evident in the results of Experiment 2. What could be observed, however, was the unusually long duration of the parietal old/new effects for all experimental conditions. As for Experiment 2, this late posterior positivity co-occurred with strong right/bilateral frontal effects for all conditions, suggesting the possibility that the unusually long duration of the effect over right posterior sites might be due to a volume effect propagating from anterior to posterior sites. Inspection of Table 7.2 reveals that the mean amplitude of the ERP effects is larger over anterior than posterior sites for all but the picture within modality condition from 900 ms post-stimulus onwards. This observation is consistent with the occurrence of a volume conduction effect from anterior to posterior sites leading to an apparent, rather than real, late positivity over right posterior sites. Interestingly, for the picture within modality condition the right lateral parietal site revealed the larger effect than the right lateral frontal site, suggesting that for this condition right medial temporal lobe activity might be elicited to a larger extent than for the other conditions.

The magnitude analyses for the parietal sites replicated the findings of Experiment 2. The picture within modality condition revealed a significantly larger effect than the across modality condition, whereas when words were the retrieval cue the across modality condition elicited a larger effect than the within modality condition. For picture retrieval cues this magnitude difference started with the emergence of the parietal old/new effect and carried on to the end of the recording epoch over the right hemisphere. For words as retrieval cues the difference was temporally restricted to the latency region in which the effect was lateralised to the left. The results support the suggestion that the parietal old/new effect is not sensitive to modality changes between study and test, but varies with the type of encoding stimulus. It is largest for those items most easily recollected (i.e., pictures), thus adding to the already considerable evidence (see Chapter 3, section 3.2) connecting the (left) parietal old/new effect with the process of recollection.

7.4.2. The Early Bilateral Frontal Old/New Effect

As well as a parietal effect, all conditions in this study elicited an early bilateral frontal effect. This effect onset much earlier for the within than the across modality conditions (in the 300–600 ms rather than the 600-900 ms latency region respectively). For the word within modality condition, the onset of the bilateral frontal effect preceded that of the parietal old/new effect by more than 100 ms. In contrast to Experiment 2, however, the early bilateral effect in the picture within modality condition onset at the same time as the left parietal effect. Possible reasons for this discrepancy will be discussed in connection with the magnitude analyses (see below). In the present experiment, onset of the bilateral frontal effect co-occurred with that of the parietal old/new effect for the picture within modality condition, suggesting that the effect might be due to a volume conduction artefact. Inspection of Table 7.2 reveals, however, that for the 300-600 ms latency region left lateral frontal and parietal sites show nearly equal mean amplitudes for the ERPs, thus virtually ruling out the possibility of volume conduction.

Considering these results, it is clear that the emergence of the early bilateral frontal effect for the word within condition in Experiment 2 was not due to the randomised presentation condition at test. However, this result directly contradicts the findings from Experiment 1 where words did not show any sign of a frontal positivity for correctly recognised items. There is no immediately obvious explanation for this difference in results, apart from the suggestion already voiced in connection with the parietal old/new effect that slight differences in experimental material and differences in encoding task could have contributed to the change in results. Further research will have to clarify this issue.

Turning to the across modality conditions, a bilateral frontal effect, which onset later than the parietal effects, was evident for both types of retrieval cue. For the picture across modality condition, the effect took the form of a positive shift in the ERPs to correctly recognised items whereas for the word across modality condition the shift was negative. This negative shift for the word across modality condition was very surprising and no explanation is readily available. As discussed previously, given the co-occurrence of the parietal and (positive) frontal effect in the picture across modality condition, a volume conduction artefact from posterior to anterior sites cannot be excluded. Indeed, inspection of Table 7.2 reveals that the mean amplitude over the left parietal site is larger than that over the left frontal electrode site, indicating the strong possibility of a conduction artefact. The present results replicate the results of Experiment 2 and thus support the earlier conclusion that the early bilateral frontal effect is sensitive to perceptual overlap between study and test. As far as the tentative suggestions of a connection of this component with familiarity-driven recognition (Rugg et al., 1998 and Chapter 6, section 6.4.2) are concerned, the present results do not add to this conjecture, nor do they provide any evidence against it.

Magnitude comparisons conducted on the data from Experiment 2 suggested that for the within modality conditions, pictures show the larger effect than words during the time period in which the bilateral frontal effect is sensitive to perceptual overlap between study and test stimuli (i.e. 300 – 600 ms post-stimulus). The same comparisons conducted on the present data did not reveal any magnitude differences between the two conditions. Furthermore, there was no onset difference for the bilateral frontal and the parietal old/new effect for the picture within modality condition whilst for the word within modality condition the frontal effect onset more than 100 ms earlier than the parietal effect. The findings from Experiment 2 were taken to suggest that the bilateral frontal effect is not only sensitive to perceptual overlap between items at study and test, but also to those processes contributing to the picture superiority effect. The present results throw doubt on these conclusions. Looking at the behavioural data, it is evident that, other than in Experiment 2, pictures do not show a reliably better recognition rate than words in the within modality conditions, whereas words show a much improved recognition accuracy. Thus, there was no evidence for a picture superiority effect in the recognition performance of the present experiment, whereas there was a reliable superiority of pictures over words in Experiment 2. This state of affairs suggests that the bilateral frontal effect could be sensitive to the amount of information that is retrieved, in other words the retrieval success. In the present experiment, pictures did not show an accuracy advantage over words and the magnitude of the effects did not differ for the early part of the bilateral frontal old/new effect. In Experiment 2, however, pictures did reveal a reliably better recognition performance than words, a result correlated with a larger magnitude of the bilateral frontal effect for the very items which were more successfully recognised. These suggestions are, of course, of a tentative nature and further research is needed to assess the accuracy of this conjecture.

7.4.3. The Late Right Frontal Old/New Effect

As in Experiment 2, a late right frontal effect occurred for all experimental conditions except the picture within modality condition where the frontal effect was still of a bilateral distribution at the end of the recording epoch. Thus, the change in test-format did not abolish the effect for those conditions in which words were the encoding stimuli. As already discussed for the bilateral frontal effect, it is not clear why the current results should be so different from those obtained in Experiment 1. However, the differences in experimental material and encoding task could be a possible explanation.

Magnitude comparisons did not reveal any differences between within and across modality conditions for word retrieval cues in the 1200–1400 ms latency region. Picture retrieval cues did however show a larger effect for the across than the within modality condition. This result was not entirely unexpected as there is no right hemisphere maximum for the within modality condition effect. Direct comparison of the within and across modality conditions across types of retrieval cue support these results. The comparisons revealed a magnitude difference in the 1200–1400 ms latency region only for the within modality conditions, with words showing the larger effect than pictures. No magnitude difference could be found for the across modality conditions in this latency region. These findings support the suggestion (Experiment 2) that the late right frontal effect does not show any sensitivity to the type of information that is retrieved, correlating it functionally to post-retrieval monitoring processes as first suggested by Wilding and Rugg (1997a,b). As for Experiment 2, however, these conclusions have to be tentative as the frontal effects co-occur with bilateral parietal effects that could influence the magnitude of the effects over frontal sites. This possibility can, unfortunately, not be excluded by the present data.

7.4.4. Topographic Comparisons

Topographic comparisons show that, for pictures, the within modality condition has a slightly more posterior maximum than the across modality condition from 600 ms post-stimulus onwards (see Figure 7.9). For words this pattern is reversed, with the across modality condition having the more posterior maximum than the within modality condition from 600–1200 ms post-stimulus (Figure 7.11). Thus, the results of the present experiment are slightly different from those of Experiment 2, where the within modality conditions generally showed the more anterior maximum in comparison to the across modality conditions, independent of type of retrieval cue. In the present experiment, this pattern is reversed for the picture retrieval cues. Why should there be a difference? The most likely explanation lies in the reduced magnitude of the frontal effects in the within modality condition for picture retrieval cues in comparison to Experiment 2. In the present experiment, this reduced frontal effect co-occurs with a strong parietal effect which most likely places the maximum effect size at more posterior sites than in Experiment 2. Similarly, the word within modality condition shows much stronger frontal effects than in Experiment 2, co-occurring with a relatively small parietal effect, thus placing the maximum of the effect size over more centro-frontal sites. Indeed, inspection of Figures 7.9, 7.11, 7.13 and 7.14 shows that for all conditions and all latency regions, maxima in the effects are situated closely to the central midline, varying in only slight degrees in terms of anterior and posterior, left and right distribution. This suggests that for all conditions the same generators contribute to the effect but are active at different levels and with a different time-course for the different conditions.

One notable exception is, however, the neural substrate underlying the late right frontal old/new effect. This generator is consistently active in the 1200–1400 ms latency region, independent of type of encoding and type of retrieval stimulus (with the exception of the picture within modality condition). No topographic difference was evident in this latency region for the within and across modality conditions for words as retrieval cue, neither was there any difference in the direct comparison of the across modality conditions. This pattern of results supports the conclusions drawn earlier that the effect is insensitive to type of encoding and retrieval stimulus as well as to modality change between study and test.

7.5. Summary and Conclusions

The present experiment addressed the question whether test format would influence the emergence of the early and late frontal effects. To this end experimental conditions were presented in a blocked format, rather than a randomised format as in Experiment 2. This allowed the direct comparison of the results from Experiment 1 with those of the two within modality conditions from the present experiment. Unexpectedly, pronounced early and late frontal effects emerged for all experimental conditions, including the word within modality condition which did not show any of these effects in Experiment 1. Thus the results were very similar to those of Experiment 2, which also showed frontal effects for all experimental conditions. It can thus be concluded that the test format was not the cause for the occurrence of the frontal effects in Experiment 2.

As in Experiment 2, the early bilateral frontal effect showed a sensitivity to perceptual overlap between study and test items. Interestingly, in the present experiment pictures did not show the larger magnitude and earlier onset for this effect as in Experiment 2. This finding was taken to suggest that the effect is sensitive to the amount of retrieved information or the success of the retrieval operation, as the picture within modality condition showed a lower recognition memory performance than in Experiment 2. In addition to an earlier bilateral frontal effect nearly all conditions revealed a late right frontal effect. As in

Experiment 2, the effect did not show any magnitude differences between conditions, nor any differences in topography. These findings were the basis for the suggestion that the effect is insensitive to the information inherent in the encoding stimulus and to changes in modality between study and test, thus providing further support for the conjecture of a functional correlation of the effect with post-retrieval monitoring processes (Wilding & Rugg, 1996, 1997a).

Rather surprisingly, the within modality conditions showed bilateral parietal old/new effects, whereas the across modality conditions revealed the expected lateralisation of this effect to the left. In spite of these differences in distribution between the present experiment and Experiment 1 and 2, the effect was largest for those conditions in which pictures were the encoding stimuli. Thus, the current results support those from Experiment 2, providing further support for the functional correlation of this effect with the process of recollection. It was suggested that the unexpected bilateral distribution of the parietal old/new effect for the within modality conditions could be due to the differential use of available information for the within and across modality conditions. In the within modality conditions pictorial and semantic information contributes to the retrieval of the items, which engages the medial temporal lobe memory system bilaterally, resulting in a bilaterally distributed parietal old/new effect. In the across modality condition, however, it is the most common aspect of the item which is retrieved – the name. This retrieval of semantic information results in the predominant engagement of the left medial temporal lobe memory system and thus in a left lateralised parietal old/new effect. It might therefore have been the test format which caused the separation of these two retrieval strategies. The randomised test format might have encouraged the retrieval of the semantic information, common to all test items, for all the presented retrieval cues.

Why should the results of the current experiment differ so radically from those of the first experiment in which the word condition did not present any frontal effects and the picture condition revealed a strongly left lateralised parietal old/new effect. One possible explanation is the slight difference in experimental material and the difference in the encoding task between Experiment 1 and the subsequent two studies. In Experiment 1, subjects were required to imagine the object depicted on the screen, or the referent to the word depicted on the screen in its real life size, and to judge if this object would be bigger or smaller than the screen on which the item was presented. For Experiments 2 and 3, the encoding task was the judgement if the item on the screen was a household object or not. Thus, whereas the encoding task of Experiment 1 contained a strong imaging component, the encoding task used in Experiments 2 and 3 had a strong semantic component. It is of course not clear whether subjects did indeed use the image of the object to judge the size as this type of judgement can to be made from the semantic information attached to the name of the object alone. Similarly, the function task could have resulted in strong imaging tendencies (e.g., subjects visualising similar objects at home) in order to make the required judgement. It is therefore futile to speculate how the different components of the task might have influenced the results. A further study is needed to establish if the task differences are indeed responsible for the emergence of the frontal effects and the differences in distribution in the parietal old/new effect.

Table 7.1 Summary of Accuracy and Reaction Time results for Experiment 3

	Retrieval			***Retrieval***		
	Picture (Group1)			**Word (Group 2)**		
Encoding	p(Hit)	p(Hit) – p(FA)	p(CR)	P(Hit)	p(Hit) – p(FA)	p(CR)
Accuracy:						
Within Modality	93.6 (7.1)	86.9 (12.0)	93.3 (6.6)	95.6 (5.0)	86.4 (13.9)	90.8 (11.5)
Across modality	81.1 (10.3)	65.3 (13.6)	83.1 (10.3)	90.9 (6.5)	80.4 (9.7)	87.8 (6.5)
Reaction Time						
Within Modality	762 (107)		846 (177)	885 (147)		976 (203)
Across Modality	1027 (152)		1230 (232)	928 (198)		1138 (274)

Table 7.2. Mean amplitude of the ERP effects (within modality hit – new and across modality hit – new) at lateral frontal and parietal sites for the 300-600, 600-900, 900-1200 and 1200-1400 ms latency regions for pictures and words as retrieval cue.

	Within Modality				**Across Modality**			
	LF	RF	LP	RP	LF	RF	LP	RP
PICTURES								
300 – 600 ms	2.45	1.96	2.58	2.53	0.72	0.89	1.08	0.76
600 – 900 ms	2.45	2.29	3.27	3.06	1.38	1.59	1.85	0.65
900 – 1200 ms	1.11	1.94	1.97	3.27	1.33	2.92	2.21	1.77
1200 – 1400 ms	0.58	0.33	1.84	2.66	0.66	2.30	1.71	0.86
WORDS								
300 – 600 ms	2.34	2.12	1.17	1.14	-0.05	0.44	0.75	0.47
600 – 900 ms	3.63	3.76	2.06	1.91	-0.31	-0.166	2.63	1.49
900 – 1200 ms	2.07	3.12	1.35	1.56	-0.27	1.38	1.72	1.90
1200 – 140 ms	1.98	3.58	0.87	2.02	0.64	2.79	0.71	1.91

Table 7.3 Summary of ANOVA on the mean amplitude measures for correctly recognised and new items for pictures as retrieval cue (Group 1)

	Within Modality vs. New	**Across Modality vs.New**
300 – 600 ms		
LF/RF vs. LP/RP		
RC	F(1,17) = 43.92, p < .001	F(1,17) = 5.01, p < .05
RC x LC	n.s.	n.s.
RC x HM	n.s.	n.s.
RC x LC x HM	n.s.	n.s.
LP vs. RP		
RC	F(1,17) = 33.08, p < .001	n.s.
RC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RC	F(1,17) = 24.24, p < .001	n.s.
RC x HM	n.s.	n.s.
RC x ST	n.s.	n.s.
RC x HM x ST	n.s.	n.s.
600 – 900 ms		
LF/RF vs. LP/RP		
RC	F(1,17) = 27.16, p < .001	F(1,17) = 6.97, p < .05
RC x LC	n.s.	n.s.
RC x HM	n.s.	n.s.
RC x LC x HM	n.s.	n.s.
LP vs. RP		
RC	F(1,17) = 34.63, p < .001	F(1,17) = 5.01, p < .05
RC x HM	n.s.	F(1,17) = 5.31, p < .05
F7/LF/F3 vs. F8/RF/F4		
RC	F(1,17) = 12.72, p < .005	F(1,17) = 6.43, p < .05
RC x HM	n.s.	n.s.
RC x ST	F(1.2,20) = 6.91, p < .05	F(1.1,19.1) = 4.5, p < .05
RC x HM x ST	n.s.	n.s.

	Within Modality vs. New	**Across Modality vs. New**
900 – 1200 ms		
LF/RF vs. LP/RP		
RC	F(1,17) = 16.80, p < .005	F(1,17) = 18.56, p < .001
RC x LC	n.s.	n.s.
RC x HM	n.s.	n.s.
RC x LC x HM	n.s.	F(1,17) = 3.99, p = .062*
LP vs. RP		
RC	F(1,17) = 24.55, p < .001	F(1,17) = 17.89, p < .005
RC x HM	F(1,17) = 3.62, p = .075*	n.s.
F7/LF/F3 vs. F8/RF/F4		
RC	F(1,17) = 6.34, p < .05	F(1,17) = 11.06, p < .005
RC x HM	n.s.	F(1,17) = 3.85, p = .067*
RC x ST	F(1,3,22.2) = 7.29, p < .01	F(1.2,20) = 12.73, p < .005
RC x HM x ST	n.s.	n.s.
1200 – 1400 ms		
LF/RF vs. LP/RP		
RC	F(1,17) = 6.94, p < .05	F(1,17) = 6.36, p < .05
RC x LC	F(1,17) = 11.20, p < .005	n.s.
RC x HM	n.s.	n.s.
RC x LC x HM	n.s.	F(1,17) = 6.70, p < .05
LP vs.RP		
RC	F(1,17) = 17.48, p < .005	F(1,17) = 5.36, p < .05
RC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RC	n.s.	F(1,17) = 4.82, p < .05
RC x HM	n.s.	n.s.
RC x ST	(1.5,25.4) = 3.87, p < .05	F(1.3,21.9) = 6.02, p < .05
RC x HM x ST	n.s.	n.s.

RC = Response Category (hit vs. correct rejection), ST = Site, LC = Location (anterior vs. posterior), HM = Hemisphere (right vs. left), * = marginally significant

Table 7.4 Summary of ANOVA on the subtracted mean amplitude measures for pictures as retrieval cue (Magnitude Analyses – Group 1)

300 – 600 ms

Global ANOVA	MD	F(1,17) = 13.01, p < .005
LF/RF vs. LP/RP	MD	F(1,17) = 13.02, p < .005
LP vs. RP	MD	F(1,17) = 11.08, p < .005
F7/LF/F3 vs. F8/RF/F4	MD	F(1,17) = 11.88, p < .005
	MD x ST	F(1.2,20.1) = 7.32, p < .05

600 – 900 ms

Global ANOVA	no significant results	
LF/RF vs. LP/RP	MD	F(1,17) = 4.08, p = .06*
LP vs. RP	MD	F(1,17) = 7.73, p < .05
	MD x HM	F(1,17) = 5.89, p < .05
F7/LF/F3 vs. F8/RF/F4	no significant results	

900 – 1200 ms

Global ANOVA	no significant results	
LF/RF vs. LP/RP	MD x LC	F(1,17) = 5.62, p < .05
	MD x LC x HM	F(1,17) = 15.67, p < .005
LP vs.RP	MD x HM	F(1,17) = 11.58, p < .005
F7/LF/F3 vs. F8/RF/F4	no significant results	

1200 – 1400 ms

Global ANOVA	MD x ST	F(4.3,72.7) = 4.05, p < .005
LF/RF vs. LP/RP	MD x LC	F(1,17) = 7.13, p < .05
	MD x LC x HM	F(1,17) = 21.28, p < .001
LP vs.RP	MD	F(1,17) = 5.09, p < .05
	MD x HM	F(1,17) = 6.21, p < .05
F7/LF/F3 vs. F8/RF/F4	MD x HM	F(1,17) = 7.47, p < .05

MD = Modality (within vs. across), ST = Site, LC = Location (anterior vs. posterior), HM = Hemisphere (right vs. left), * = marginally significant

Table 7.5 Summary of ANOVA on the rescaled subtracted mean amplitude measures for pictures as retrieval cue (Topographic Analyses – Group 1)

300 – 600 ms	no significant results for this latency region	
600 – 900 ms		
Global ANOVA	no significant results	
LF/RF vs. LP/RP	MD x LC x HM	F(1,17) = 5.97, p < .05
900 – 1200 ms		
Global ANOVA	no significant results	
LF/RF vs. LP/RP	MD x LC x HM	F(1,17) = 10.01, p < .01
1200 – 1400 ms		
Global ANOVA	MD x ST	F(4,67.4) = 3.35, p < .05
LF/RF vs. LP/RP	MD x LC x HM	F(1,17) = 16.66, p < .005

MD = Modality (within vs. across), ST = Site, LC = Location (anterior vs. posterior), HM = Hemisphere (right vs. left)

Table 7.6 Summary of the results of ANOVA on the mean amplitude measures for correctly recognised and new items for words as retrieval cue (Group 2)

	Within Modality vs. New	**Across Modality vs.New**
300 – 600 ms		
LF/RF vs. LP/RP		
RC	F(1,17) = 25.89, p < .001	n.s.
RC x LC	F(1,17) = 4.75, p < .05.	n.s.
RC x HM	n.s.	n.s.
RC x LC x HM	n.s.	F(1,17) = 7.39, p < .05
LP vs. RP		
RC	F(1,17) = 10.05, p < .01	n.s.
RC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RC	F(1,17) = 23.83, p < .001	n.s.
RC x HM	n.s.	n.s.
RC x ST	F(1.3,22.8) = 6.94, p < .05	n.s.
RC x HM x ST	n.s.	n.s.
600 – 900 ms		
LF/RF vs. LP/RP		
RC	F(1,17) = 55.25, p < .001	F(1,17) = 5.13, p < .05
RC x LC	F(1,17) = 11.78, p < .005	F(1,17) = 17.16, p < .005
RC x HM	n.s.	n.s.
RC x LC x HM	n.s.	n.s.
LP vs. RP		
RC	F(1,17) = 22.78, p < .001	F(1,17) = 18.53, p < .001
RC x HM	n.s.	F(1,17) = 4.14, p = .058*
F7/LF/F3 vs. F8/RF/F4		
RC	F(1,17) = 50.98, p < .001	n.s.
RC x HM	n.s.	n.s.
RC x ST	F(1.5,24.7) = 9.15, p < .005	F(1.2,20.7) = 6.68, p < .05
RC x HM x ST	n.s.	n.s.

	Within Modality vs. New	**Across Modality vs. New**
900 – 1200 ms		
LF/RF vs. LP/RP		
RC	F(1,17) = 30.13, p < .001	F(1,17) = 11.24, p < .005
RC x LC	n.s.	F(1,17) = 6.15, p < .005
RC x HM	n.s.	F(1,17) = 4.12, p = .058*
RC x LC x HM	n.s.	n.s.
LP vs. RP		
RC	F(1,17) = 11.66, p < .005	F(1,17) = 14.36, p < .005
RC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RC	F(1,17) = 25.18, p < .001	n.s.
RC x HM	n.s.	F(1,17) = 8.62, p < .05
RC x ST	F(1.3,21.6) = 9.44, p < .005	F(1.1,19.3) = 4.63, p < .05
RC x HM x ST	n.s.	n.s.
1200 – 1400 ms		
LF/RF vs. LP/RP		
RC	F(1,17) = 22.16, p < .001	F(1,17) = 16.09, p < .005
RC x LC	n.s.	n.s.
RC x HM	F(1,17) = 6.81, p < .05	F(1,17) = 10.33, p < .01
RC x LC x HM	n.s.	n.s.
LP vs.RP		
RC	F(1,17) = 7.96, p < .05	F(1,17) = 7.20, p < .05
RC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RC	F(1,17) = 19.28, p < .001	F(1,17) = 7.62, p < .05
RC x HM	F(1,17) = 7.08, p < .05.	F(1,17) = 15.27, p < .005
RC x ST	F(1.3,21.9) = 7.92, p < .01	n.s.
RC x HM x ST	n.s.	F(1.6,27.1) = 3.67, p < .05

RC = Response Category (hit vs. correct rejection), ST = Site, LC = Location (anterior vs. posterior), HM = Hemisphere (right vs. left), * = marginally significant

Table 7.7 Summary of ANOVA on the subtracted mean amplitude measures for words as retrieval cue (Magnitude Analyses – Group 2)

300 – 600 ms		
Global ANOVA	MD	F(1,17) = 8.84, p < .01
LF/RF vs. LP/RP	MD	F(1,17) = 6.94, p < .05
LP vs. RP	no significant results	
F7/LF/F3 vs. F8/RF/F4	MD	F(1,17) = 6.84, p < .05
	MD x ST	F(1.3,22.8) = 5.59, p < .05
600 – 900 ms		
Global ANOVA	MD	F(1,17) = 13.19, p < .005
	MD x ST	F(3.6,60.8) = 14.22, p < .001
LF/RF vs. LP/RP	MD	F(1,17) = 10.67, p < .01
	MD x LC	F(1,17) = 43.04, p < .001
	MD x LC x HM	F(1,17) = 4.14, p = .058
LP vs. RP	MD x HM	F(1,17) = 4.54, p < .05
F7/LF/F3 vs. F8/RF/F4	MD	F(1,17) = 27.99, p < .001
900 – 1200 ms		
Global ANOVA	MD	F(1,17) = 4.89, p < .05
	MD x ST	F(4.1,69.6) = 5.81, p < .001
LF/RF vs. LP/RP	MD x LC	F(1,17) = 23.79, p < .001
LP vs.RP	no significant results	
F7/LF/F3 vs. F8/RF/F4	MD	F(1,17) = 13.93, p < .005
1200 – 1400 ms	no significant results for this latency region	

MD = Modality (within vs. across), ST = Site, LC = Location (anterior vs. posterior), HM = Hemisphere (right vs. left), * = marginally significant

Table 7.8 Summary of ANOVA on the rescaled subtracted mean amplitude measures for words as retrieval cue (Topographic Analyses – Group 2)

300 – 600 ms		
Global ANOVA	no significant results	
LF/RF vs. LP/RP	MD x LC x HM	F(1,17) = 5.39, p < .05
600 – 900 ms		
Global ANOVA	MD x ST	F(3.6,60.9) = 14.18, p < .001
LF/RF vs. LP/RP	MD x LC	F(1,17) = 42.93, p < .001
900 – 1200 ms		
Global ANOVA	MD x ST	F(3.9,65.6) = 5.04, p < .005
LF/RF vs. LP/RP	MD x LC	F(1,17) = 24.24, p < .001
1200 – 1400 ms	no significant results for this latency region	

MD = Modality (within vs. across), ST = Site, LC = Location (anterior vs. posterior), HM = Hemisphere (right vs. left)

Table 7.9 Summary of results of ANOVA on subtracted mean amplitudes comparing within and across modality hit categories across retrieval cues (Magnitude Analyses across retrieval cues)

	Within Modality vs. New	**Across Modality vs. New**
300 – 600 ms		
LF/RF vs. LP/RP		
RTC	n.s.	n.s.
RTC x LC	F(1,34) = 3.81, p = .059*	n.s.
RTC x HM	n.s.	n.s.
RTC x LC x HM	n.s.	n.s.
LP vs. RP		
RTC	F(1,34) = 5.96, p < .05	n.s.
RTC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RTC	n.s.	n.s.
RTC x HM	n.s.	n.s.
RTC x ST	n.s.	n.s.
RTC x HM x ST	n.s.	n.s.
600 – 900 ms		
LF/RF vs. LP/RP		
RTC	n.s.	n.s.
RTC x LC	F(1,34) = 11.05, p < .005	F(1,34) = 11.09, p < .005
RTC x HM	n.s.	n.s.
RTC x LC x HM	n.s.	n.s.
LP vs. RP		
RTC	n.s.	n.s.
RTC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RTC	n.s.	F(1,34) = 6.04, p < .05
RTC x HM	n.s.	n.s.
RTC x ST	n.s.	n.s.
RTC x HM x ST	n.s.	n.s.

	Within Modality vs. New	**Across Modality vs. New**
900 – 1200 ms		
LF/RF vs. LP/RP		
RTC	n.s.	n.s.
RTC x LC	F(1,34) = 7.36, p < .05	n.s.
RTC x HM	n.s.	n.s.
RTC x LC x HM	n.s.	n.s.
LP vs. RP		
RTC	n.s.	n.s.
RTC x HM	n.s.	n.s.
F7/LF/F3 vs. F8/RF/F4		
RTC	n.s.	F(1,34) = 4.70, p < .05
RTC x HM	n.s.	n.s.
RTC x ST	n.s.	n.s.
RTC x HM x ST	n.s.	n.s.
1200 – 1400 ms		
LF/RF vs. LP/RP		
RTC	n.s.	n.s.
RTC x LC	F(1,34) = 13.37, p < .005	n.s.
RTC x HM	n.s.	n.s.
RTC x LC x HM	n.s.	n.s.
LP vs.RP		
RTC	n.s.	n.s.
RTC x HM	n.s.	F(1,34) = 4.82, p < .05
F7/LF/F3 vs. F8/RF/F4		
RTC	F(1,34) = 6.13, p < .05	n.s.
RTC x HM	n.s.	n.s.
RTC x ST	n.s.	n.s.
RTC x HM x ST	F(2,66.8) = 3.89, p < .05	n.s

RTC = Retrieval Cue (pictures vs. words), ST = Site, LC = Location (anterior vs. posterior), HM = Hemisphere (right vs. left), * = marginally significant

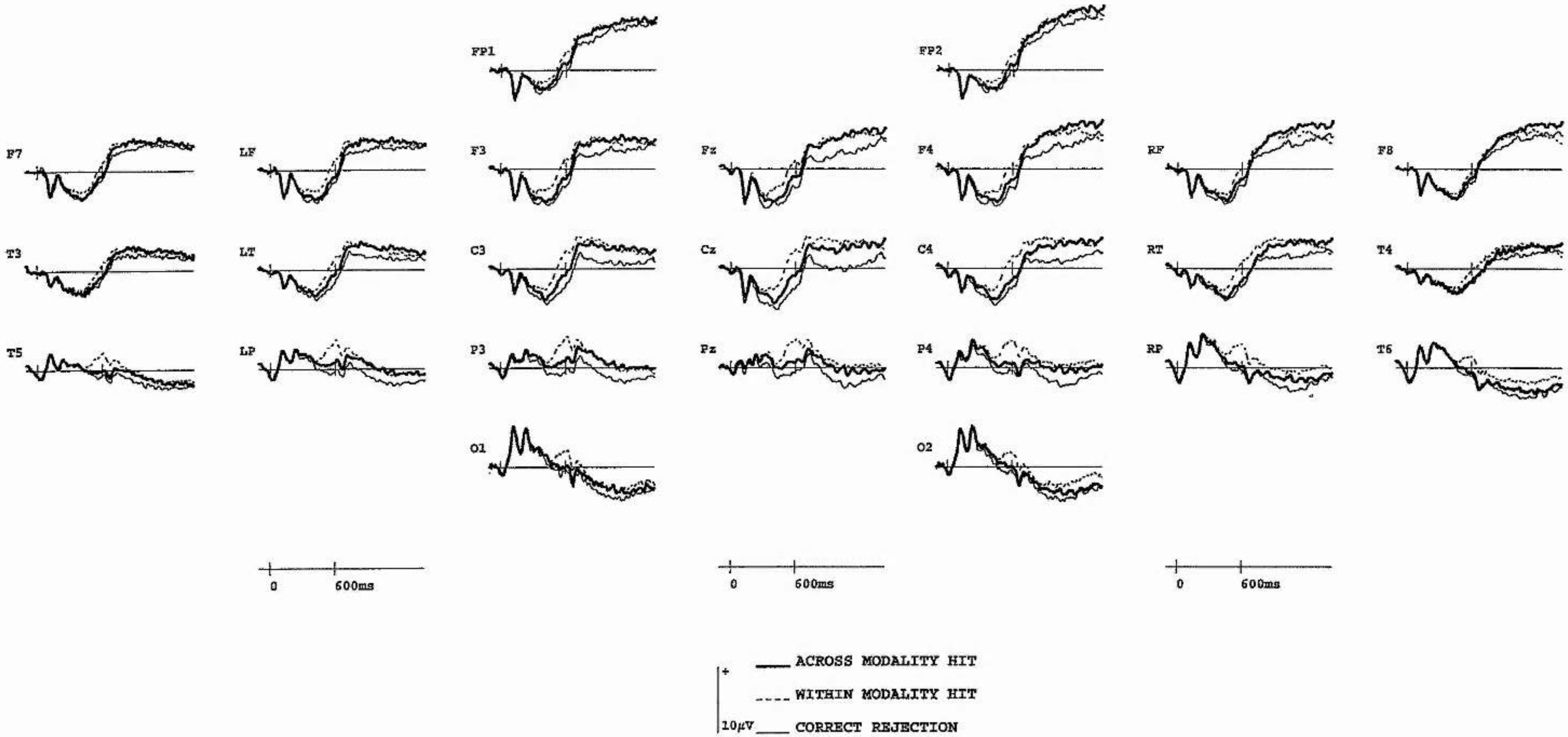


Figure 7.1: Grand average ERPs elicited by correctly recognised old items in the within modality condition (*within modality hits*) and the across modality condition (*across modality hits*) and by correctly rejected new items (*correct rejections*) for pictures as retrieval cues. See Figure 4.1 for a description of the site labels.

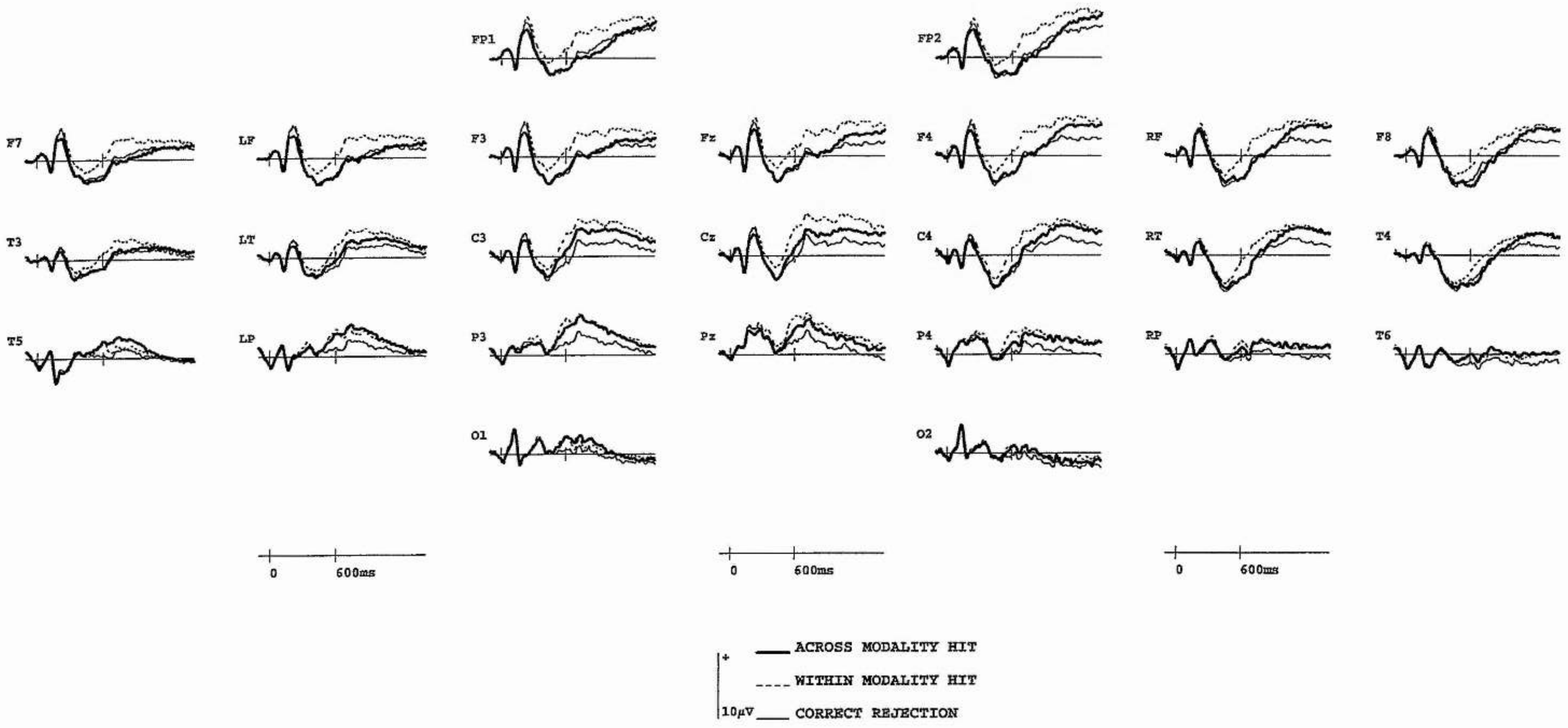


Figure 7.2: Grand average ERPs elicited by correctly recognised old items in the within modality condition (*within modality hits*) and the across modality condition (*across modality hits*) and by correctly rejected new items (*correct rejections*) for words as retrieval cues. Electrode sites as in Figure 7.1.

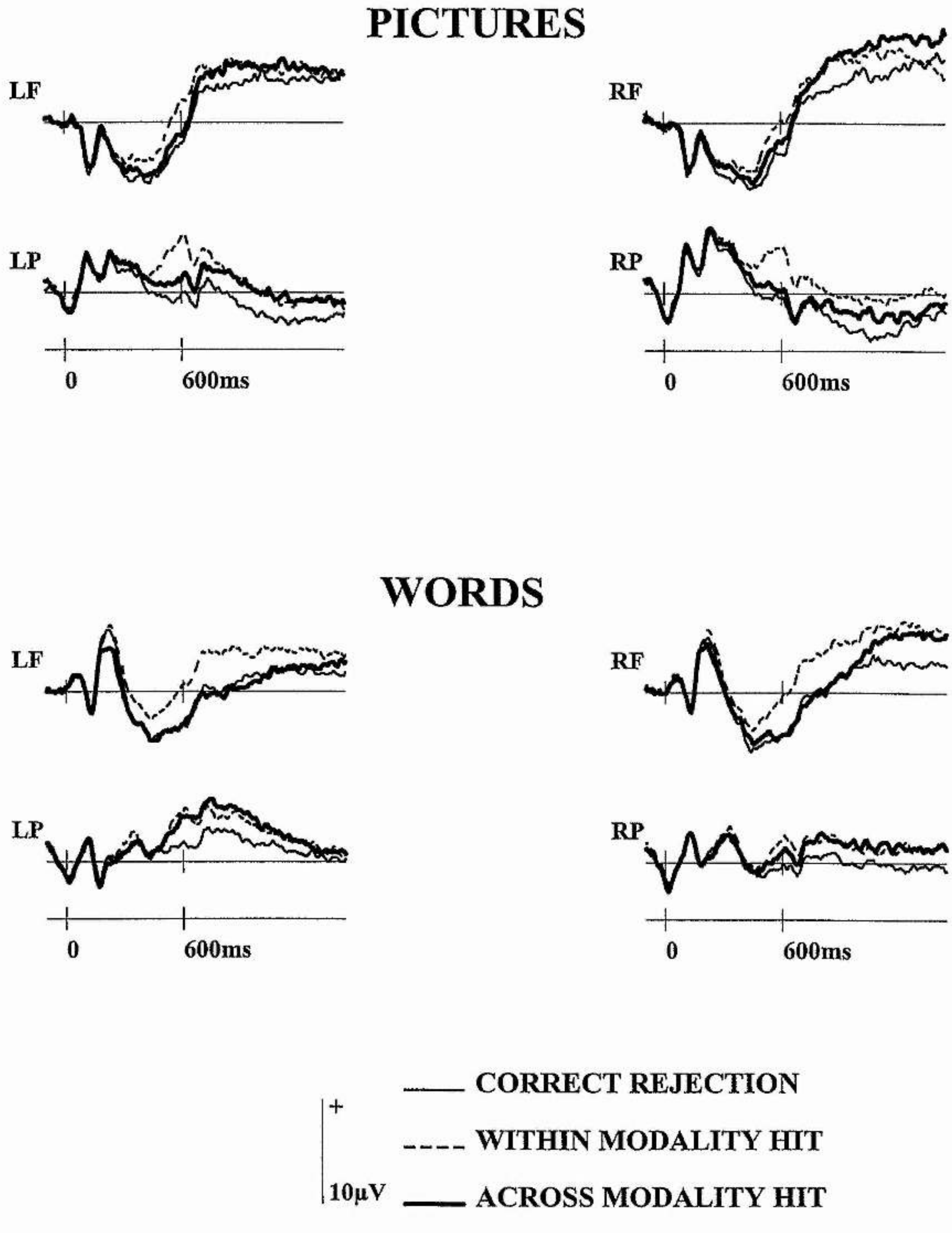
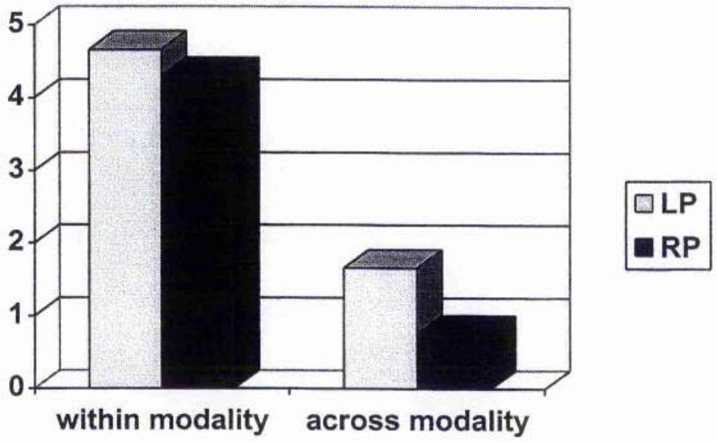


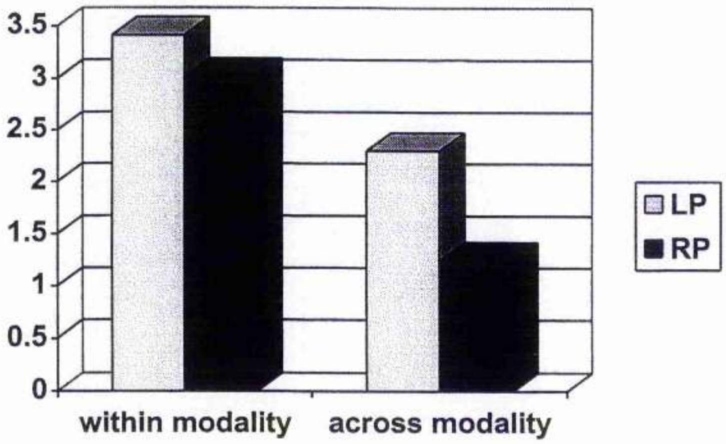
Figure 7.3: Grand average ERPs elicited by the within modality hit, across modality hit and correct rejection response categories for picture and word retrieval cues, shown at lateral frontal and parietal sites.

Figure 7.4. Mean amplitude for the difference between hit and correct rejection ERPs at left and right parietal sites for pictures as retrieval cue (a) and words as retrieval cue (b)

a) PICTURES: 500 – 700 ms



b) WORDS: 500 – 700 ms



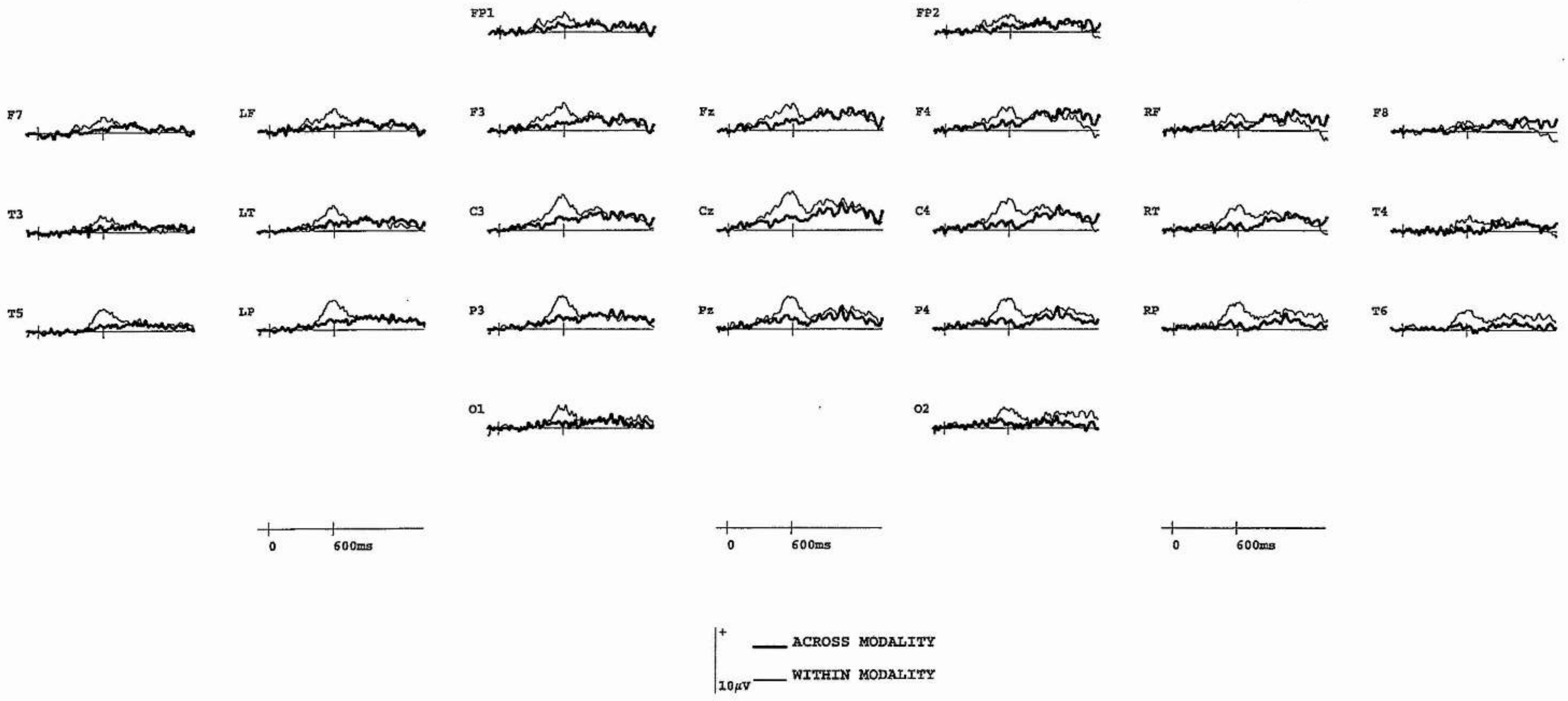


Figure 7.5: Subtraction waveforms (hit – correct rejection) for the within and across modality condition for pictures as retrieval cues. Electrode sites as described in Figure 4.1.

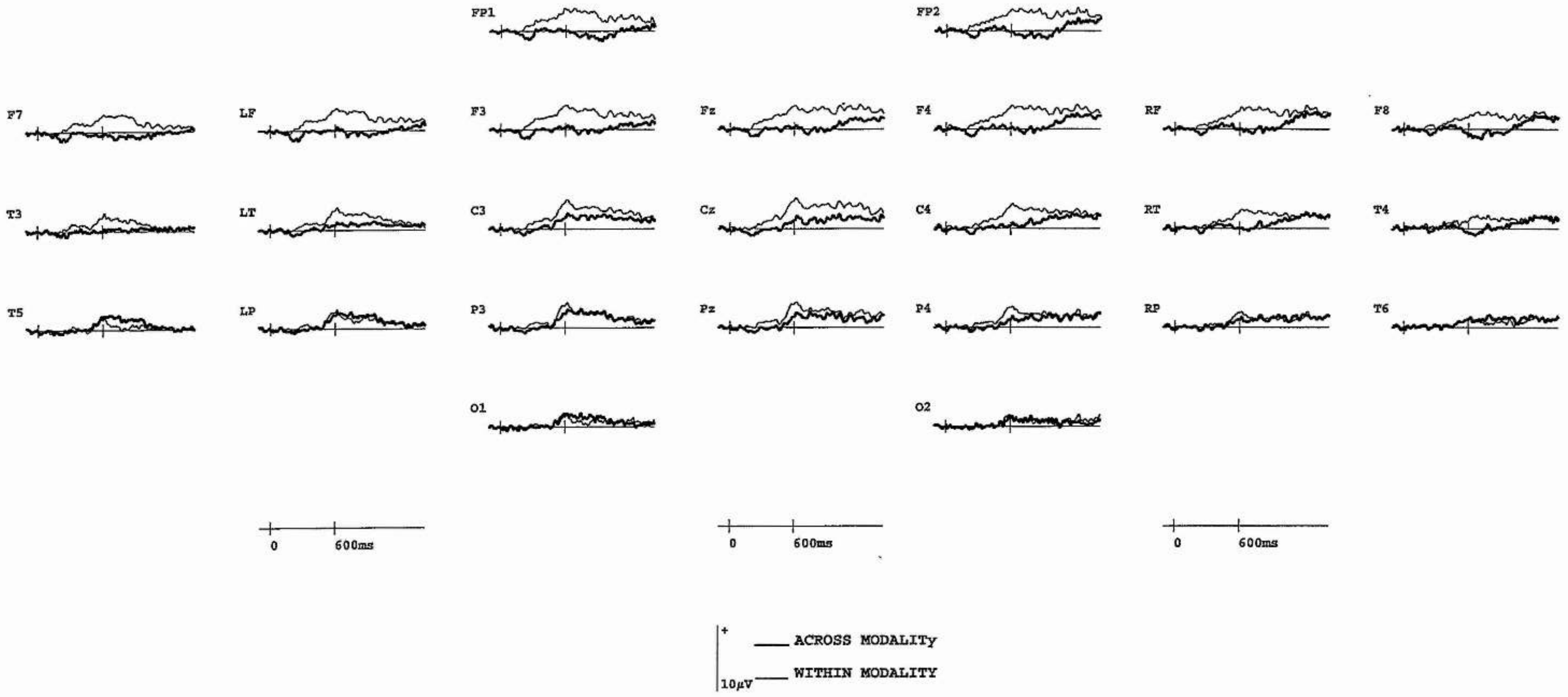


Figure 7.6: Subtraction waveforms (hit – correct rejection) for the within and across modality condition for words as retrieval cues. Electrode sites as described in Figure 4.1.

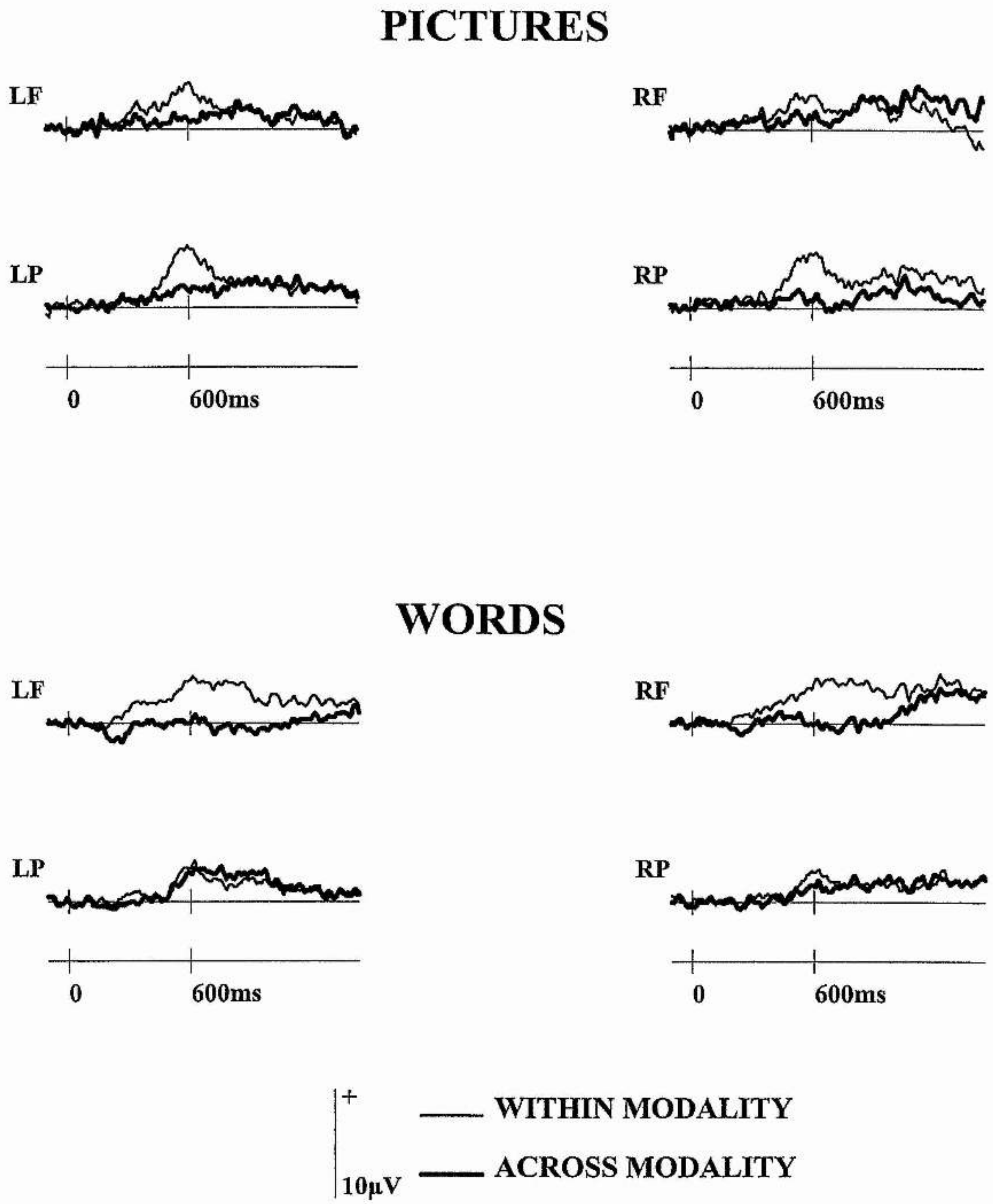


Figure 7.7: Subtraction waveforms (hit – correct rejection) for the within and across modality conditions for pictures and words as retrieval cues, shown at lateral frontal and parietal electrode sites.

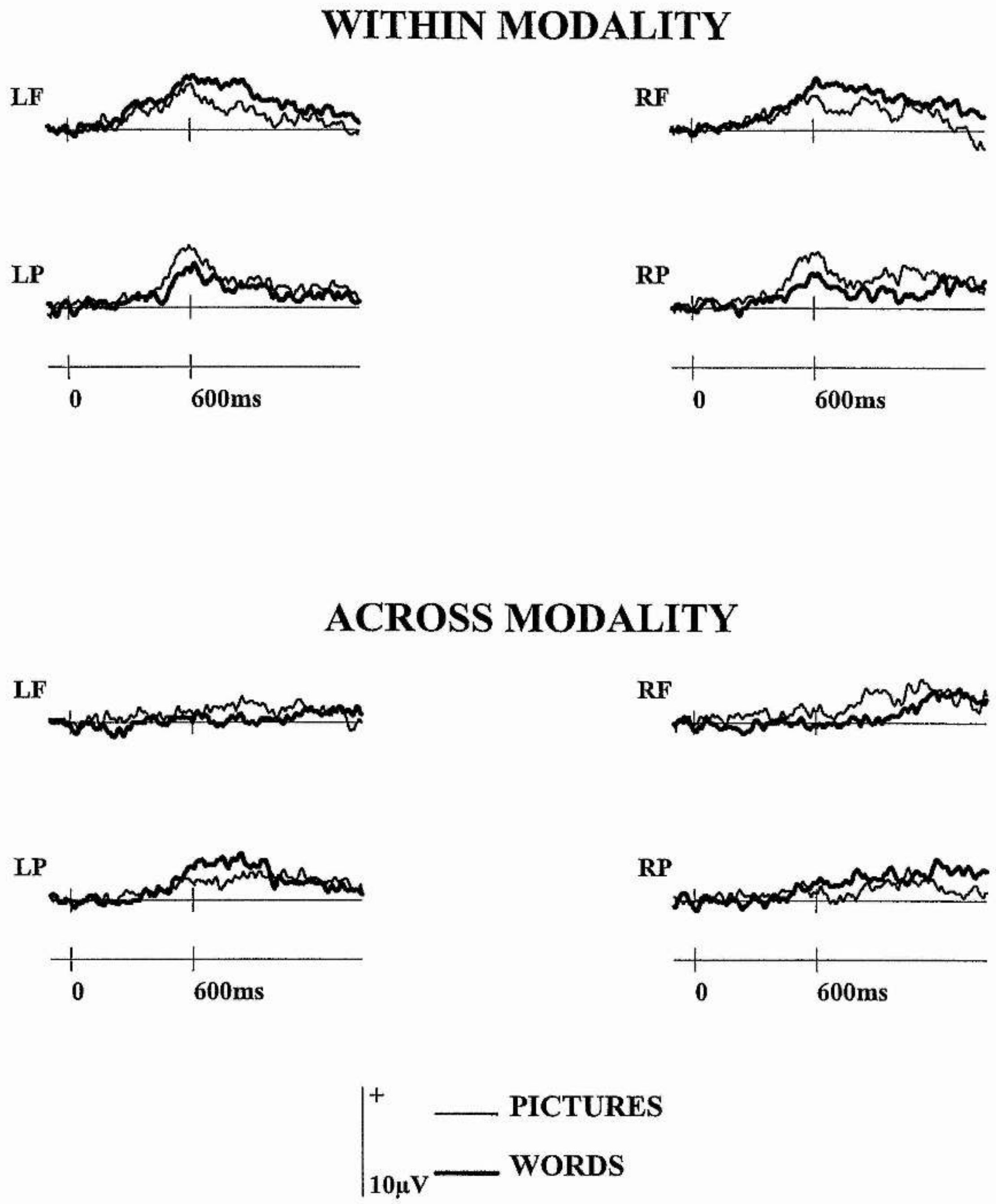


Figure 7.8: Subtraction waveforms (hit – correct rejection) for the within and across modality conditions compared across retrieval cues, shown at lateral frontal and parietal sites.

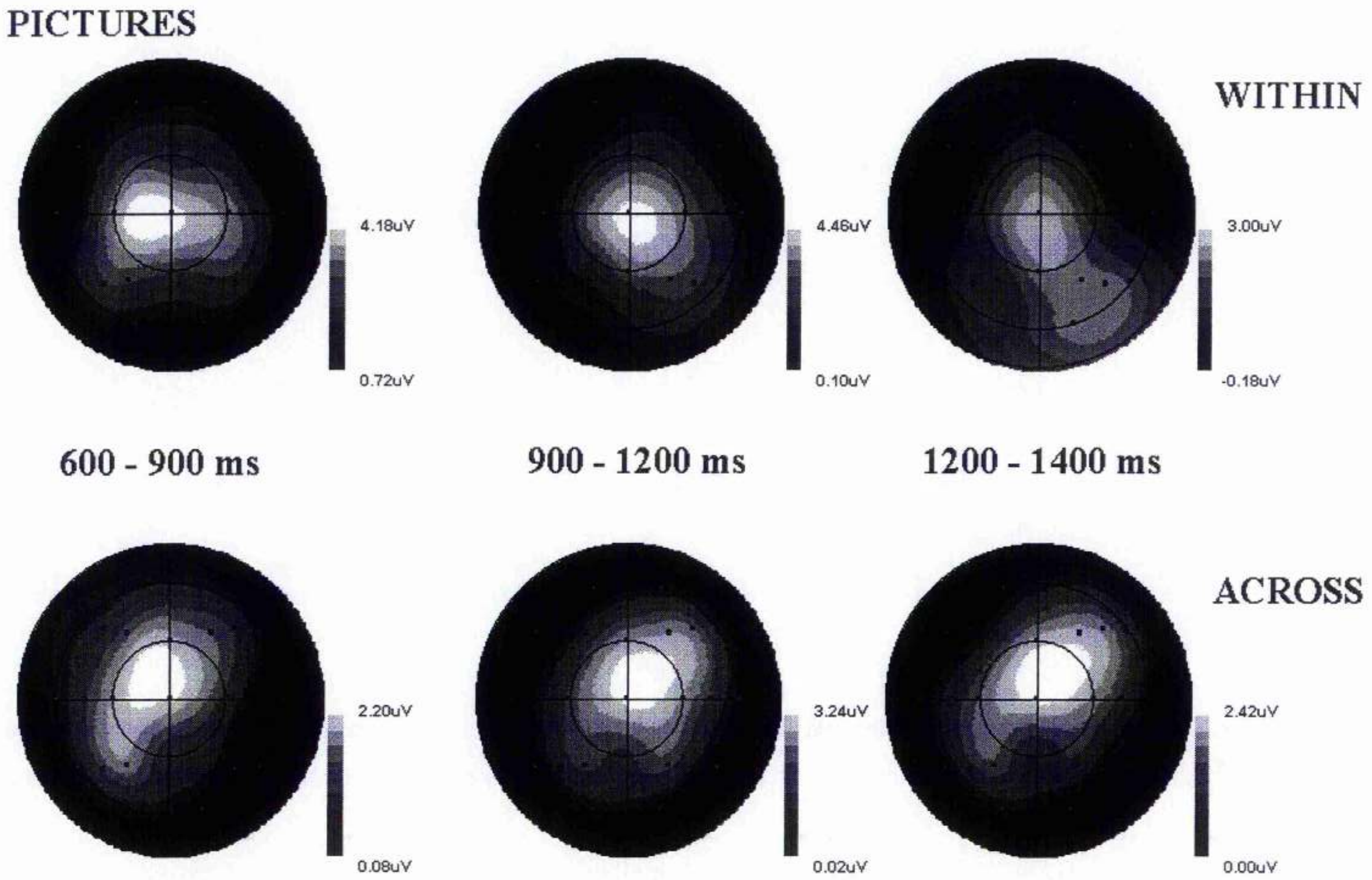


Figure 7.9: Topographic maps of the ERP old/new effects in the 600-900, 900-1200, and 1200-1400ms latency regions for the picture within and the picture across modality conditions, showing the relative amplitudes of the differences between hit and correct rejection ERPs over all 25 electrode sites.

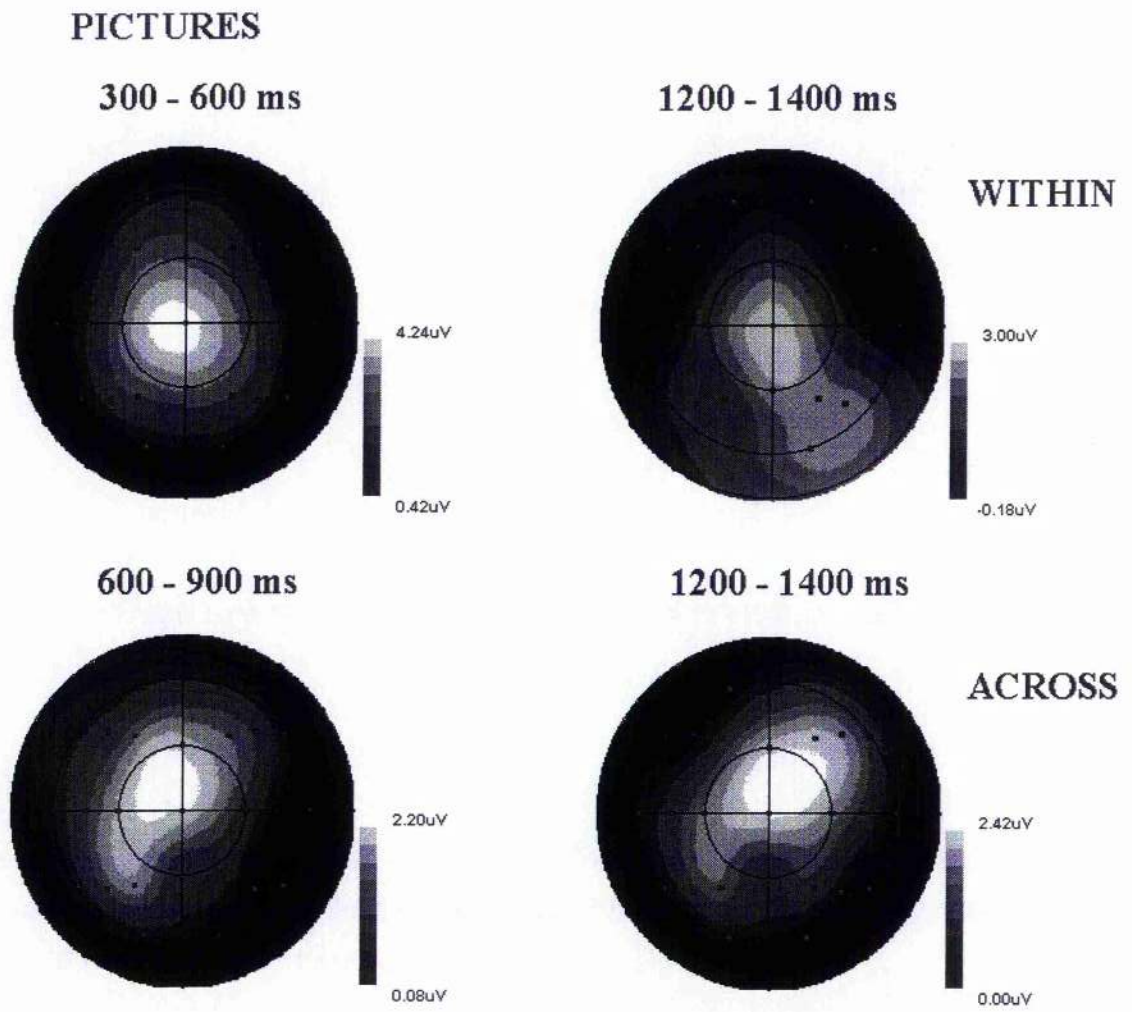


Figure 7.10: Topographic maps of the ERP old/new effects in the 300-600 and 1200-1400ms latency regions for the picture within modality condition and in the 600-900 and 1200-1400 ms latency regions for the picture across modality condition. The maps display the relative amplitudes of the differences between hit and correct rejection ERPs over all 25 electrode sites.

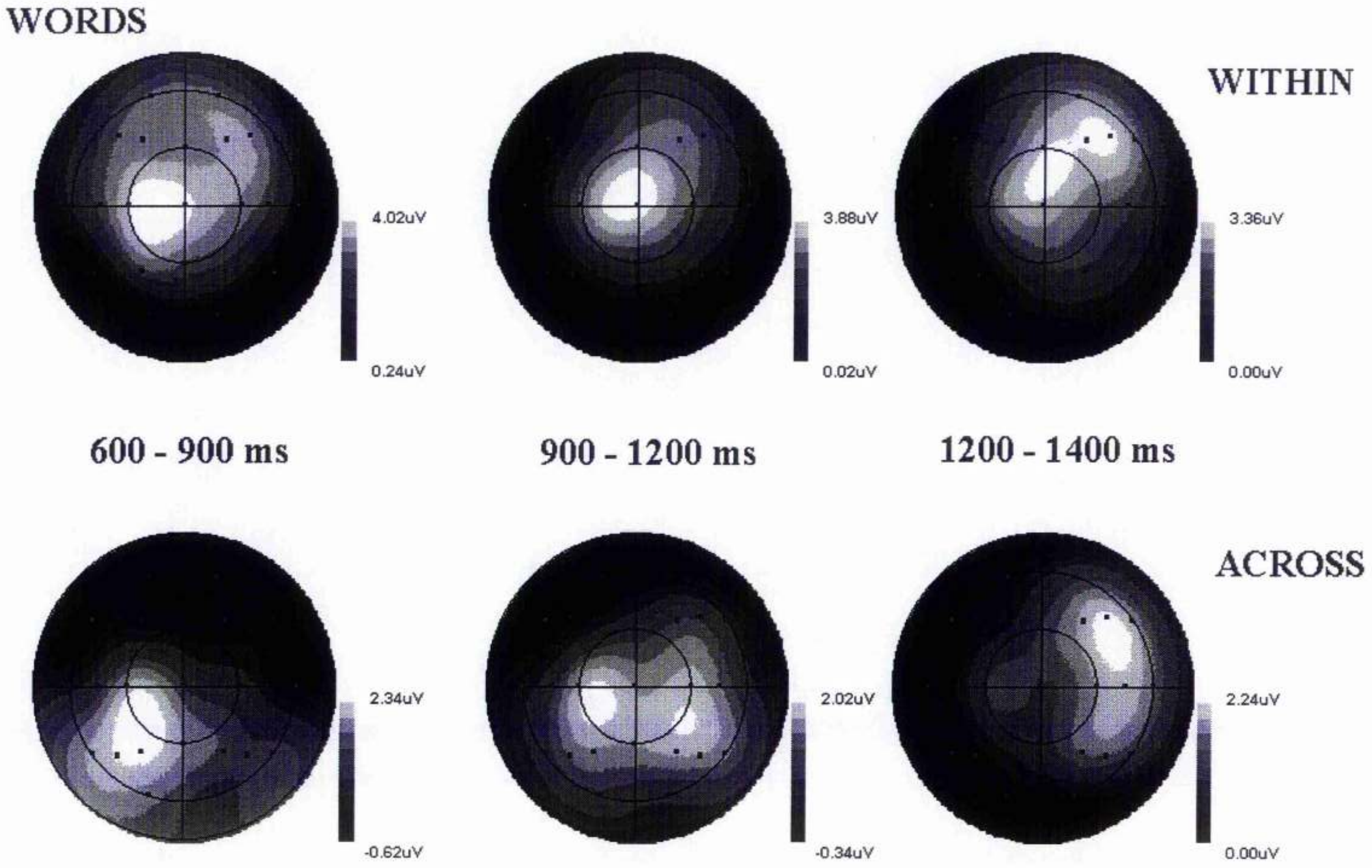


Figure 7.11: Topographic maps of the ERP old/new effects in the 600-900, 900-1200, and 1200-1400ms latency regions for the word within and the word across modality conditions, showing the relative amplitudes of the differences between hit and correct rejection ERPs over all 25 electrode sites.

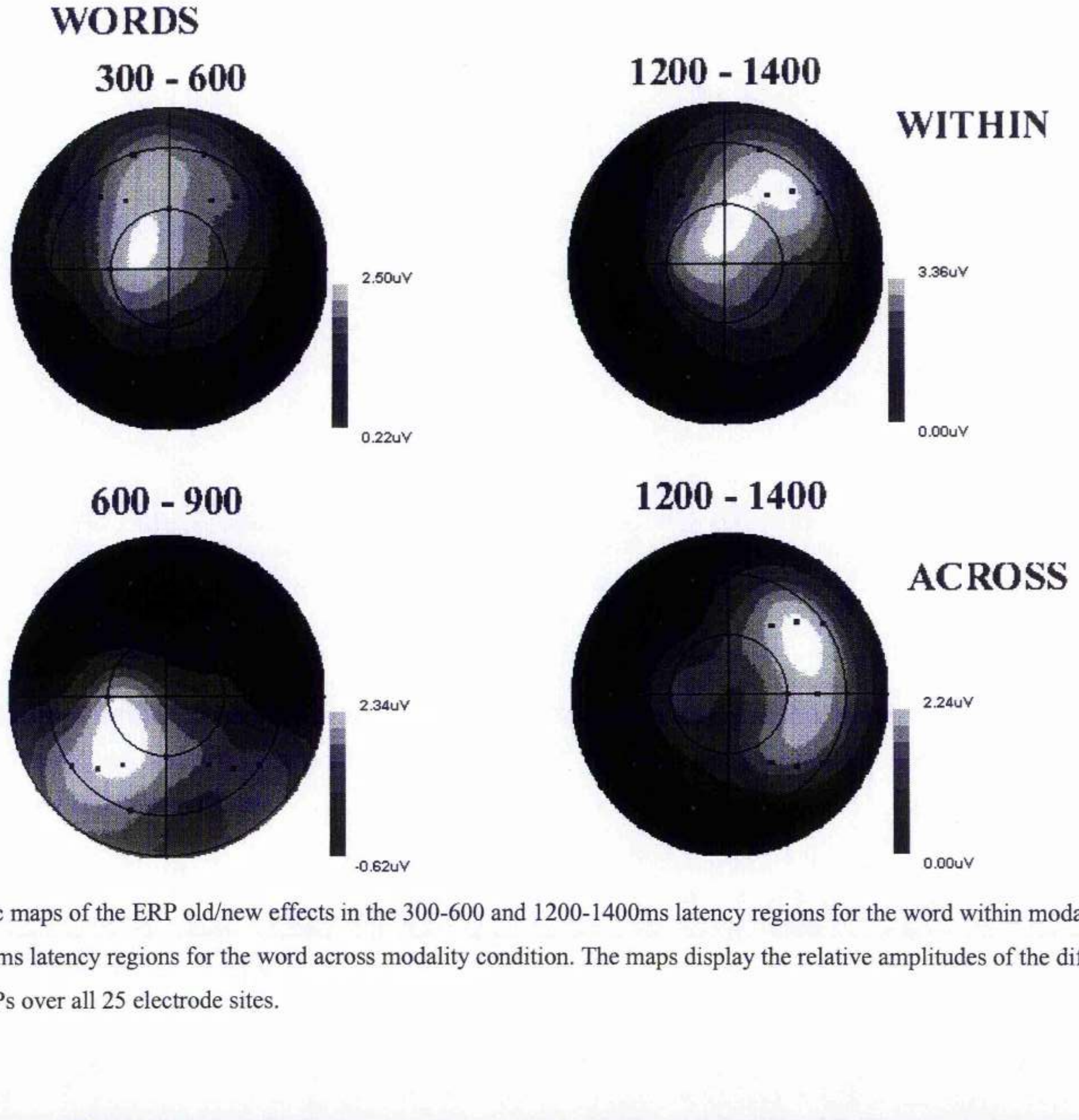


Figure 7.12: Topographic maps of the ERP old/new effects in the 300-600 and 1200-1400ms latency regions for the word within modality condition and in the 600-900 and 1200-1400 ms latency regions for the word across modality condition. The maps display the relative amplitudes of the differences between hit and correct rejection ERPs over all 25 electrode sites.

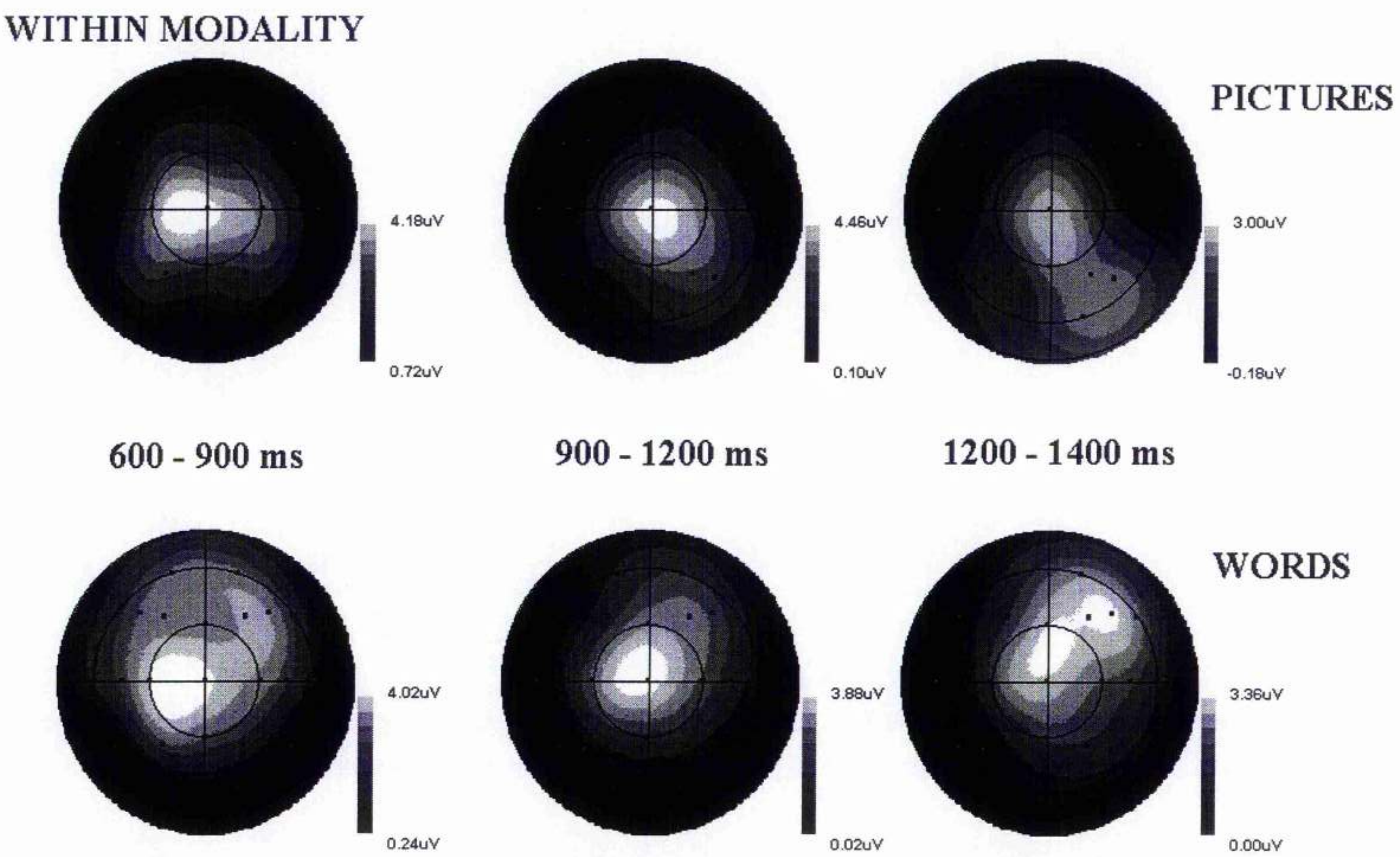


Figure 7.13: Topographic maps of the ERP old/new effects in the 600-900, 900-1200, and 1200-1400ms latency regions for the picture within and the word within modality conditions, showing the relative amplitudes of the differences between hit and correct rejection ERPs over all 25 electrode sites.

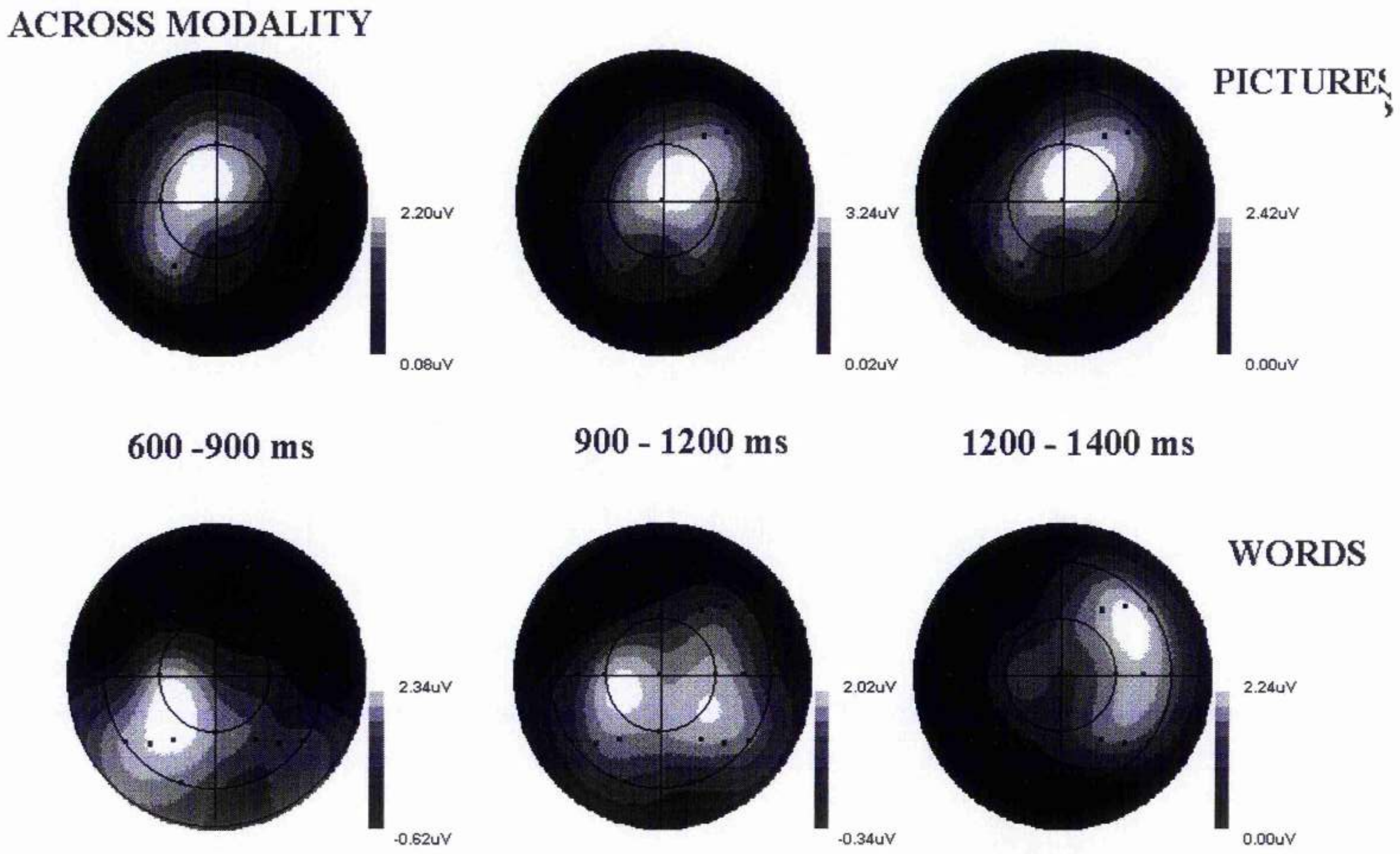


Figure 7.14: Topographic maps of the ERP old/new effects in the 600-900, 900-1200, and 1200-1400ms latency regions for the picture across and the word across modality conditions, showing the relative amplitudes of the differences between hit and correct rejection ERPs over all 25 electrode sites.

CHAPTER 8

General Discussion

The specific details of the behavioural and electrophysiological findings from each experiment have been considered in the relevant discussion chapters. The present chapter will provide a broader account, bringing together the results of the three experiments presented in this thesis with focus on the significance of these results for the functional accounts of the ERP old/new effects. As part of this discussion, important areas for future research will be highlighted. In the first section of this chapter the rationale for and the main results of the empirical work will be briefly summarised. The second section focuses on the discussion of the ERP old/new effects, relating the present results to those of previous work (see Chapter 3). The discussion focuses on the functional significance of the effect and the relevance of this interpretation to the current models of memory discussed in chapter 1.

8.1. Summary of the Experimental Findings

ERP studies of explicit memory have suggested that successful retrieval is associated with two temporally and topographically dissociable ERP old/new effects – the left parietal and the right frontal effects, associated with retrieval and post-retrieval processes respectively. A third old/new effect, the early bilateral frontal effect, has also been linked with successful memory retrieval, however, not much is known so far about the boundary conditions under which it can be observed and hence about its functional significance. The experiments reported in this thesis aimed to investigate these effects further through the use of different stimulus materials (pictures and words) as a means to study the material specificity of the old/new effects. More specifically, the studies addressed the question whether ERP old/new effects vary according to the nature of the information that is retrieved.

Experiment 1 compared the ERP effects for picture and word retrieval directly. In this study, subjects completed two study-test cycles, one of which used words (names of objects) as experimental items, whereas the other one used pictures (of common objects). The test task was simply to discriminate old from new items. For the words, correctly recognised old items exhibited the expected left parietal effect relative to correctly rejected new items. Pictures, however, in addition to a left parietal effect, also exhibited two temporally and topographically dissociable frontal effects – an early left lateralised and a later right-sided effect. The emergence of a left lateralised parietal effect for picture stimuli was somewhat unexpected. A possible explanation for this finding could be that the two classes of item were treated equivalently by the medial temporal lobe memory system. The pictures used in this study were easily nameable and could therefore have been encoded and retrieved by the same processes as those engaged by words. The late right frontal effect, also elicited by pictures, showed the same latency and distribution as the effect described by Wilding and Rugg (1996), who suggested a functional relationship between this effect with recollective post-retrieval processes. It was suggested that pictures induce these post-retrieval processes in absence of the actual task requirements to recollect contextual information, on the basis of the more distinct sensory-semantic code, in which they are represented and which facilitates recollection (Dewhurst & Conway; 1994; Rajaram, 1996). Similarly it was suggested that the early left frontal effect emerged due to the richer sensory-perceptual information inherent in pictures. It was argued that the richer perceptual code would facilitate early retrieval of the perceptual aspects of the stimuli which would then lead to the more effortful episodic retrieval process as indexed by the left parietal old/new effect.

Experiment 2 consequently set out to investigate whether it was indeed the processing of the richer sensory-semantic code inherent in pictures which led to the emergence of the frontal effects for pictures in Experiment 1. To test this hypothesis, the exact replication of stimuli between study and test (within modality conditions replicated from Experiment 1) was contrasted with two conditions in which the identity of the item was kept constant between study and test but the surface form was altered (across modality conditions). As in Experiment 1, the test task was a simple old/new judgement in which subjects had to respond 'old' to all items seen at study, independent of study modality. It was expected that frontal effects would only emerge in those conditions in which pictures were the encoded stimuli.

Replicating the results from Experiment 1, all four conditions exhibited a left parietal old/new effect which did not seem sensitive to a change in surface form between study and test. However, the effect appeared to be sensitive to the type of information that was retrieved as it was largest for the retrieval of those items which were most easily recollected (i.e., pictures as encoded stimuli). Thus the results provided further evidence for a functional account of the left parietal old/new effect in terms of recollection (Paller & Kutas, 1992; Smith, 1993; Wilding & Rugg, 1996, 1997a). Unexpectedly, both within modality conditions (i.e. pictures and words) also exhibited a bilateral frontal old/new effect, which onset earlier than the left parietal effect. This finding indicated that it was not the processing of the rich perceptual code of the pictures alone which was responsible for the emergence of this effect in Experiment 1. There was no clear bilateral frontal effect for the across modality conditions, suggesting that the effect is sensitive to surface change between study and test, and is only present when there is a perceptual overlap between study and test stimulus. The larger magnitude of the effect for pictures than words was taken to indicate that it most probably is sensitive to the factors responsible for the memory advantage of pictorial stimuli. Based on these findings and on the strong evidence linking the picture superiority effect to the distinctive perceptual code in which pictures are represented (Rajaram, 1996), it was argued that the effect might be functionally correlated to perceptual, data-driven processes as described in the transfer-appropriate processing approach (Jacoby, 1983; Roediger et al., 1989). Equally unexpectedly, all but the picture within modality condition exhibited a late right frontal effect. As for the early bilateral frontal effect, the results indicated that it was not the processing of the distinctive perceptual code inherent in pictures which resulted in the emergence of the right frontal effect for pictures in Experiment 1. To the contrary, magnitude and topographic comparisons revealed no difference between the effects for the different conditions, suggesting that it is insensitive to the type and amount of information retrieved, thus providing further evidence for a functional account in terms of post-retrieval processes (Wilding & Rugg, 1996, 1997a).

The occurrence of the bilateral and right frontal effects for those conditions in which words were the encoded stimuli was somewhat surprising. A possible explanation for these results could be that the presentation of the test items was randomised, rather than blocked as in Experiment 1. This type of test format might make a switch between retrieval strategies, normally employed for the different types of items, difficult. Experiment 3 therefore used a blocked design to investigate this possibility. However, blocking did not remove the frontal effects in those conditions in which words were the encoding format. Furthermore, the two within modality conditions now displayed a bilateral parietal old/new effect, whereas the across modality conditions showed the expected left hemisphere maximum. Finally, the early frontal effect did not reveal a larger magnitude for the picture within than the word within modality condition any more.

It thus appeared that test format was not the deciding variable in the occurrence of the frontal effects in Experiment 2. Rather, test format seemed to subtly influence which and how much information was retrieved in response to the retrieval cue. This was apparent in the behavioural data, where blocked designs did not result in a picture superiority effect, whereas the randomised design produced a reliable memory advantage for pictures. In terms of the (left) parietal effect, thought to index recollection, it appeared that test format also influenced the type of information which was retrieved in the different experimental conditions. In the blocked, but not the randomised test format, it seems that for the within modality conditions perceptual as well as semantic features of the items were retrieved in response to the cue. This suggestion is based on the emergence of a bilateral parietal effect for these conditions, in comparison to a left lateralised parietal effect which was evident for the across modality conditions. For the across modality conditions it thus appears that semantic information played a predominant role in retrieval, most probably in response to a lack of perceptual similarity between the study and test items.

The magnitude differences observed for the within modality conditions in Experiments 2 and 3 suggests that the early bilateral frontal effect might be sensitive to amount of information that is retrieved. The picture within modality condition showed a smaller effect size in Experiment 3 in comparison to Experiment 2. This change in effect size was accompanied by a difference in retrieval accuracy, which was higher for Experiment 2 than Experiment 3. Similarly, the word within modality condition showed a larger effect size in Experiment 3 than Experiment 2, which was correlated with an increase in retrieval accuracy from the former to the latter study.

The occurrence of frontal effects for the word within modality condition, and the bilateral distribution of the parietal old/new effects for both within modality conditions, stand in direct contrast to the findings from Experiment 1. One possible explanation for this discrepancy could lie in the slightly different experimental material and the difference in encoding tasks between Experiment 1 and the subsequent two studies. These differences could have affected the encoding and retrieval of information presented in verbal format disproportionately more than information presented in pictorial format. Future research will have to determine in how far the old/new effects are influenced by task instructions and experimental material.

8.2. Functional Accounts of the ERP Old/New Effects

8.2.1. The Left Parietal Old/New Effect

A large array of evidence (for review see Allan, Wilding & Rugg, 1998; chapter 3) suggests that the left parietal old/new effect is associated with recollection – the retrieval of information about specific prior episodes – and indexes the activity of the medial temporal lobe memory system. Studies of item recognition and source memory suggest that the magnitude of the effect is sensitive to the amount of information that is retrieved from memory.

As would be expected, a parietal effect was present in the ERPs for both types of stimuli, pictures and words. Furthermore, the effect was consistently larger for those conditions in which pictures were the encoding stimuli. As suggested by studies investigating the picture superiority effect, it is the relatively greater distinctiveness of the visual sensory features of pictures that produce the better memory performance in comparison to words (Dewhurst & Conway, 1994; Nelson, 1979; Rajaram, 1996; Weldon & Coyote, 1996). According to Jacoby and Dallas (1981), it is this distinctiveness of the original encoding episode which determines if and how much information is recollected about the context in which the item was experienced. Thus it can be argued that the picture superiority effect is based on recollective processes which occur to a greater extent for pictures than words. By this argument, the present finding that the parietal old/new effect is consistently larger for those conditions in which pictures were presented at encoding, provides further evidence for a connection between the left parietal effect and the process of recollection.

The magnitude difference between the retrieval of items encoded from verbal or pictorial stimuli also provides further evidence for the suggestion that the effect is sensitive to the amount of information that is retrieved. This suggestion derived primarily from source memory and associative recognition and recall studies (Donaldson & Rugg, 1998; Rugg et al., 1996; Wilding et al., 1995; Wilding & Rugg, 1996, 1997b) in which the left parietal effect was reliably attenuated for those items which were assigned the incorrect source judgements or the incorrect study associate. In the present studies, verbally encoded stimuli showed the consistently smaller effect than pictorially encoded items. As discussed above, at retrieval verbally encoded items will not provide as much episodic information as pictorially encoded items, which suggests that the smaller parietal effect for these items is directly linked to the ease with which contextual information can be retrieved.

As discussed in chapter 3, neuroanatomical accounts of the left parietal old/new effect suggest that it is an index of cortico-hippocampal interactions that results from retrieval-related activity of the medial temporal lobe memory system (Wilding & Rugg, 1996). Thus it can probably be assumed that the activity of the medial temporal lobe is directly connected to the magnitude of the left parietal old/new effect. Assuming that this is the case, an array of neuroimaging studies provide support for a connection between the magnitude of the left parietal old/new effect and the success with which relevant contextual information can be retrieved (for review see Fletcher et al., 1997; Schacter & Buckner, 1998). A number of studies have examined medial temporal regions in the context of the distinction between successful conscious recollection, on the one hand, and intentional retrieval effort, on the other. In a PET study of stem cued recall, Schacter, Savage, Alpert, Rauch and Albert (1996b; see also Schacter et al. 1996a) manipulated retrieval success and retrieval effort through manipulation of the study conditions. In the 'high-recall' condition, subjects studied items 4 times with a semantic encoding task. In the 'low-recall' condition, items were studied only once and with a perceptual task. The logic underlying the experiment was that regions that were selectively activated during the high recall condition are preferentially associated with successful conscious recollection, whereas regions that are activated during the low recall condition are preferentially associated with intentional efforts to search memory. Subjects remembered many more words in the high than the low recall condition, thus confirming the validity of the study manipulation. Analyses of the PET data revealed blood flow increases bilaterally in the hippocampal formation during the high recall condition compared with a baseline condition (completion of nonstudied three-letter stems with the first words that came to mind), and blood flow increases in the right hippocampal area in comparison with the low recall condition. Interestingly, the low recall condition did not differ from the baseline condition. These results seem to indicate that the hippocampal formation is not activated by the effort involved in intentional attempts to remember past events as in the low recall condition subjects tried to remember study list words, but successfully recalled relatively few of them. Similar results were obtained by Rugg et al. (1997), who manipulated depth of encoding at study to differentiate between retrieval effort and retrieval success. They also included an incidental memory test (an animacy decision task) which did not require intentional retrieval. In the intentional memory task subjects performed significantly better on the deeply than the shallowly studied items. In the incidental memory task subjects reported more unintentional recollections for the deeply studied items than the shallowly studied ones. Interestingly, PET data revealed greater activation in the left medial temporal lobe after deep than shallow encoding during both intentional and unintentional retrieval. Thus, these data suggest that hippocampal activity during retrieval is observed with high levels of conscious recollection, regardless of whether subjects voluntarily try to remember the study list.

Taken together, the present data provide further evidence for a functional account of the parietal old/new effect in terms of recollection and a sensitivity of the effect to the ease with which contextual information can be retrieved successfully. However, the main question addressed by the present studies was whether ERP old/new effects vary according to the nature of the information that is retrieved. Specifically, the initial expectation, based on observations of material specific deficits for non-verbal material after unilateral temporal lobe lesions (Milner, 1966; 1968), was that the left parietal old/new effect might be bilaterally distributed for the retrieval of material that was encoded in pictorial form. The present studies provide mixed results with regard to this expectation. In the first two studies the parietal old/new effect did exhibit a lateralisation to the left hemisphere. In the third study the effect was bilaterally distributed for the within modality conditions and left lateralised for the across modality conditions. These results suggest that the engagement of the bilateral medial temporal lobe systems may not necessarily be determined by the nature of the encoded material, but also by the encoding and retrieval strategies employed in response to the task demands (see also Jha et al., 1996; Kroll et al., 1996).

The results of Experiments 1 and 2 clearly indicate that when verbal/semantic information about a picture is readily available, retrieval can predominantly rely on this type of information (see also Jha et al, 1996). The results of Experiment 3, however, suggest that, independent of the type of material, the medial temporal lobe memory system can be engaged bilaterally (if it is assumed that the left parietal effect and a corresponding right parietal effect are indices of activity contingent on the activation of the medial temporal lobe). This bilateral engagement was only present in a blocked experimental design and here only for the 'within modality' conditions. These findings tentatively suggest that (i) different encoding strategies, engaging additional neural systems, can be employed when all study stimuli are presented in the same format (as in a blocked experimental design)[1] rather than in varying formats (as in the randomised design of Experiment 2), and (ii) the additional engagement of the right medial temporal lobe at retrieval is dependent on perceptual overlap between study and test items. The latter observation is especially interesting in the context of Metcalfe et al.'s (1995) suggestion that processing in the two hemispheres is material independent, but differs in process with a right hemisphere advantage for rote memorization and veridical encoding. The present results also indicate that the availability of semantic information about an item dominates any other available information, at least under encoding and retrieval conditions which provide a multitude of information and require fast switches between retrieval strategies. However, this argument stands in contrast to the results of the neuroimaging studies reviewed in chapter 1 (section 1.6.3.2). These studies mostly revealed bilateral or right-sided medial temporal activation at encoding and/or retrieval of pictorial or facial stimuli (Grady et al., 1998; Haxby et al., 1996; Stern et al., 1996). Similarly, lesion studies suggest an involvement of the right medial temporal lobe memory system in a variety of tasks for both verbal and pictorial stimuli (Dobbins et al., 1997; Jha et al., 1996; Kroll et al. 1996). It is not clear why this discrepancy should arise. Nevertheless, it would be of interest to further investigate if and in how far various encoding tasks, emphasising different processing strategies (perceptual vs. semantic, pictorial vs. verbal) influence the engagement of the lateralised medial temporal lobe memory systems at retrieval for various materials.

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[1] Different encoding tasks, emphasizing differential processing of the study items, in Experiments 1 and 3 could be the reason why no bilateral parietal effect was observed in Experiment 1.

8.2.2. The Early Bilateral Frontal Old/New Effect

As discussed previously (see Chapter 3), there is accumulating evidence that old/new effects at frontal sites can be differentiated into two temporally and topographically dissociable components, an earlier bilateral and a later right frontal component. The present studies add further to this evidence. While the late right frontal effect is insensitive to the modality manipulation used in Experiments 2 and 3, the early bilateral frontal effect is heavily influenced by changes in modality between items at study and test (for similar results see Wilding & Rugg, 1997b). Furthermore, the results also support the notion, discussed in Chapters 3 and 5, that the effect can emerge independently of the task requirement to retrieve contextual information. In the present studies the effect consistently emerged in a simple old/new recognition task which did not require the intentional retrieval of contextual information regarding the study episode.

A study by Donaldson and Rugg (in press) suggested that the early bilateral frontal effect is, under certain task demands, sensitive to test format. In two studies, they investigated the electrophysiological correlates of associative recognition and associative recall. In the first study, the experimental design took a randomised test format in which both tasks were administered in the same test block. In the second experiment the two tasks were administered in blocked conditions. Results revealed that for associative recall the early bilateral frontal effect was present in the randomised test format, but not in the blocked format. For associative recognition, however, the effect was elicited under both test formats (Donaldson, unpublished doctoral thesis). Donaldson and Rugg (in press) argued that the differential modulation of the effect for the two different tasks suggests that the effect is highly sensitive to the context in which retrieval occurs. The present studies, however, did not reveal such context sensitivity as there was no differential effect of test format on the early bilateral frontal effect. Interestingly, however, Experiments 1 and 3 showed differential results regarding the early bilateral frontal effect under the *same* test format. In Experiment 1 the effect was absent for the word condition, whereas in Experiment 3 the effect was present for the word within modality condition, which constituted a replication of the word condition in Experiment 1. The principal differences between Experiments 1 and 3 were the use of slightly different experimental materials and a different encoding task. This suggests that the effect might be sensitive to the conditions under which the item was encoded, rather than the retrieval conditions, at least where verbal stimuli are concerned. The effect was consistently present across all three experiments for pictorial stimuli. It is therefore paramount to explore this issue further by using the verbal stimuli from Experiment 1 under the encoding instructions of Experiments 2 and 3 (or vice versa) to investigate whether the frontal effect is indeed sensitive to the encoding instructions. Given the robustness of the effect across different test formats for pictures, it would, furthermore, be of interest whether different types of material (highly imageable or very abstract) under varying encoding conditions (emphasizing perceptual, image-related aspects and semantic aspects differentially) would influence the emergence of the effect at retrieval (also under different test formats).

Contrary to the suggestion made with respect to the results of Experiment 1, the early bilateral frontal effect does not appear to be material-specific and thus is not mediated by the comparatively richer sensory-perceptual information inherent in pictures. The presence of the effect in a number of other studies (Donaldson & Rugg, 1998; Rugg et al., 1998; Tendolkar et al., 1997; Wilding & Rugg, 1997b) which used a variety of tasks and exclusively verbal materials, supports this notion. Given the wide range of conditions under which the effect emerges, what is its functional significance? The established right-sided frontal old/new effect has been accounted for in terms of 'post-retrieval' processes that, monitor and evaluate retrieval output. The time course of the effect in the present experiments – the effect consistently onsets earlier than the parietal old/new effect (see also Tendolkar et al. 1997) - makes it difficult to reconcile it with this function. Rather, it seems more likely that the effect reflects processes that either initiate or support episodic memory retrieval, or act in parallel, possibly on a different type of information.

One specific proposal regarding the functional significance of the early frontal old/new effect comes from a recent study of item recognition by Rugg et al. (1998), which employed a depth of processing manipulation at study. Rugg et al. (1998) found that recognised words were associated with an early (300 – 500 ms post-stimulus) bilaterally distributed frontal old/new effect which was present in the ERPs for both deeply and shallowly studied words, but was insensitive to the depth of processing manipulation. This bilateral frontal old/new effect was taken to provide an index of familiarity. Consistent with this proposal, the bilaterally distributed effect was not found in the ERPs for unrecognised old words from the shallow condition. More significantly for present purposes, the bilateral frontal old/new effect was followed by a left parietal effect (500 – 800 ms post-stimulus), which was only present for recognised words that were deeply studied. Thus, Rugg et al. (1998) proposed that shallowly studied items were recognised solely on the basis of the familiarity of the item, whereas deeply studied items were associated with both, familiarity and recollection (reflected by the later left parietal effect). Whilst Rugg et al. (1998) provide a plausible account of the functional significance of the effect, the interpretation rests on the assumption that depth of processing exclusively influences recollection based responding. However, recent data (Jacoby, 1996; Yonelinas & Jacoby, 1995; Toth, 1996) suggest that depth of processing also influences familiarity based responding. This influence is exerted on conceptual processes which (possibly in addition to perceptual, data-driven processes) contribute to this basis for recognition memory.

The present results add a new dimension to this proposal. Not only does the effect not seem to be influenced by levels of processing, it is also sensitive to the perceptual overlap of an item between study and test. In other words, the effect is largest when the recognition cue is an exact replication of the study stimulus and smaller or absent when the item is represented in different surface forms at study and test (Donaldson & Rugg, 1998; Wilding & Rugg, 1997b). In the present studies the effect is only present for the within modality conditions in which study and test stimuli replicate, but was absent for the across modality conditions in which surface form changes from picture to word or vice versa. This sensitivity of the early bilateral frontal effect to changes in surface form between study and test suggests a correlation of the effect with perceptual, data-driven processes (Jacoby, 1983). Thus it could be argued that the bilateral frontal effect is the neural signature of the 'reprocessing' of perceptual information first encountered in the study phase. This account is reminiscent of the proposals of the 'transfer-appropriate-processing' framework (Morris et al. 1977; Roediger et al., 1989). To recap briefly (but see Chapter 1, section 1.2.3), proponents of this framework argue that the dissociations observable between performance on direct and indirect memory tasks reflect differences in the underlying processing demands, rather than differences in underlying memory systems. Thus, the ability to access or make use of memory information is dependent upon the degree to which the processing operations required at test overlap with those performed at study. Accordingly, they suggested a classification of memory tests according to processing demands and proposed a distinction between 'data-driven' (perceptual) and 'conceptually-driven' (semantic) processing to replace the categorisation of tasks as direct and indirect. They argued that most indirect memory tasks depend predominantly on data-driven processing, whereas most explicit tests benefit from conceptual processing at study (Roediger & Blaxton, 1987). Importantly however, they proposed that most memory tasks involve both types of processing.

By this argument, recognition will have a data-driven and a conceptually-driven processing component. It is possible that the early bilateral frontal old/new effect reflects this data-driven processing component of recognition memory. The use of the exact same stimulus with completely overlapping perceptual features at study and test in the within modality conditions would enable the 're-processing' of the perceptual information acquired at study. In the across modality conditions, this is not possible, as there is no perceptual overlap at all between study and test. In this instance, memory performance would have to derive completely from the use of the conceptual processes which were carried out at study. Thus, this speculation could be extended even further. In this framework, it would be possible to argue that the parietal old/new effect reflects the conceptual processing component of recognition memory, a component very likely to be used extensively under the requirement to retrieve contextual information about a study episode (Jacoby, 1983; Roediger & Blaxton, 1987; Roediger et al., 1989). Indeed, a recent neuroimaging study by Blaxton, Bookheimer, Zeffiro, Figlozzi, Gaillard and Theodore (1996) suggests that conceptual and perceptual memory processes are subserved, at least in part, by different neurological substrates, supporting the above speculations. In order to investigate further whether data-driven and conceptually- driven processes do indeed map onto the early bilateral frontal and the parietal old/new effects, the systematic manipulation of perceptual and conceptual processes at encoding would have to be crossed with retrieval tasks demanding more or less of either of these types of processes. In this framework, it should be possible to match a data-driven encoding task with a data-driven retrieval task, resulting in ERPs in which the early bilateral frontal effect occurs in the absence of the parietal old/new effect. This type of investigation might also help to elucidate why the bilateral frontal effect can sometimes be observed, even in strongly conceptually oriented tasks, and sometimes not.

An interpretation of the functional significance of the effect in terms of the data-driven processing component of recognition memory does not exclude a functional interpretation of the effect in terms of familiarity, as suggested by Rugg et al. (1998). In fact, Jacoby and Dallas (1981, see also Chapter 1, section 1.4) clearly suggested that familiarity is based on a strong perceptual component. They argue that it is the relative perceptual fluency, the facilitation of processing through the perceptual similarity of an item when encountered for the second time, and the attribution of this fluency to the reoccurrence of the item, which is the basis for familiarity-driven recognition. Recent evidence (Jacoby, 1996, Toth, 1996) suggests that conceptual processes also contribute to familiarity based recognition. This however, does not exclude a contribution of data-driven processes. Thus, the early bilateral frontal effect might reflect the attribution process by which the perceptual fluency experienced for the repeated item is attributed to the reoccurrence of the item in the test list. To further elucidate this possibility, it would be interesting to study whether the early bilateral frontal effect would be modulated by the manipulation of perceptual fluency in a recognition memory test. One procedure of interest would be the subliminal pre-exposure of identical or unrelated primes during the test-phase of a recognition memory test as suggested by Jacoby and Whitehouse (1989). Furthermore, to establish if it is indeed the attribution process that is reflected by the early bilateral frontal effect, it would be interesting to study the attribution of the perceptual fluency to other causes, like stimulus duration on the screen (Witherspoon & Moscovitch, 1989) or perceived fame (Jacoby, Woloshyn & Kelley, 1989).

The present results give some tentative indication that the transfer-appropriate processing approach provides a possible framework for the interpretation of at least the early bilateral frontal and the parietal old/new effects. Taken to the extreme, the transfer-appropriate processing framework proposes a single memory system using different types of information depending on retrieval requirements. However, as has been established in a number of studies (Donaldson & Rugg, 1998; Tendolkar et al., 1997; Wilding & Rugg, 1997b) the early frontal effect and the parietal old/new effect are topographically dissociable, indicating that they are mediated by different neural generators. This suggests, that probably, as proposed by the systems approach (see Chapter 1), more than one neural system contributes to the ability to remember past events. However, there is no reason to believe that these different systems could not operate on different types of information using distinct processes. In fact, these are two of the requirements for the distinction of systems, proposed early on (Schacter & Tulving, 1994). Thus, systems and processing theories of memory might ultimately be compatible and, in time, provide a more precise account of the neural substrates of memory and their processing operations (Hayman & Tulving, 1989; Roediger et al., 1989; Schacter, 1993).

8.2.3. The Late Right Frontal Old/New Effect

The late right frontal old/new effect was first found in studies of source memory (Wilding & Rugg, 1996). Interpretations of the effect have been predominantly in terms of post-retrieval support processes, rather than memory retrieval per se. However, the precise functional role of the right frontal old/new effect remains uncertain. The present results have no major impact on the functional account of this effect, but do, however, refine a few aspects of the post-retrieval hypothesis.

First, the present findings demonstrate that the right frontal effect is not confined to tasks such as source memory, where the correct response relies on accurate recollection of the study episode. That is, the explicit requirement to engage in strategic discrimination between different classes of old items is not necessary for the engagement of the generators of the effect. Secondly, the present findings demonstrate that the effect is not material-specific, that is, it does not vary according to the nature of the information that is retrieved. The late right frontal effects in the various experimental conditions did not show any magnitude differences, nor any topographic differences according to stimulus type. These properties of the right frontal old/new effect are strongly characteristic of a post-retrieval process, operating on the outcome of retrieval operations.

The absence of any magnitude differences in the effects for the different types of encoding and retrieval stimulus speak to a third issue. As discussed in Chapter 1, current neuroimaging work is investigating the issue of the functional significance of the right prefrontal activations found in episodic memory tasks. The two possibilities currently investigated are those of retrieval effort and retrieval success (see Chapter 1, section 1.4). In the present data, especially the data of Experiment 2, reliable behavioural differences between the picture and the word within modality conditions were not accompanied by reliable magnitude differences in the right frontal old/new effect. Thus, in spite of greater 'retrieval success' in the picture within modality condition, the effect remained of the same size as for the condition with the lesser retrieval success. Under the assumption that the right frontal old/new effect and the right prefrontal activations found in functional anatomical studies of episodic memory are mediated by the same neural generator(s), this result stands in direct contrast to the retrieval success hypothesis. However, it has recently been suggested that the right frontal old/new effect (Johnson et al., 1996; 1997) as well as the right prefrontal activations in imaging studies (Wagner et al., 1998) are sensitive to the retrieval context (test format and task instructions). This might provide a possible explanation, why in some instances (Donaldson & Rugg, 1998; Rugg et al., 1996; Wilding & Rugg, 1996) the right frontal old/new effect appears to be sensitive to retrieval success, reflected by an attenuated magnitude for incorrect source retrieval, and sometimes not, as in the present results. Further investigation of the boundary conditions for the occurrence of this effect will be needed.

8.3. Conclusions

The present studies provided further evidence for the proposal (for review see Allan et al. 1998) that explicit memory retrieval is neither functionally nor neurologically homogeneous. Three temporally and topographically dissociable components could be distinguished, an early bilateral and a late right frontal effect in addition to a predominantly left-sided temporo-parietal effect.

None of the components appeared to be material-specific, that is, none varied according to the nature of the information that is retrieved. However, the parietal old/new effect did show a slight indication for a sensitivity towards task requirements at encoding and retrieval. This sensitivity is most probably material-independent and might be influenced by the availability of perceptual information, even if self-generated in form of imagery, in addition to semantic information.

New functional properties of the early bilateral frontal effect were discovered. The effect was shown to be highly sensitive to the perceptual similarity of an item between study and test. This property correlates it functionally to perceptual, data-driven processes proposed to be one of the bases of familiarity-driven recognition.

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APPENDIX

Appendix A: Stimuli used in Experiment 1

PICTURES

Spatula
Chair
Duck
Funnel
Ambulance
Saw
Button
Golfball
Soap
Glue
Pistol
Battery
Shoebrush
Purse
Hairbrush
Winebottle
Kettle
Banana
Helicopter
Toilet-Roll
Cat
Stapler
Face-mask
Microwave
Goggles
Horse
Ashtray
Stanley Knife
Espresso Machine
Tin of tuna
Book
Match
Dog
Walnut
Cow
Stapler
Pen
Spanner
Mask
Flash
Packet of Coffee
Compact Disk
Face Cream
Bulb
Adapter
Deodorant
Tin of Sweetcorn
Shovel
Car
Motorbike
Bag of Pasta
Pack of Cigarettes
Drill
Bag of Rice
Cable Stripper
Orange
Packet of Angel Delight
Mousetrap
Plate
Speaker
Sharpener
Hotwaterbottle
Packet of Crisps
Shoecreme
Egg-Timer
Jar of Sweetener
Plug
Tin of Tea
Vitamin Pills
Wool
Umbrella
Chisel
Syringe
Watch
Lipstick
Circuit Board
Coil
Spraycan
Peg
Toy car
Calculator
Jar of Marmite
Bottle of Shampoo
Key
Rugby Ball
Stamp
Pig

Bottle of Tippex
Cassette
Toothpaste
Sheep
Tapemeasure
Saw
Comb
Tank
Packet of Espresso
Taxi
Hexkey
Golfclub

Rose flower
Iron
Lighter
Glove
Pliers
Spanner
Tissues
Shell
Radio
Mannequin
Cork
Spanner

Hairdrier
Apple
Screwdriver
Football
Sunglasses
Walkman
Floppy Disk
Bottle of Juice
Mug
Toy
Marker-Pen
Needle

Where different exemplars of the same kind were employed they were easily discriminable.

WORDS

Vampire
Denture
Forest
Spine
Bicycle
Badge
Pillow
Pole
Motor
Suitcase
Cushion
Bath
Rocket
Belt
Ankle
Policeman
Circle
Slipper
Pyjamas
Flute
Medallion

Desk
Slug
Town
Brick
Hotel
Cake
Camera
Parrot
Elephant
Thimble
Perfume
Mill
Fire
Sauce
Liver
Robe
Fern
Bible
Carpet
Sherry
Heart

Shrapnel
Wing
Bakery
Throne
Patio
Jelly
Waffle
Ranch
Tile
Organ
Ferry
Pastry
Sweater
Wheel
Hawk
Sausage
Tail
Rifle
Shrimp
Seed
Heater

Fist
Cupboard
Crown
Radish
Frog
Wall
Eagle
Train
Rhubarb
Sphinx
Anvil
Coin
Ticket
Pool
Pitcher
Figurine
Larder
Ruler
Salmon
Collar

Tent
Shed
Pencil
Curtain
Bear
Jacket
Diamond
Bomb
Hen
Olive
Kilt
Washer
Whip
Drape
Aerial
Hammock
Potato
Plum
Feather
Brochure

Grape
Person
Flame
Basket
Banjo
Sheet
Tooth
Rabbit
Globe
Flag
Vessel
Nail
Tower
Tattoo
Ballgown
Paper
Barrrel
Ship
Dome
Rat

Appendix B: Stimuli used in Experiments 2 and 3

Remote Control
Stapleremover
Toy
Ashtray
Horse
Fridge
Mask
Melon
Lipstick
Folder
Glove
Spanner
Watch
Dog
Stanley-Knife
Battery
Speaker
Milk
Golfball
Bulb
Calculator
Radio
Monitor
Keyboard
Iron
Chisel
Chocolate
Glue
Answer-Machine
Cigarettes
Lamp
Football
Button
Car
Electric Fire
Tapemeasure
Lemon
Telephone
Brain
Wrench
Shovel
Shoebrush
Key
Saw
Hairbrush
Sheep
Motorbike
Purse
Helicopter
Pasta
Seashell
Rugby-Ball
Marker-Pen
Funnel
Banana
Syringe
Pliers
Wool
Chair
Pig
Rucksack
Duck
Hairdrier
Sponge
Stamp
Pistol
Chessboard
Peppermill
Circuit-Board
File-Box
Scraper
Spoon
Cow
Cat
Hat
Lighter
Mouse
Plug
Saucer
Floppy Disk
Fork
Mousetrap
Book
Toaster
Goggles
Mug
Sharpener
Matches
Flour
Peg
Makeup-Box
Comb
Screwdriver
Umbrella
Ambulance
Rice
Microwave
Toiletbrush
Spider
Candle
Egg-Timer
Sunglasses

Flower
Toiletroll
Sellotape
Razor
Shoecreme
Drill
Teapot
Telly

Spring
Weight
Clock
Diary
Apple
Winebottle
Taxi
Perfume

Knife
Pen
Kettle
Stapler
Pineapple
Mannequin
Tank
Soap