Event Related Potential Studies of Recognition Memory for Faces

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Abstract

The retrieval processes supporting recognition memory for faces were investigated using event-related potentials (ERPs) and behavioural measures. The ERP old/new effects elicited by faces were investigated in five experiments in which participants were required to distinguish between old and new (studied and non-studied) faces. A direct comparison between the ERP old/new effects elicited by faces and words in an old/new recognition memory task in Experiment 1 provided evidence for at least one common old/new effect, as well as evidence for a material-specific retrieval effect that was only present for faces. The subsequent experiments employed "recognition confidence judgments" (Experiments 2 and 3) and "source memory" manipulations (Experiments 4 and 5) to separate neural activity that might be tied to the processes of recollection and familiarity. Across the two recognition confidence experiments, reliable old/new effects were evident mainly for responses that attracted high confidence judgments, and there was little evidence for modulations that were sensitive to the level of recognition confidence systematically. These data indicate that ERPs index memory processes supporting face judgments that are linked to recollection. The two source memory experiments also revealed superior old/new effects which covered both frontal and parietal scalps and which were larger for those correct old responses that attracted correct rather than incorrect source judgments. The ERP data thus provides strong evidence for neural indices of recollection across all experiments. It might be regarded as surprising that, given the findings in ERP studies with verbal materials, no strong evidence for an ERP correlate of familiarity was found in the ERP data. In Experiment 4, a mid-frontal old/new effect in the 300-500ms time window was present for all correct old responses, and was insensitive to the source judgments, suggesting that this modulation is a neural index of familiarity. This pattern of data, however, was not replicated in Experiment 5 when a more rigorous separation between familiarity- and recollection-based responding was employed. These ERP findings are considered in the context of dual-process theories of recognition memory and their broad application across markedly different kinds of studied materials.

Acknowledgements

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My family has always been the source of love and care, thanks are not enough.

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Chapter One: Memory

The focus in this thesis is on the processes that support recognition memory for faces. The work comprises a series of careful event-related potential (ERP) studies of long-term memory for faces, which are designed to determine the sensitivity of ERPs to memory processes that are engaged when memory for faces and face features is probed. The framework within which this work is set is dual-process accounts of the bases on which memory judgments can be made. This two-way separation between processes that might provide different means of making judgments about prior occurrence is one of a large number of proposed distinctions in human memory. The principal broad distinctions that have been made (and debated) are described below, providing background for a detailed account of the specific processes (recollection and familiarity) that are key to the work described in this thesis and which are considered extensively in later sections.

Organization of Human Memory

The most widely discussed separation for the organization of memory is between short-term memory (STM) and long-term memory (LTM) (James, 1890; Atkinson & Shiffrin, 1968). This distinction provided a fundamental framework for the study of memory, and most importantly it formally introduced the idea that memory is not a single entity. The development of subsequent memory models has been facilitated greatly by the development of functional imaging techniques in the 1990s, and this has opened up a new area of research linking cognitive psychology with the neural basis of cognition. Extensive research in the past twenty years, encompassing brain imaging, neuropsychology and cognitive psychology has established the consensus view that memory consists of multiple functionally and neurally distinct systems and/or processes.

Short Term and Long Term Memory

The 'modal' view of short-term and long-term memory is that it consists of separate STM and LTM stores, and most models explain how memory transfers from STM to

LTM via rehearsal (e.g. Atkinson & Shiffrin, 1968). Firstly, information is registered in specific sensory modality forms and is then maintained in the STM store. This temporarily stored information is selectively processed and rehearsed. Irrelevant information is filtered out at this stage and rehearsed information is transferred into the LTM store. The LTM store may well have unlimited capacity and information can be held for an indefinite period of time (Atkinson & Shiffrin, 1968).

The strongest evidence for the distinction between STM and LTM comes from neuropsychological case studies of brain damaged patients. Severely amnesic patient H.M. had lesions bilaterally in the medial temporal lobe and had an inability to form new long term memories. H.M., however, had intact STM and was able to recall a list of up to six or seven numbers on digit span tasks (Scoville & Milner, 1957; Squire 2009). In contrast, Shallice and Warrington (1970) reported that patient K.F., who had damage to the left temporo-parietal cortex, had severely impaired STM for numbers and words, and an intact long-term memory. This double dissociation in patient studies suggests that memory is not a single system. There are dissenting views, however, and these have come from findings that some of the characteristics associated with STM can also be seen in LTM.

The main characteristic is serial position effects, which are separated into primacy and recency effects are believed to influence STM and LTM differently (Glanzer & Cunitz, 1966; Atkinson & Shiffrin, 1968). Items presented at the beginning and at the end of a study list are better recalled than items presented in the middle of the list. It is believed that the primacy effect results from the transformation from STM into LTM, whereas the recency effect is supported solely by STM (Rundus, 1971; Shallice & Warrington, 1970; Tulving & Craik, 2000). Contradicting this explanation, however, are studies that have shown that the recency effect is evident in memory tasks involving long term retention of information (Bjork & Whitten, 1974; Glenberg, Bradley, Kraus, & Renzaglia, 1983; Howard & Kahana, 2002; Davelaar, Goshen-Gottstein, & Ashkenazi et al., 2005). For example, using a continuous distractor paradigm in which a distracting period intervened between the study and the test phase, it was expected that the recency effect would be eliminated, but the recency effect remained (Bjork & Whitten, 1974). Glenberg and colleagues (1983) have reported long-term recency effects even after a retention interval of up to 14 days.

These studies suggest that long-term and short-term recency effect share a common mechanism, hence an explanation that does not require distinct memory stores is viable.

The distinct STM and LTM memory stores account also predicts non-overlapping neuroanatomical structures. In fact, the neuroanatomical structures engaged for LTM have been shown to overlap with those involved for STM (for a review see Ranganath & Blumenthal, 2005). For example, the perirhinal cortex in the medial temporal lobe (MTL) is strongly associated with LTM (see later sections for more information); however, studies have shown that this structure is also engaged when supporting memories for complex visual stimuli in STM (Holdstock, Mayes, & Cezayirli et al., 2000; Owen, Sahakian, & Semple et al., 1995). These studies (see also D'Esposito & Postle, 1999; D'Esposito, Cooney, & Gazzaley et al., 2006) challenge the view that STM and LTM have distinct neural bases, and suggest that a strict STM/LTM split is a conceptual/descriptive framework only (Ranganath & Blumenthal, 2005).

Short Term Memory and Working Memory

The unitary concept of STM has largely been replaced by a multi-component working memory (WM) system (Miller, Galenter, & Pribram, 1960; Baddeley & Hitch, 1974; Hitch & Baddeley, 1976) that focuses on the maintenance and processing of information in a temporary working space in service of high-level cognitive operations. The WM model developed by Baddeley and colleagues (Baddeley & Hitch, 1974; Hitch & Baddeley, 1976; Baddeley, 1990) had 3 components originally: the central executive, the phonological loop (or articulatory loop), and the visuo-spatial sketchpad. A new component: the episodic buffer, was added to the system by Baddeley in 2000 (see Figure 1.1).

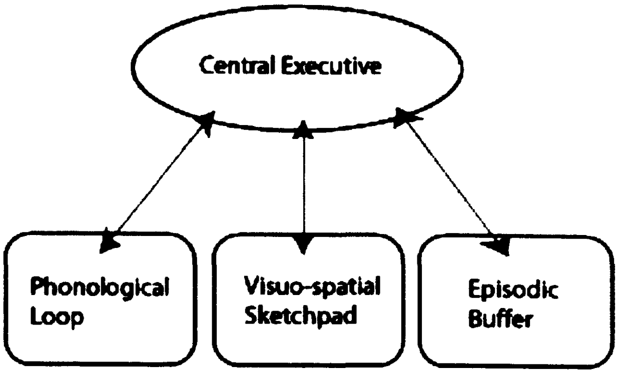


Figure 1.1. Working memory model (Baddeley, 2000)

The central executive component is a supervisory system that coordinates cognitive processes, in particular, to allocate attention to specific information and filter out irrelevant information. The phonological loop stores phonological information and information is retained via rehearsal. The visuo-spatial sketchpad permits online maintenance of visual and spatial information with subsystems dealing with different aspects of visual information such as spatial content, color, shape and texture.

The role of the episodic buffer is to integrate information from the phonological loop and the visuo-spatial sketchpad to form a unitary episodic representation that is temporarily stored in WM. The addition of the episodic buffer component is useful in accommodating data points that amnesic patients who were unable to form new long-term memories were still able to recall stories over the short term that involved verbal and spatial information (Baddeley &Wilson, 2002).

Long Term Memory

It is now also widely accepted that there are divisions in long-term memory, and H.M. (described briefly above) was influential in this development. H.M. learnt to perform the reverse mirror drawing task which required re-learning hand-eye coordination skills despite the fact that H.M. had no memory for the learning episode (Scoville & Milner, 1957; Milner, 1962). This suggests some form of LTM (procedural memory: Squire & Zola-Morgan, 1991), was unimpaired in H.M.

Different terms have been used to describe the divisions of LTM, with one division being between explicit and implicit memory (e.g. Anderson, 1976; Graf & Schacter, 1985). The terms declarative and non-declarative memory have also been used to define what is effectively the same distinction (Squire, Knowlton, & Musen, 1993). The term "non-declarative" or "implicit" memory is viewed as an umbrella term for several additional systems (Squire & Zola-Morgan, 1988) (see Figure 1.2 for one taxonomy of memory). Both terms refer to memory for events that manifest in performance but which are not accompanied by conscious awareness of the event. In contrast, declarative or episodic memory refers to conscious forms of memory that involve conscious access to content.

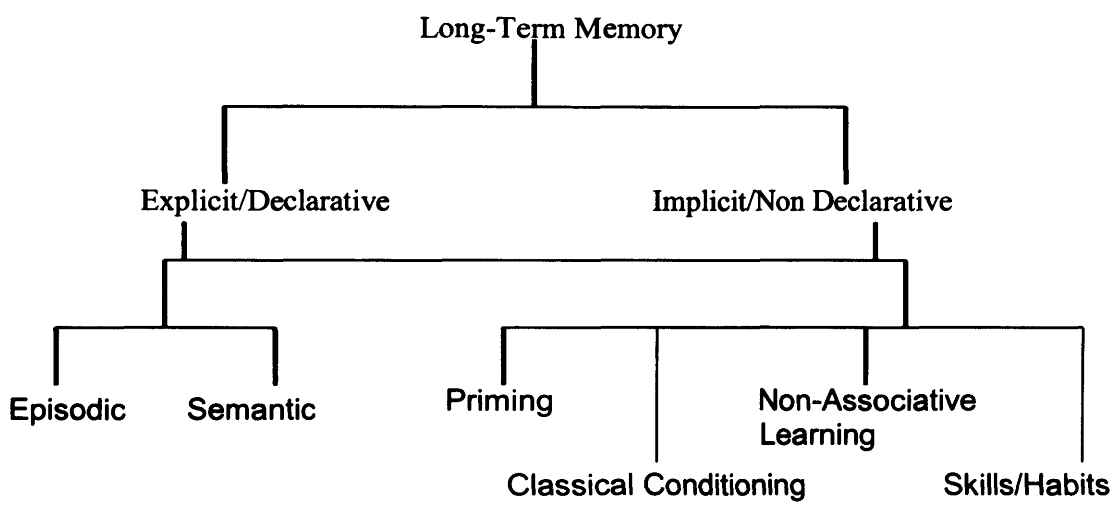


Figure 1.2. One taxonomy of memory. Adapted from Squire and Zola-Morgan (1991)

Implicit memory is tested primarily in "indirect tests" in which no reference to a prior learning episode is given to participants. The most widely used procedures induce priming: 'primed' stimuli (typically as a function of pre-exposure) are associated with facilitated performance such as a decrease in reaction times in comparison to unprimed stimuli (Squire, 1992; Gabrieli, Fleischman, & Keane et al., 1995). The experiments described in this thesis comprise "direct" retrieval tasks, where the task instructions involve reference to a prior learning episode. It is possible, however, that performance on these tasks is influenced by implicit memory processes (Dunn &

Kirsner, 1998, 1999; Jacoby, 1991; Reingold & Merikle, 1990; Toth, Reingold, & Jacoby, 1994), so some discussion of these processes, along with their relations to explicit memory, is provided here (see also Anderson, 1976; Graf & Schacter, 1985).

In a typical priming experiment, participants are presented with lists of items (such as words, objects, and/or faces), some of which are then re-presented along with unstudied items. Priming is revealed by performance changes for primed (studied) items compared to unprimed items. The strongest evidence that priming is dissociable from explicit memory comes from demonstrations in MTL patients that priming is spared while performance on direct memory tests is impaired (Gabrieli et al., 1995; Golby, Silverberg, & Race et al., 2005).

Priming can be separated into perceptual and conceptual priming. Perceptual priming requires the re-presentation of at least some physical elements of the prime. Conceptual priming does not require any perceptual overlap, and is a facilitation in performance because of the correspondence between a prime and a probe at the semantic level. The relationship between priming and explicit memory, and more importantly between priming and familiarity, is of relevance to the work in this thesis. One way of conceiving of priming is that previously encountered items are processed more fluently than new items, and it has been proposed that this fluency process provides one basis for memory judgments (Mandler, 1980). This idea has been developed most fully by Jacoby and colleagues (Jacoby & Dallas, 1981; Jacoby, 1983; Jacoby & Kelley, 1992), who provided an early influential account of the relationship between implicit memory and recognition memory judgments. Under this framework, one way of making recognition memory judgments is based on the same cognitive processes that contribute to implicit memory (priming). This said to come about because perceptual and conceptual 'fluency' can lead to a 'feeling of familiarity' by virtue of an unconscious attribution process (Mandler, 1980, Jacoby & Dallas, 1981; Whittlesea, Jacoby, & Girard, 1990; Jacoby & Kelley, 1992; Whittlesea, 1993). The central idea is that processing fluency can be used as a heuristic for whether or not an item has been encountered before, so if fluency is attributed to prior exposure then it can provide a basis for recognition memory judgments. This account is consistent with findings that levels-of-processing (Gardiner, 1988; Fay, Pouthas, Ragot, & Isingrini, 2005; for a review see Richardson-Klavehn, Clarke, & Gardiner, 1999), and divided attention manipulations have little or no effect on recognition memory judgment based upon familiarity in the same way that they do not influence priming (Gardiner & Parkin, 1990; Schacter, Chiu, & Ochsner, 1993; Bentin, Kutas, & Hillyard, 1995; Mulligan, 1998, for contradictory data see Toth, 1996; Yonelinas & Jacoby, 1995).

There is also substantial evidence, however, that implicit and explicit memory are distinct forms which have dissociable neural bases and operate independently (Mandler, 1980; Squire, 1992; Squire et al., 1993; Ratcliff & Mckoon, 2000). In this context, the main challenge to the proposal of Jacoby and colleagues is evidence that amnesic patients display severely impaired explicit memory and exhibit normal implicit memory in the form of priming for non-words, line-drawings of novel objects, performance on word-stem completion tasks, as well as perceptual identification and lexical decision tasks (Schacter, Cooper, & Delaney et al., 1991; Squire et al., 1993). In addition, using the remember/know procedure (for details, see below), amnesic patients were impaired for both R and K responses relative to controls and showed no deficit in priming (Knowlton and Squire, 1995). The above studies suggests that the cognitive process that underlying implicit memory and "know" responses (and by extension familiarity) are not the same (Verfaellie & Treadwell, 1993; Gabrieli et al., 2006; Golby et al., 2005). It is therefore unlikely that feelings of familiarity are a simple consequence of the occurrence of perceptual and/or conceptual processing priming.

It may be that conceptual priming is either (a) correlated with or (b) contributes to familiarity under some circumstances (Yonelinas, 2002), and the outline given here serves as important background for an ensuing discussion (see Chapter 2) in which links between conceptual priming and familiarity are considered in the context of claims that an ERP modulation that some have linked to familiarity is in fact an index of conceptual priming. The remainder of this chapter, however is concerned with explicit memory processes, and in particular episodic memory.

Explicit Memory: Episodic and Semantic Memory

As mentioned, explicit or declarative memory is memory for prior events that is accompanied by conscious awareness of the learning episode. Tulving (1972, 1983) divided explicit memory into semantic and episodic memory. Fundamentally, these two forms of memory differ in the nature of the stored information. Semantic memory has been defined as general knowledge about the world, such as facts, concepts, and vocabulary. Episodic memory has been defined as memory for personally experienced events, and in episodic retrieval an individual is, in Tulving's terms, deemed to mentally re-experience elements of prior events. Semantic memory is viewed as being the more stable of the two, as new inputs do not change the stored information easily, whereas information stored as episodes is more vulnerable to changes and the retrieval of episodic content itself could lead to changes in the stored content (Tulving, 1972; for recent work on the instability of memories during retrieval see Nader & Hardt, 2009). These two forms of memory are also often interactive. A to-be remembered word, such as "dog" may be stored as a concept in semantic memory, and this semantic information might also be used to encode specific (instance-based) information in episodic memory.

Neuroimaging studies have shown that episodic and semantic memory rely on different neuroanatomical structures. For example, a study with multivariate analysis of PET data provided evidence that the retrieval of personal semantic information involved a different neural network from the retrieval of episodic information (Nyberg, Forkstam, & Petersson et al., 2002). In general, the encoding and retrieval of episodic memory involves the medial temporal and the frontal lobes (Aggleton & Brown, 1999; Fletcher & Henson, 2001); whereas semantic memory depends on the lateral and anterior temporal cortex, as well as ventro-lateral prefrontal cortex (Graham, Patterson, & Hodges, 1999).

The strongest evidence for the distinction between explicit and semantic memory comes from patient studies which show a double dissociation between performance on tasks thought to tap one or other kind of memory. Amnesic patients have intact semantic, but impaired episodic memory (Vargha-Khadem, Gadian, & Watkins et al., 1997; Vargha-Khadem, Gadian, & Mishkin et al., 2001; Gadian, Aicardi, & Watkins et al., 2000); whereas the opposite pattern has also been reported (Temple & Richardson, 2004). In general, neuroimaging and neuropsychological studies have demonstrated that episodic and semantic memory are functionally and anatomically distinct components of explicit memory (Vargha-Khadem et al., 1997; 2001; Graham, Simons, & Pratt et al., 2000; Mayes & Montaldi, 2001; Wheeler & McMillan, 2001). The two forms of memory are, however, tightly linked, and presumably interact to support various kinds of memory functions. Several debates exist concerning the relationship between episodic and semantic memories during development (Vargha-Khadem et al., 1997, 2001; Tulving, 1985), as well as how they might contribute to explicit retrieval (Vargha-Khadem et al., 1997, 2001; Greve, Rossum, & Donaldson, 2007). In the following sections, the focus is on episodic memory retrieval, and the processes that support this kind of memory.

Episodic Memory Tests

Episodic memory is commonly tested using recall and recognition memory tasks. In a recall memory test, this could be in the form of cued, serial, or free recall; participants are required to retrieve items from a learning episode. For example, participants might be asked to recall all items seen on a prior study list. For recognition memory tests, participants are shown items, some of which were encountered in a designated study phase. They are required to distinguish between previously learnt (old) items and new (unstudied) items. The processes supporting recall are commonly assumed to be a sub-set of the set supporting recognition memory (Hirst, Johnson, & Kim et al., 1986; Hirst, Johnson, Phelps, & Volpe, 1988), and the following section provides a review of models of recognition memory.

Models of Recognition Memory

The two principal competing accounts for the characterization of human recognition memory are single process and dual-process models. These two accounts are the subject of ongoing debate concerning how well they account for findings across different experiments and paradigms. The former describes recognition memory as relying upon only a strength-based signal, and the later assumes that recognition memory relies upon two qualitatively distinct processes, as described in detail below (for reviews and relevant commentaries, see Yonelinas, 2002; Wixted & Stretch, 2004; Diana, Reder, Arndt, & Park, 2006; Parks & Yonelinas, 2007; Malmberg, 2008).

Single Process Models of Recognition Memory: Global Matching Models

Models based on the assumption that recognition memory is a single process that can be characterized in terms of signal detection accounts are collectively called global matching models (for review see Clark & Gronlund, 1996; Ratcliff & McKoon, 2000). The early global matching models were combined from a search model (Tulving, 1984) and a direct-access model (Kintsch, 1970).

The search model (Tulving, 1984) assumes that items are stored individually. The presentation of a test cue will activate a series of search processes, and the match between the test cue and the stored memory trace for the item will result in memory retrieval. The degree of the match determines retrieval strength. The direct access models assume that items are stored as nodes (Kintsch, 1970). Items are recognized when they have direct access to the associated notes, and the strength of the nodes determines the recognition judgment (whether a positive or negative decision is made). The first formal single process model is the "search of associative memory" model (SAM) which was developed from a series of experiments that were conducted to test the search and the direct access accounts of recognition memory (Gillund & Shiffrin, 1984).

Two models that are related to SAM are MINERVA 2 (Hintzman, 1984, 1986, 1988); and TODOM (Murdock, 1982, 1983, 1993). Although the underlying assumptions for these models differ to some extent, common to all is the assumption that a test item and its associated context are combined to form a single test probe that is matched against all items in the memory trace concurrently, and that the degree of match between the test probe and the memory trace will produce a global familiarity value. This value will determine the memory judgment that is given, and this is often formalized in terms of the signal detection theory framework (Gillund & Shiffrin, 1984; Hintzman, 1988; Murdock, 1982; Glark & Gronlund, 1996; for review, see Ratcliffe & McKoon, 2000).

Signal Detection Models

The models assume that the memory (or familiarity) strengths of old and new items have two partially overlapping normal distributions (see Figure 1.3). The placement of a response criterion along the familiarity level determines whether an item is classified as old or new. Common to the global matching models is the assumption that the familiarity strength of an item and criterion placement will determine the memory judgment. Items falling above the criterion are endorsed as old, whereas items that fall below the criterion are endorsed as new. It is assumed that, under nearly all circumstances, the mean level of familiarity for old items is higher than that for new items. The ability to discriminate between old and new items is often referred to as discrimination sensitivity, and it is the distance between the mean level of familiarity for old and new items (the distance between the peaks of the distributions), commonly calculated as *d'* (Green & Swets, 1966). The location of the criterion can also be calculated, and one measure of this is C, although other measures exist (Snodgrass & Corwin, 1988). A fundamental assumption is that criterion and sensitivity are independent.

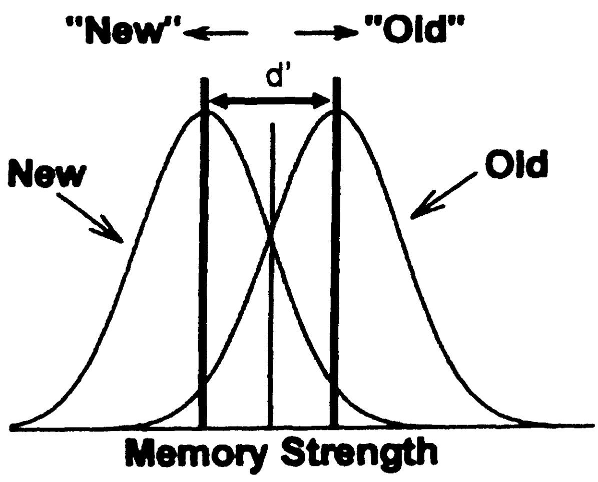


Figure 1.3. The equal-variance signal-detection model of recognition memory.

Signal-process models in the equal-variance form described above provide a parsimonious account for some findings in recognition memory tasks, but challenges to all single process models of recognition memory come from a range of empirical data that can arguably be interpreted most straightforwardly as evidence for the contribution of functionally dissociable mnemonic processes to recognition memory (Yonelinas, 2002; Rotello, Macmillan, & Reeder, 2004; Diana et al., 2006; Wixted, 2007). One long-term challenge for global matching models, for example, is the inability to account for the "mirror effect" (Glanzer & Adams, 1990; see Donaldson, 1996 for an alternative view). This effect describes experimental conditions where an increase in hits is accompanied by a decrease in false alarms for one class of items (i.e. deeply encoded items), and the reverse for another (i.e. shallowly encoded items).

Changes to single process models have permitted the accommodation of some existing data points. The original version of the signal detection models assumes two equal-variance Gaussian distributions for old and new item strengths (see Figure 1.3), but because of data points that do not fit this model, an unequal-variance model has been proposed, which assumes that the variance of the old item distribution exceeds that of the new item distribution (see Figure 1.4 and Wixted, 2007). This model has provided a more accurate fit than the equal-variance model for some data points (Dodson, Holland, & Shimamura, 1998; Gruppuso, Lindsay, & Kelley, 1997; Simons, Dodson, Bell, & Schacter, 2004; for a review see Wixted, 2007); nevertheless, these data are also readily accommodated by dual-process accounts of recognition memory.

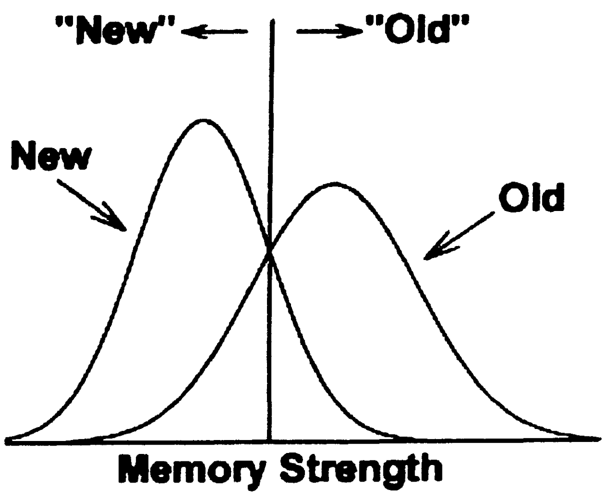


Figure 1.4. Unequal-variance signal-detection model of recognition memory.

Dual-Process Models of Recognition Memory

Common to all dual-process models of recognition memory is the proposal that two qualitatively dissociable processes support recognition memory (Atkinson & Juola, 1974; Mandler, 1980; Jacoby, 1991; for review see Yonelinas, 2002). They are now commonly referred to as recollection and familiarity. The distinction between the two processes relies on the nature of the recovered information. The definition of recollection has evolved as a threshold, controlled process which is associated with the retrieval of qualitative information from a past episode. Familiarity is an acontextual, fast-acting, automatic, strength-like memory signal. From the dual-process view (and critically from an operational perspective), familiarity is viewed as an episodic process that entails no recovery of contextual information, whereas recovery of contextual information is associated strongly with recollection. Brief reviews of key dual-process models are provided below.

Atkinson and Juola (1974)

This early model recognized the temporal dynamics of recognition memory. It assumes that two criteria are placed along the familiarity spectrum. Items that fall above the high criterion are classified as old, whereas items falling below the low criterion are classified as new. Items that fall in between the high and low criteria initiate a second slow retrieval search process. Successful search will lead to a recollection-based judgment. The central assumption of this model is that recollection only activates when familiarity is not a reliable basis for judgments, and therefore assumes that recollection-based judgments will take longer than familiarity-based judgments.

Mandler (1980, 1991)

This model provided the first detailed theoretical framework for the functional characteristics of recollection and familiarity, based on the findings from a sorting/recall memory paradigm (Mandler, Pearlstone, & Koopsman, 1969).The interpretation and model are based on the view that recall is a measure of recollection. The key studies showed that the numbers of categories (organizational variables) into which items were sorted had different effects on subsequent recall and recognition memory over a short and a long interval. The number of "categories" sorted correlated with the recall rate when the study-test interval was short (2 mins) and the correlation reduced when the interval increased (up to 35 mins); in contrast, the number of categories had no effect on recognition performance over a short intervening period; where this number only correlated with recognition memory over an extended period of time. Mandler and colleagues (1969) suggested that recognition performance depends upon familiarity (occurrence information), and that a 'recollection' (retrieval search) process was engaged when familiarity failed. Mandler and colleagues also proposed that familiarity decays faster over time relative to recollection because the later process has a stronger organization structure in memory (for recent data consistent with this conclusion, see Yonelinas & Levy, 2002).

The distinction between familiarity and recollection was also generated by data showing that deep processing (i.e. semantic processing) - which reinforces organizational structure in memory and promotes recollection - has effects on recall and recognition; whereas shallow processing (i.e. phonemic processing) has an effect on recognition only (Gillund & Shiffrin, 1984). Mandler (1980) was the first to propose that familiarity and recollection are two *independent* processes that work jointly in support of recognition memory.

Jacoby (Jacoby and Dallas, 1981; Jacoby, 1983; Jacoby and Kelley, 1992)

This model (an introductory discussion of the 'familiarity' component has already been provided in a previous section) placed more emphasis on the relation between familiarity and implicit memory, and proposed that conceptual and perceptual processing fluency can contribute to familiarity in the form of a "fluency heuristic". The relationship between processing fluency and familiarity is considered to be indirect, with an attribution of fluency to familiarity being the result of an unconscious inference (Jacoby & Kelley, 1992; Jacoby & Whitehouse (1989). Jacoby and Whitehouse (1989) reported an increased in false alarm rates for new items that were presented subliminally immediately before their presentation during a recognition memory test. This effect was abolished when new items were pre-presented supraliminally (200ms). These results indicate that perceptual fluency does not support memory judgments entirely, but depends upon the attribution of fluency which is itself dependent upon the particular task context.

Jacoby and colleagues have emphasised that acontextual processes are prone to errors, as items with high perceptual fluency could in fact have a non-mnemonic basis (Jacoby, Woloshyn, & Kelley, 1989). In contrast, recollection is regarded as a more robust conscious process that is not influenced by the processing fluency of items. In line with this account, Jacoby and colleagues have also emphasized that familiarity is a relatively automatic whereas recollection is a controlled process and as a result subject to capacity limitations (this distinction is key to their development of the process-dissociation procedure which is discussed in a later section; for a review see Jacoby, 1991).

Yonelinas (1994)

This model is based on an extensive research using receiver operating characteristics (ROCs: for a recent review see: Parks & Yonelinas, 2007). Familiarity is described as a process that can be modeled via a signal detection model that is based on Gaussian distributions. Recollection is regarded as a threshold process that does not behave in a graded manner. The central assumption is that recollection occurs when items exceed a high threshold and familiarity-based responses can be made when recollection fails. This is perhaps the most widely accepted dual-process account currently available.

The Relationship between Recollection and Familiarity

While all dual-process models propose that recognition memory can be supported by two functionally distinct processes, the relationship between recollection and familiarity might be described as one of exclusivity, redundancy or independence (Jones, 1987, for a similar description and considerations about related neural processes see Montaldi, Spencer, Roberts, & Mayes, 2006). These relationships are critical because they make different predictions for psychological studies, and for neuropsychological and brain imaging studies where the focus is on the brain structures that support the two processes. A relationship of exclusivity indicates that recollection and familiarity would never co-occur. This is the assumption underlying the Remember/Know paradigm when estimates of recollection and familiarity are inferred directly from remember and know responding rates, respectively (Gardiner, 1988; Gardiner & Parkin, 1990; Gardiner & Java, 1993; Gardiner & Ramponi, 1998). A relationship of redundancy is typically considered to take a form such that recollection could only occur with familiarity but familiarity could occur in the absence of recollection. An independence relationship indicates that recollection and familiarity can co-occur, but there is no contingent relationship between them (see Figure 1.5). This is the most widely assumed model in the literature, which is supported by the findings from various manipulations and paradigms. The redundancy relationship reminds a possibility, however (although see Jacoby, Yonelinas, & Jennings, 1996)

Figure 1.5. Relationships between recollection and familiarity.

Paradigms for Studying Recollection and Familiarity

Various approaches have been developed, initially in behavioral and later in neuropsychological and neuroimaging studies, to investigate the processes that support recognition memory. The old/new recognition paradigm is perhaps the simplest design. It is a forced choice method which most commonly consists of a study and a test phase. Participants are required to study a list of items, and to discriminate between old and new items at test. Correctly recognizing an old item is termed a *hit*; failing to recognize it is a *miss.* Incorrectly recognizing a new item as old is a *false alarm*; correctly recognizing a new item as new is a *correct rejection.*

This paradigm can be used to measure response accuracy and response bias, however it provides very limited insight into the underlying memory processes that support the memory judgment. This is because there is no immediate way of assessing how many processes contribute to performance using this basic paradigm. As a result, several paradigms have been developed to assess the adequacy of single- or dual-process accounts, or both. Although each procedure suffers some criticisms, it is necessary to use different paradigms in order to provide converging evidence relevant to the understanding of recognition memory (Roediger, Rajaram, & Srinivas, 1990; Schacter, 1992). The following section provides a short review of the main procedures used; and criticisms of these approaches are also considered.

The Process-Dissociation Procedure

The process-dissociation procedure (PDP) was initially developed by Jacoby (1991) in order to separate and estimate the contributions of recollection and familiarity to recognition memory judgments (for a review see: Jacoby, Yonelinas, & Jennings, 1997). Assumptions about the automatic and controlled nature of familiarity and recollection, respectively, are central to this procedure. These two processes contribute to memory performance independently and the PDP arguably offers a way to provide a "process pure" separation of recollection and familiarity.

A typical PDP study consists of two tasks that are completed under 'inclusion' and 'exclusion' instructions. Participants are required to study items in two different contexts (for example, different lists). It is assumed that item recognition could be supported by familiarity and recollection, and this aspect is tested in the inclusion instruction, in which participants are required to make old responses to all studied items regardless of list, and to reject new items. In contrast, the controlled process of recollection is required for specific judgments in the exclusion task. Participants are required to make old responses to studied items presented in one list only (targets), and to make new responses to studied items presented in the other list (non-targets), as well as to new (unstudied) items. Performance in the exclusion task therefore requires conscious retrieval of the encoding context of the items.

The differential requirements of the two instructions can be expressed in equations and are used to estimate the contribution of recollection (R) and familiarity (F) to recognition memory performance:

In the inclusion task, the probability of identifying old items relies on both recollection and familiarity in the absence of recollection.

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

In the exclusion task, the probability of making a target judgment to a non-target is when familiarity occurs in the absence of recollection, on the basis of the assumption that had recollection occurred this error would not have been made.

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

The probability of recollection is computed by subtracting exclusion from inclusion scores.

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

The probability of familiarity is computed as follows (Jacoby, Toth, & Yonelinas, 1993):

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

The PDP has been used widely as a mean to separate the contributions of recollection and familiarity in recognition memory (Jacoby, 1991; Yonelinas & Jacoby, 1996; Jacoby, 1998). One criticism of the PDP is that old items for which there is a failure to retrieve task-relevant contextual information might still be associated with others kinds of retrieval (non-criterial recollection), so that PDP provides an index of the likelihood of recovering source memory rather than recollection occurring *per se* (Yonelinas and Jacoby, 1996). It is also unclear whether the likelihood of recollection occurring is equivalent when it is (exclusion task) and is not (inclusion task) required explicitly. In addition, it is not clear why a familiar but not recollected non-target will always be labeled as a target. If it is not, then the PDP may also under-estimate the availability of familiarity for test judgments. None the less, the findings using the

PDP have broadly converged with findings in which other paradigms have been employed, as described below.

The Remember/Know Procedure

This approach was originally developed by Tulving (1985) with an emphasis on the states of awareness that accompanied the test items in recognition memory tasks. Tulving proposed that such conscious awareness could be separated into "noetic" and "autonoetic" forms. Noetic awareness accompanies memories involving "mental time travel" and is linked to recollection. In contrast, memory that does not involve recollecting contextual information is associated with noetic awareness. In a typical Remember/Know test, participants are instructed to judge whether their memory is associated with the conscious recovery of any contextual information from study, as indicated by a "Remember" response, or to make a "Know" response when the memory is associated with a pure sense of familiarity in the absence of recollection.

This procedure was used extensively by Gardiner and colleagues (Gardiner, 1988; Gardiner & Java, 1991; Parkin, Gardiner, & Rosser, 1995; Gregg & Gardiner, 1994) who demonstrated that R responses are more sensitive to levels of processing, retention interval and dividing attention; and that K responses are more sensitive to perceptual processing such as a change of modality between study and test. This evidence for opposite dissociations provides a strong basis for arguing that R and K responses depends upon different processes, and their behaviour seems to map on to many of the characteristics associated with the processes of recollection and familiarity. In addition, one advantage of this procedure in some contexts is that it is not in principle restricted to details of only some kinds of recovered information, and therefore allows a more sensitive or complete measure of recollection compared to other procedures that require criterial recollection (for example, in forced choice source tasks such as the PDP).

While most of the dual-process models assume that recollection and familiarity are independent processes, uncorrected R and K responses are exclusive of each other, so estimates of recollection and familiarity taken directly from estimates of R and K assume that recollection cannot occur in the presence of familiarity, and vice versa

(Gardiner & Parkin, 1990). If independence is in fact the correct relationship between recollection and familiarity, then the contribution of familiarity is underestimated by the raw probability of a K response (Yonelinas & Jacoby, 1995).

The independence Remember/Know (IRK) method was introduced to correct the underestimation of the contribution of familiarity (Yonelinas & Jacoby, 1995). The equation is given below, and the rationale for this correction is that, under independence, some items given R responses would also have been given a familiar response if recollection had failed. So, an accurate estimate of the likelihood of familiarity-based responding can be obtained by calculating the likelihood of a K response on the proportion of trials on which an R response was not given:

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

Although the Remember/Know procedure was originally developed under the dual-process model framework, attempts have been made to explain the results using signal process theories. Donaldson (1996) proposed a two criteria signal-detection model in which Remember responses are made when familiarity strength exceeds the upper criterion; when strength exceeds the lower criterion, and is below the upper criterion, this will result in Know responses (see Figure 1.6).

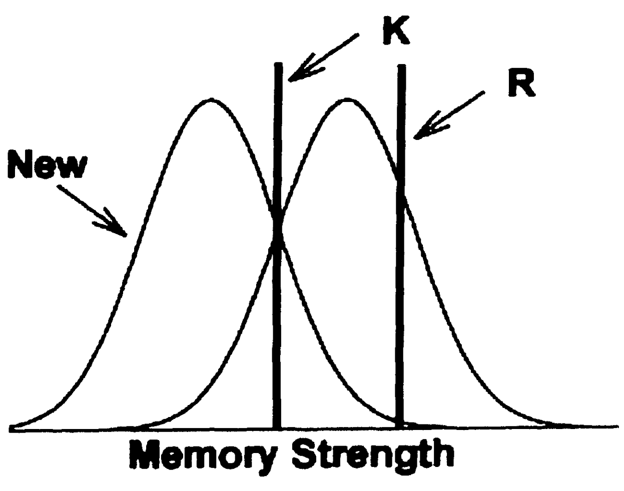


Figure 1.6. The two criteria signal-detection model of recognition memory

Under this theory, R and K responses are proposed to reflect differences in criterion placement along a single dimension. The strongest challenge for the two criteria signal-detection model is that this model predicts a positive correlation between Remember-Hit and False Alarm rates: they should both increase when the upper criterion becomes more liberal (a shift towards the left). However, Dobbins and colleagues (2000) have demonstrated that the hit rate and the false alarm rate are uncorrelated, suggesting a pure strength-based processing model is inadequate in accommodating Remember/Know data.

Squire, Wixted, and Clark (2007) have proposed that the RK distinction measures strong and weak memories. Consistent with this view, the Know response option has been shown to be associated with the recovery of some episodic information. This challenge the notion that Know responses tap into the familiarity process only (Wais, Mickes, & Wixted, 2008). One current view is that the effectiveness of the Remember-Know distinction depends critically on the instructions and task administration (Rotello, Macmillan, Reeder, & Wong, 2005; Mayes, Montaldi, & Migo, 2007). These authors have shown that, unless appropriate steps are taken to monitor the performance of participants, the RK judgments may reduce to memory strength judgments. One approach to counter this is to insert random remember catch trials on which participants are required to explicitly describe the basis for a Remember response. Another approach is to have two testing sessions. In the recollection condition, all recollected responses are justified by descriptions of the recollected details. In the familiarity-only condition, participants are asked to focus on feelings of familiarity and to avoid conscious recollection; any involuntary recollection should be reported and those trials will be excluded from analysis. Since recollection is kept minimal in this approach, this avoids the problem of underestimating the contribution of familiarity in recollection-based responses under the independence assumption. These techniques are relatively new and have not been tested extensively, but they are certainly promising and have also been useful in showing how familiarity and recollection differentially activate MTL structures (Montaldi et al., 2006).

The Receiver-Operating Characteristic (ROC)

ROCs comprise a function that describes the relationship between hits and false alarms at different criterion points (Yonelinas, 1994, 1997, 1999; Yonelinas, Dobbins, Szymanski, & King, 1996). In a typical experiment design from which ROCs are plotted, participants are required to make recognition judgments on a 6-point confidence scale ranging from high confidence new to high confidence old (see Figure 1.7). Hit rates are plotted against false alarm rates across levels of confidence in a cumulative manner (see Figure 1.8). The x-axis represents false alarms and the y-axis represents hit rates. It is assumed that different response criterion settings are adopted at each confidence level. The leftmost point on the ROC curve reflects the most confident response (see Figure 1.7) which also corresponds to the most 'conservative' criterion.

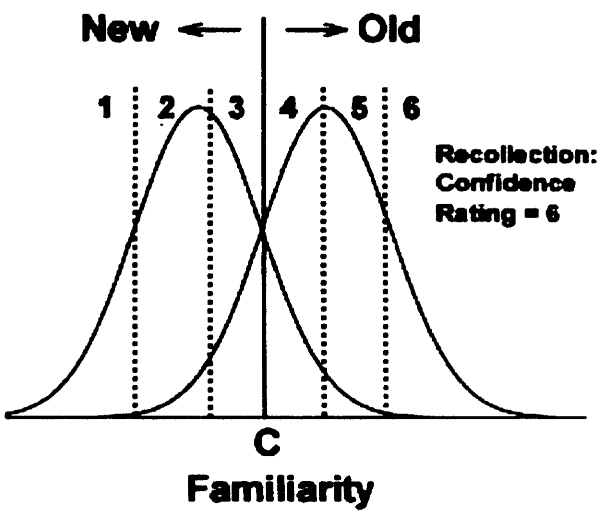


Figure 1.7. The equal-variance signal-detection representation of recognition memory. The 6 confidence ratings ranged from high confidence old (6) to highly confidence new (1).

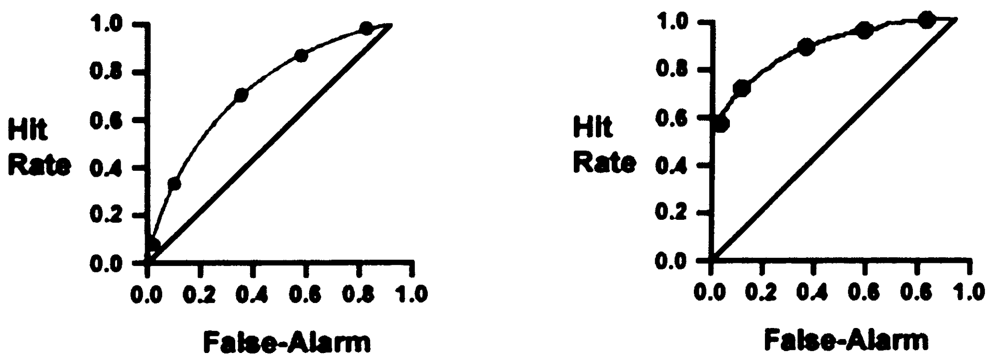


Figure 1.8. Symmetrical and skewed receiver operating characteristic curves plotted on probability coordinates.

The receiver operating characteristic (ROC) curves predicted by the equal-variance single process model (left) and predicted by the dual-process model (right) are shown in Figure 1.8. Each ROC plots five pairs of hit and false alarm rates on the 6-point confidence rating. The two competing accounts of recognition memory make different predictions for the shape of the ROC. The equal-variance signal-detection model assumes that old and new items have the same distribution, thus predicting a symmetrical and curvilinear ROC. However, most studies gave rise to asymmetric ROCs that are pushed toward the left in probability space, and with a slope less than 1.0 in z-space (Yonelinas, 2001, Yonelinas, 1994; Ratcliff, McKoon, & Tindall, 1994; Ratcliff, Sheu, & Gronlund, 1992). The single process equal variance model has difficulty accommodating these findings. In contrast, the asymmetrical ROC is predicted by dual-process accounts which suggested that a signal-detection and a threshold process supporting recognition memory give rise to asymmetrical curvilinear ROCs. The same prediction is made by unequal-variance signal detection models.

The explanation for asymmetrical ROCs for dual-process accounts is that the asymmetry arises because the threshold recollection process increases the number of high confidence hits without increasing markedly the number of false alarms. This will push up the leftmost point and result in an asymmetrical ROC with a skewed slope less than 1.0 (see right-hand Figure 1.8) (Ratcliff et al., 1992). Consistent with this interpretation, using the R/K procedure, Yonelinas and colleagues (2001) found that R responses produced linear and asymmetrical ROCs and that K responses produced curvilinear and symmetrical ROCs. In situations when recollection is unavailable and the memory judgment is dependent on familiarity, the ROC predicted by the single process equal variance account is expected. Consistent with this account, Yonelinas and colleagues (1998) reported an asymmetrical ROC in healthy subjects, and a symmetrical ROC in amnesic patients who had impairments in recruiting recollection for memory judgments.

An unequal variance signal detection model is also capable of accommodating the asymmetrical ROC by assuming that the variance for old items is larger than that for new items, and that the degree of asymmetry is dependant upon memory accuracy rather than the contribution of an additional threshold process (Ratcliffe et al., 1992; Yonelinas, 2001). It has been suggested, however, that the dual-process models can readily accommodate most ROC data and some of these data points pose a challenge for the unequal variance signal detection model (Yonelinas, 1999; Yonelinas et al., 1996). In addition to the problematic patient data already described above, Yonelinas and colleagues (1996) noted that the dual-process model predicts a ROC that has more of a 'U-shape' than that predicted by the unequal variance signal detection model as the contribution of recollection increases. Using a "levels of processing" manipulation, the unequal variance signal was found to be inadequate because of the increase in the curvilinearity of the ROC with the depth of processing manipulation.

In summary, the PDP, R/K and ROC approaches have strengths and weaknesses that are not shared with each other. One reason why this is important is because, in each case, broadly similar results have been obtained across a series of manipulations, and these outcomes are most straightforwardly interpreted with a dual-process framework for explaining recognition memory judgments. Assumptions for one measure are not shared by the others, hence the correspondence between findings across the measures is an important commonality. In sum, the existing data from behavioural studies is broadly consistent with a dual-process account of recognition memory, and there are several data points, from patients as well as intact individuals, that challenge both the equal-variance signal detection account, and more importantly, the unequal variance account.

Neuropsychological Evidence for a Dual-Process Account of Recognition Memory

This section provides additional perspectives on human neuropsychological evidence (already touched on briefly above) for functionally distinct retrieval processes (recollection and familiarity) and the neural structures that support them. An important meta-analysis of amnesic patient studies demonstrated that damage restricted to the hippocampus is associated with spared recognition memory that requires familiarity (Aggleton & Shaw, 1996). This lead to one of the most influential neuropsychological frameworks of recognition memory, which is the dual-process account of MTL function. Aggleton and Brown (1999) evaluated data from amnesic patients with damage to MTL structures systematically, and on the basis of a combination of structural and functional considerations, as well as outcomes in studies with experimental animals, they proposed a dual-process account of MTL function which states that recollection is dependent primarily on hippocampus and the surrounding diencephalon, whereas familiarity is supported by a separate system dependent on the perirhinal cortex (Brown & Aggleton, 2001; Yonelinas, Otten, Shaw, & Rugg, 2005; Cipolotti & Bird, 2006).

The general pattern of findings supporting their argument is that patients with selective hippocampal damage have intact recognition memory for single items; but impaired recall and associative recognition memory (Aggleton, Vann, & Denby et al., 2005; Holdstock, Mayes, & Gong et al., 2005; Mayes et al., 2004). This makes sense for the model if recollection is necessary for recall and (at least some kinds of) associative recognition, but item recognition can be supported by familiarity and this is sustained by the perirhinal cortex.

Using the PDP paradigm, studies have shown that amnesic patients had impaired estimates for recollection, whereas the estimates for familiarity were either spared (Mayes, Van Eijk, & Isaac, 1995) or slightly reduced (Yonelinas, Kroll, & Dobbins et al., 1998). Yonelinas and colleagues (1998) have also plotted the ROCs for amnesic and control patients. The ROC data shows that the slope is significantly lower than 1 in the controls only, suggesting controls relied on recollection for making recognition memory judgments and this process was unavailable in amnesic patients. This pattern of differences is consistent with the assumptions of Aggleton & Brown's dual-process models of recognition memory, namely that functionally distinct cognitive processes rely on different regions of the MTL.

In contrast, however, some studies have shown that damage to the hippocampus can result in markedly impaired recognition memory (Reed, Hamann, Stefanacci, & Squire, 1997). This has been employed to support an alternative view to the Aggleton and Brown dual-process account of MTL function, in which the hippocampus is equally important for both recollection and familiarity (Squire, Stark, & Clark, 2004), and that recollection could be regarded as a reflection of high memory strength whereas familiarity reflects low memory strength (Squire, Wixted, & Clark, 2007). Most of the supporting evidence for this alternative account has come from neuropsychological studies which show that patients with damage restricted to the hippocampus have impaired recall and recognition memory for both single items and associations (Squire et al., 2004; Manns, Hopkins, & Reed et al., 2003; Wixted and Squire, 2004; Wais et al., 2006). The reasons for these disparities across apparently similar patients, and across relatively similar tasks, remain to be explained fully, and the field would probably benefit from uniformity obtained by subjecting different patient populations to the same battery of agreed tasks.

It is also noteworthy that the functional roles played by structures within the MTL are complicated by evidence of material-specific deficits in a few amnesic patients. This has led to a model which postulates that the functional divisions within the MTL depend partly upon the type of material that is processed. Lee and colleagues (2005) reported that patients with hippocampal damage and those with more extensive MTL damage that extended to the perirhinal cortex had normal recognition memory for complex objects such as faces and virtual reality scenes. However, the more severely damaged patients had impaired memory for scenes that presumably required additional spatial processing. Taylor and colleagues (2007) have also shown that patients with damage in both hippocampus and the perirhinal cortex had impaired memory for faces and scenes, whereas patients with damage limited to the hippocampus showed impaired memory for scenes only.

Similarly, in the single case study of the amnesic patient Jon, he was shown to have spared recognition memory and impaired recall (Baddeley, Vargha-Khadem, & Mishkin, 2001). In a study that compared the ROCs for faces and scenes, Jon's ROC for faces resembled those from the matched controls, who had the same shape for faces and scenes. Jon's ROCs for scenes, however, were symmetric and differed from those of the controls (Bird, Vargha-Khadem, & Burgess, 2008). This suggests that, despite intact recollection based memory for faces, Jon has impaired recollection for scenes. This suggests that some of the functions of sub-regions within the MTL are material specific, and more importantly for present purposes, it indicates there could be neural signatures for recollection and familiarity that are differentially activated according to stimulus type.

In summary, the patient data suggests some degree of material specificity in MTL function, and this data is also generally consistent with a dual-process account at the functional level. The data reviewed previously is somewhat more inconsistent. The reasons for the disparate results are unknown, and consequently it is important to consider the outcomes from other measures that might speak to this issue as well as to understand fully the retrieval processes involved during recognition memory for different material types.

Neuroimaging Evidence for Dual-Process Accounts of Recognition Memory

The outcomes from several neuroimaging studies of recognition memory are consistent with a dual-process account. The strongest evidence has come from demonstrations that manipulations designed to tap into familiarity and recollection are associated with qualitatively distinct patterns of neural activity.

Eldridge and colleagues (2000) reported significant left-posterior hippocampal activation for recollection-based judgments. Similarly, Wheeler and Buckner (2004) and Yonelinas and colleagues (2005) reported greater bilateral hippocampal activation for recollection relative to familiarity judgments. These studies all found perirhinal relative deactivation for familiarity judgments (in comparison to activity for new test items) and are thus consistent with dual-process accounts in that distinct neural substrates are associated with these two kinds of process.

These findings have not gone unchallenged, however, and the debate about the brain regions supporting recollection and familiarity is ongoing. An important move, however, has been that, even for those researchers who maintain that separate MTL structures do not support exclusively separate processes, there is an acknowledgment that recollection and familiarity are distinct processes that contribute to long-term memory judgments (Kirwan, Wixted, & Squire, 2008; Diana, Yonelinas, & Ranganath, 2007; Eichenbaum, Yonelinas, & Ranganath, 2007; Mayes et al., 2007; Squire, Wixted, & Clark, 2007; Wixted & Squire, 2004). The view that the MTL is critical for recognition memory judgments is held widely. How it supports recognition memory remains at issue, but the de-coupling of claims about unitary MTL operations and single versus dual-process accounts of recognition memory is a recent development.

Summary

This chapter has provided a review of the organization of memory, focusing on elements of particular relevance to this thesis, along with key behavioral and neuroimaging methods that have been used to study and disentangle the retrieval processes that are central to recognition memory. Neuropsychological and fMRI studies, as well as behavioural studies in intact individuals, have provided a body of evidence that fits with dual-process accounts of recognition memory. Electrophysiological evidence from event-related potential (ERP) studies of recognition memory is also relevant to this issue, and given the importance of these data points for the work in this thesis, the relevant studies and outcomes are described in detail in the next chapter.

Chapter Two: ERPs and Recognition Memory

Introduction

Various approaches have been used to investigate recognition memory; these include cognitive studies in healthy individuals, behavioural and neurological studies of experimental animals, neuropsychological studies on brain-damaged patients, and neuroimaging research. Arguably, the use of ERPs in recognition memory tasks and variants has produced the strongest evidence to date that functionally distinct memory processes - consistent with dual-process models of recognition memory – are engaged at the time of retrieval (Rugg, Mark, & Walla et al., 1998; Duzel, Cabeza, & Picton et al., 1999; Curran 1999, 2000). The real-time nature of ERPs permits the temporal separation of processes of interest, and in addition, the presence of particular ERP effects that have certain quantitative and qualitative characteristics has permitted the separation of neural activity linked to recollection and familiarity, as well as the identification of other retrieval-related cognitive processes.

A set of pre-defined criteria is necessary to guide the search for neural correlates for recollection and familiarity in recognition memory experiments. The central characteristic of recollection is the retrieval of contextual information from a study episode. Therefore, neural signatures of recollection should be observed by contrasts between correctly identified old items that are or are not associated with the recovery of contextual information. In contrast, familiarity is regarded as a process that does not typically provide information about context. Therefore neural signatures of familiarity should be observed in contrasts between items that attract correct old judgments but are not associated with recovery of context information, and an appropriate baseline. Often this baseline is neural activity associated with correct rejections. In most accounts, a correct new decision is assumed to be made on the basis of low levels of familiarity in the absence of recollection.

The following chapter will provide a review of the ERP literature relevant to the investigation of the neural correlates of episodic memory. This chapter is divided into three main sections. The first two sections are separated for 1) findings in studies where non-facial stimuli were employed and 2) studies employing facial stimuli. The final section 3) focuses on the implications of the evidence generated from both facial and non-facial materials, and how they contribute to an understanding of human recognition memory. The first section is further divided into three subsections, the first of which will focus on the left-parietal old/new effect and findings that support its association with recollection. The second will focus on the late-frontal old/new effect and the third will focus on the mid-frontal old/new effect.

ERP Old/New Effects

The majority of recognition memory studies have employed a study-test structure in which participants are presented with a list of items to encode at study, and are then required to make old/new memory judgments to a list of items comprising studied (old) and unstudied (new) items at test (for ERP old/new effects acquired in continuous recognition memory paradigms, see Friedman, 1990). ERP studies of recognition memory have demonstrated that the ERPs elicited by correctly identified old items (hits) are relatively more positive-going than those elicited by correctly rejected new items (CRs) (Rugg & Coles, 1995; Friedman & Johnson, 2000). This is referred to as the ERP old/new effect. It is assumed that hits are made on the basis of conscious memory retrieval, therefore the old/new differences between the ERPs index cognitive processes that are linked to successful episodic memory retrieval. This claim is supported by the fact that old/new effects are typically small or absent for incorrect judgments to new and old items (false alarms and misses, respectively; Wolk, Schacter, & Lygizosc et al., 2006; Rugg, Mark, & Walla et al., 1998; Wilding & Rugg, 1996, 1997). The old/new effect was initially characterised as a positive-going deflection occurring from approximately 400ms to 800ms post-stimulus (Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980). It has subsequently been shown to be largest at left-parietal electrodes (see Figure 2.1 and the reviews by Johnson, 1995; Rugg, 1995; Rugg & Allen, 2000). Subsequently several ERP old/new effects have been identified, some within this time period, others later in the recording epoch.

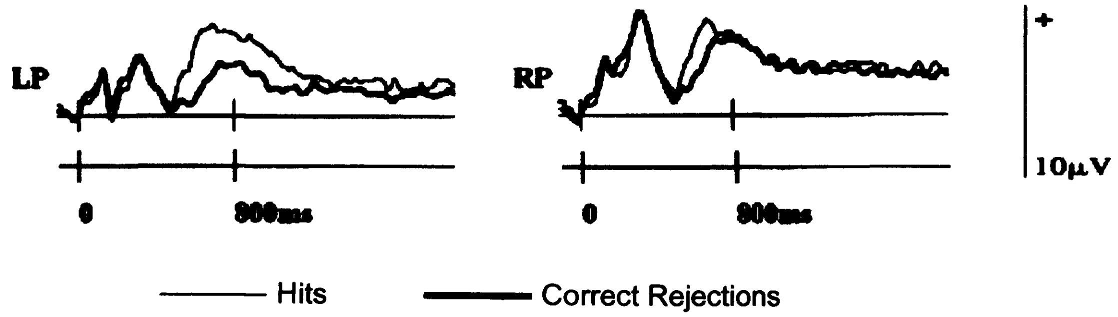


Figure 2.1. Grand-average ERPs from the left and right parietal electrode site in Allan and Rugg (1997).

The functional characterisation of some ERP old/new effects has been made from within the framework of dual-process models of recognition memory, and has been characterised in terms of familiarity and recollection mainly. Dissociating neural correlates of familiarity and recollection requires the demonstration that the ERP correlate associated with familiarity is qualitatively different from the correlate for recollection in two ways. First, in terms of sensitivity to experiment manipulations. Second, in terms of scalp distribution. It is now apparent that a left-parietal old/new effect in the 500-800ms post-stimulus epoch is functionally linked to recollection, whereas a mid-frontal old/new effect in the 300-500ms has been described as an index of familiarity at least for verbal stimuli. This latter association is still open to some debate, however. The evidence for each of these ERP old/new effects will be discussed in detail in the following sections, along with a third effect – the right-frontal ERP old/new effect – that has been observed in some memory studies and which may reflect post-retrieval monitoring. This effect is largest at frontal sites and has a time course that can extend from as early as 500ms to as much as 2000ms post-stimulus.

Evidence from Non-Facial Stimuli

The Left-Parietal Old/New Effect

An ERP old/new effect that was largest over the posterior scalp was first referred to as the late positive component – LPC (Paller & Kutas, 1992; Rugg & Doyle, 1992), and it was first characterized as a correlate of familiarity, based on the finding that low frequency words elicited a greater old/new effect than high frequency words (Rugg & Doyle, 1992). It was assumed that low frequency words have a higher level of overall familiarity (Jacoby & Dallas, 1981), therefore giving rise to the greater old/new effect for low frequency relative to high frequency words. Because these old/new differences were left-lateralized, Rugg and Doyle (1992) proposed that the laterality reflects language processing (although it later became apparent that the effect is left-lateralized even for non-verbal stimuli).

A familiarity characterisation of this effect was challenged by findings that the recognition of low frequency words required recollection mainly (Gardiner & Java, 1990; Rugg, Cox, Doyle, & Wells, 1995; Cuttentag & Carroll, 1997). These data have led to the proposal that this left parietal old/new effect is a correlate of recollection and this view has gained a significant amount of support.

The supporting evidence has come from experimental manipulations that are thought to influence recollection selectively and which also influence the parietal old/new effect. Using a one-stage Remember/Know procedure (Gardiner & Richardson-Klavehn, 2000), Smith (1993) reported that the parietal old/new effect in the 550 to 700ms was markedly larger for "Remember" responses relative to "Know" responses. These findings link the parietal old/new effect to recollection, and in this study the differences between remember and know responses were quantitative, and not qualitative, suggesting that ERPs do not index familiarity.

Subsequently, Duzel and colleagues (1997) used a two-stage Remember/Know procedure that required initial old/new discrimination for old and semantically related lures at test. Remember/know responses were required following all old responses. They reported a parietal old/new effect for remember responses and a different pattern of old/new effects for know responses, which prompted the conclusion that distinct memory processes were engaged (Duzel, Yonelinas, & Mangun et al., 1997). However, no analyses were conducted on rescaled data, which weakens the claim that the old/new effects for remember and know responses differed qualitatively (Friedman & Johnson, 2000).

Another line of evidence is that the parietal old/new effect is sensitive to the "depth of processing" manipulation (Paller & Kutas, 1992; Rugg, Mark, & Walla et al., 1998; Rugg, Allan, & Birch, 2000). Consistent with the view that the parietal effect indexes recollection, Rugg and colleagues (2000) reported words that were deeply encoded (use the target word to generate a sentence) elicited greater left-parietal old/new effects than words that were shallowly encoded (an alphabetic judgment). Deep encoding enhances recollection more so than does shallow encoding (Craik & Lockhart, 1972).

The processes of recollection and familiarity have also been separated by objective measures of the ability to retrieve source information. Source information refers to contexts in which study items are presented; it is assumed that the accurate retrieval of source information depends upon recollection, whereas the failure to retrieve such information, but to be able to identify an item as old, is supported by familiarity or non-criterial recollection (Wilding, Doyle, & Rugg, 1995; Wilding & Rugg, 1996). Wilding and Rugg (1996) presented participants with words that were spoken in either a male or female voice at study. Participants saw old and new words at test and were required to make old/new judgments followed by a voice judgment. They observed a left-parietal old/new effect for words that were correctly classified as old, and this effect was larger for responses followed by correct source judgments relative to those followed by incorrect source judgments. If correct source judgments are associated with recollection to a greater degree than are incorrect source judgments, these findings link the parietal old/new effect with recollection.

In a similar design, Donaldson and Rugg (1998) tested recognition memory for un-related word pairs that were subsequently re-presented in either the same pairings or in re-arranged pairings at test. Pairings comprising two unstudied words were also shown at test. In Experiment 1, participants were required to make old/new judgments. A decision indicating whether the pair was the same or rearranged followed each old judgment. In Experiment 2, only an old/new discrimination judgment was required. Reliable left-parietal old/new effects were obtained for the same and re-arranged pairs in both experiments. This effect also showed a greater magnitude for the same relative to the re-arranged pairs. Donaldson and Rugg suggested that memory for the same word pairs is associated with recollection to a greater extent than that for the rearranged pairs irrespective of whether the retrieval of associative information is an explicit task requirement. Importantly, these findings point to the graded nature of the left-parietal modulation.

The view that the left-parietal old/new effect indexes recollection rather than other decision processes that might be linked to confidence was tested directly by Curran (2004; see also Finnigan, Humphreys, Dennis, & Geffen, 2002). In Experiment 2 in that paper, Curran acquired confidence ratings for both old and new test words on a four-point scale. The logic of this experiment was that no recollection-based memory should be associated with new responses. Therefore if the left-parietal old/new effect was an index of recollection, this modulation should be obtained for old items only. However, if this modulation reflects more general decision processes that are linked to confidence, this effect should be obtained for both old and new items and should vary with confidence for new items. Consistent with the recollection account, the left-parietal effect was obtained for old items, undermining the view that the effect reflects decision making processes (see also Woodruff, Hayama, & Rugg, 2006).

Since the magnitude of an ERP modulation is considered to reflect the extent to which a certain cognitive process is engaged, the size of the parietal old/new effect should vary according to the amount of information recollected (Wilding, 2000; Vilberg, Moosavi, & Rugg, 2006), if that is in fact the process that it indexes. This view is supported by evidence that correct source judgments, and memory for re-presented word pairs, elicited larger left-parietal old/new effects than incorrect source judgments and rearranged word-pairs (Wilding et al., 1995; Wilding & Rugg, 1996; Donaldson & Rugg, 1998). Directly testing this view, Vilberg and colleagues (2006) showed participants pairs of colour pictures of objects at study. At test, participants were required to subjectively indicate whether they could recover fully or partially visual object information. They were instructed to make a "Remember 2" (R2) response if they could remember the test item as well as its associated object at study, a "Remember 1" (R1) response for the recovery of the test item as well as other non-specific details, a "Know" response if the test item was familiar but no contextual information could be recalled, and a "new" response for unstudied test objects.

For old items, the behavioural data showed a trend for a reduction in the proportion of old items attracting responses R2, R1, Know and New; new items were judged to be new primarily. The left parietal ERP old/new effect was evident for both 'recollected' response categories, and it was also sensitive to the amount of information that was recovered: it was larger for R2 relative to R1. The authors argued that the data supports the view that the left-parietal ERP old/new effects indexes a high-threshold representation-based process that is also sensitive to the amount of the information recovered (Vilberg et al., 2006; see also Wilding, 2000; Vilberg & Rugg, 2007, 2009).

Another important aspect of the left-parietal old/new effect as an index of recollection is its insensitivity to the nature of the stimuli or the content of the information that is recollected. This modulation has been elicited by a variety of different stimuli including visually presented words (Smith, 1993; Duzel et al., 1997), pictures (Schloerscheidt & Rugg, 1997; Curran & Cleary, 2003), objects (Tsivilis, Otten, & Rugg, 2001; Vilberg et al., 2006) and auditorily presented words (Wilding & Rugg, 1996; Curran & Dien, 2003). These findings have led to the proposal that it is an index of "generic" recollection-based processes that are independent of the nature of the stimuli (Johnson & Rugg, 2007; Johnson, Milton, & Rugg, 2008; for reviews, see Friedman & Johnson, 2000; Rugg & Allan, 2000; Rugg & Curran, 2007). Overall, the evidence in the literature is consistent with a functional interpretation of the left-parietal effect as a context independent index of recollection. The data for faces that is relevant to this question will be considered below in section two.

The Right-Frontal Old/New Effect

Wilding & Rugg (1996) were the first to report in detail a late right frontal old/new effect in the source memory experiment described above (see Figure 2.2 below). This right frontal effect is usually not obtained in simple old/new recognition memory paradigms (although see Rugg, Allan & Birch, 2000; Allan & Rugg, 1998), leading to the proposal that this old/new effect is specific to the requirement to retrieve source information (Wilding & Rugg, 1996). Based on the finding that this right frontal effect is topographically and temporally distinct from the left-parietal old/new effect, it was initially thought to index post-retrieval processes that are necessary for correct source retrieval (Wilding & Rugg, 1996; Johnson, Kreiter, Russo, & Zhu, 1998). Subsequent experiments with similar designs have replicated the findings (Rugg, Schloerscheidt, & Doyle et al., 1996; Rugg, Schloerscheidt, & Mark, 1998; Wilding & Rugg, 1997; Donaldson & Rugg, 1998; Allan, Wilding, & Rugg, 1998), however, the interpretation of the effect has been challenged (Donaldson & Rugg, 1998; Senkfor & Van Petten, 1998; Van Petten, Senkfor, & Newber, 2000; Hayama, Johnson, & Rugg, 2008).

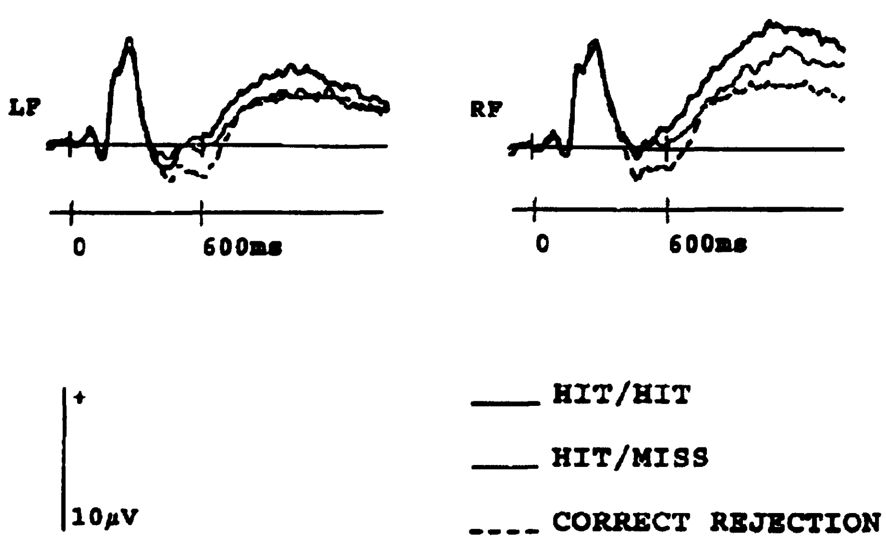


Figure 2.2. Grand-average ERPs from the left and right frontal electrode site in Experiment 1 in Wilding and Rugg (1996).

In other experiments it has been shown that the effect is sometimes insensitive the accuracy of source judgments (Senkfor & Van Petten, 1998; Trott, Friedman, & Ritter et al., 1999; Van Petten, Senkfor, & Newberg, 2000). The magnitude of the right-frontal old/new effect has been equivalent for correct and incorrect source judgments (Senkfor & Van Petten, 1998; Van Petten et al., 2000); or larger (although not statistically so) for incorrect relative to correct source judgments (Trott et al., 1997).

Using the Remember/Know procedure, the effect was found to be equivalent in magnitude for remember and know responses (Duzel et al., 1997).

Senkfor and Van Petten (1998) have proposed that the right-frontal old/new effect might index a retrieval search process in an attempt to retrieve the source information, but this fails to accommodate the data points where the effect does predict the accuracy of source judgments, and the occurrence of the effect in recognition memory paradigms. In one important "depth of processing" recognition memory study, the magnitude of the right-frontal old/new effect was larger for shallowly encoded than deeply encoded items (Rugg et al., 2000). This finding led the authors to propose that words encoded in the shallow condition required more monitoring and evaluation than for words encoded in the deep condition, therefore the right-frontal old/new effect might index the degree to which these processes were engaged (Rugg et al., 2000). However, this interpretation is undermined by the data in Woodruff and colleagues (2006).The retrieval monitoring account predicts that the right-frontal old/new effect should be larger when memory retrieval is uncertain; therefore the effect should be largest for responses falling closest to an old/new response criterion. In contrasting to this prediction, Woodruff and colleagues reported a larger right-frontal effect for confidently judged old items relative to those responses associated with less confidence. This is difficult to assimilate with a monitoring account if low confidence responses are assumed to reflect items falling relatively close to an old/new decision criterion.

While the functional significance of the right-frontal old/new effect is still an on-going debate, event-related fMRI studies have shed some light on the issues. It has been suggested that the neural generator of the right-frontal old/new effect is the right dorsolateral prefrontal cortex (DLPFC) (see Rugg, Otten, & Henson, 2002 for review). Henson and colleagues (2000) reported greater DLPFC activation for low confidence relative to high confidence old responses, which links this region to monitoring if high confidence judgments require less monitoring than low confidence judgments. An alternative account, however, is that DLPFC activity is in fact sensitive to the number of internal decision required in a task (Dobbins & Han, 2006; Han, Huettel, & Dobbins, 2009). The first key finding for this account was greater

DLPFC activation for a two-step "same-different" rather than a one-step "forced-choice" judgment in memory tasks.

To test directly the decisional account and the retrieval monitoring account, Cruse & Wilding (2009) acquired source confidence judgments (high/low) in a task requiring the retrieval of colour information. The logic driving this experiment was that the number of internal decisions was equated for all old responses regardless of source and confidence judgments, therefore the decisional account predicts that the right-frontal old/new effect should be equivalent for all classes of old response (Dobbins & Han, 2006; from Hayama, Johnson, & Rugg, 2008). On the other hand, the retrieval monitoring account predicts the right-frontal old/new effect should vary according to the high and low confidence source judgments. According to Henson and colleagues (2000), a greater degree of monitoring is required for low confidence responses because memory retrieval is impoverished compared to that for items attracting high confidence response. Therefore a larger right-frontal old/new effect should be obtained for low relative to high confidence judgments.

Cruse & Wilding (2009) reported equivalent right-frontal old/new effects for correct and incorrect source judgments when the level of confidence was collapsed, which is generally supportive of a decisional account. However, a larger right-frontal old/new effect was elicited for high relative to low confidence judgments when the analysis was restricted to correct source judgments only. While the data challenge a decision account, they also do not fit with the monitoring account as articulated by Henson and colleagues (2000; see also Woodruff et al., 2006). Thus, while the findings in this experiment undermine a decisional account, the retrieval monitoring account of the right-frontal old/new effect that is offered most frequently does not fit in entirely (for further comments and a possible reconciliation, see Cruse & Wilding, 2009). It is also likely that the commonly observed right-frontal old/new effect is one of at least two separate frontal old/new effects that share similar time-courses and topographies (Woodruff et al., 2006; Cruse and Wilding, 2009).

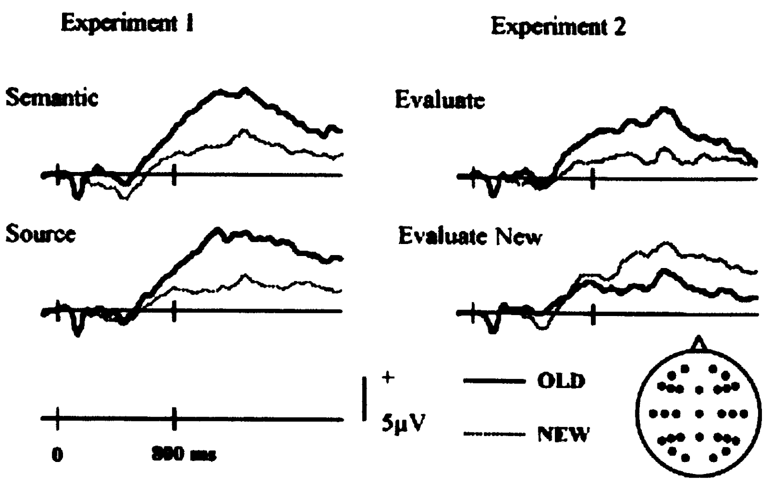


Figure 2.3. Grand-average ERPs from the lateral frontal electrode site (AF8) at which right frontal effects were most prominent across Experiments 1 and 2. Data taken from Hayama, Johnson, and Rugg (2008).

Finally, two experiments reported by Hayama and colleagues (2008) merit comment. In Experiment 1, they reported right-frontal effects for correctly identified old items that required either source or semantic memory judgments. In Experiment 2, in which a semantic judgment was required for either correctly identified old or new items, the right frontal effect was larger whenever the semantic judgment was required (see Figure 2.3). Importantly, the right frontal effects for old and new items that required the semantic judgments were topographically and temporarily indistinguishable, which favors the interpretation that the right frontal modulation is sensitive to general decision demands rather than at least some kinds of post-retrieval processes.

The Mid-Frontal Old/New Effect

The functional significance of this effect was first linked to familiarity in a study conducted by Rugg and colleagues (1998). This effect is evident from 300 to 500ms post-stimulus over anterior-superior scalp locations, and comprises a greater relative positivity in the ERPs elicited by old items. Rugg and colleagues (1998) varied depth of processing at study and this manipulation had no influence on the mid-frontal old/new effect: the magnitude of this effect was equivalent in size in both shallow (orthographic) and deep (semantic) conditions. They also examined “misses”, for which the mid-frontal old/new effect was smaller and not reliable. If familiarity does not change markedly with depth of processing manipulations (Yonelinas, 2002), and if misses are responses made on the basis of low familiarity, then a link between the effect reported by Rugg and colleagues (1998) is reasonable. In addition, at posterior electrodes in the 300-500ms epoch, the old/new effects elicited by misses shared the same magnitude as those elicited by correctly identified old items encoded in both shallow and deep conditions. This parietal component was considered to reflect implicit memory, because it signalled prior occurrence but did not predict response accuracy.

Subsequently, different experiment designs have been used to study the mid-frontal old/new effect and its association with familiarity. The logic behind some of these studies is to compare retrieval of different classes of correctly identified old items to correctly identified new items. It is expected that a neural index of familiarity should be indistinguishable for different classes of old items that are associated with varying amounts of contextual information, whereas an index of recollection would be sensitive to this outcome. In addition, if familiarity is a graded index of memory strength, this property will be reflected in any correlate of familiarity that is revealed by ERPs (see Azimian-Faridani & Wilding, 2006; Woodruff et al., 2006).

A series of experiments conducted by Curran over the last decade has provided strong support for the link between the mid-frontal ERP old/new effect and familiarity using non-facial stimuli (Curran 1999, 2000, 2004; Curran, Schacter, Johnson, & Spinks, 2001; Curran & Cleary, 2003). A series of manipulations have modulated the magnitude of left-parietal old/new effects while keeping the mid-frontal old/new effect unchanged. In an early experiment, Curran (1999) compared the ERP old/new effects associated with words and pseudowords. Curran reported a larger left-parietal old/new effect for correctly identified words than pseudowords, and critically, no reliable difference was found in the mid-frontal regions in the 300-500ms epoch between the old/new effects for the two classes of studied words. This finding is consistent with a familiarity account of the mid-frontal old/new effect because recognition memory for pseudwords is likely to be based primarily on familiarity (Curran, 1999).

In several experiments, Curran and colleagues manipulated the global similarity between classes of stimuli presented in experiments. In one example experiment, Curran (2000) varied the plurality of words in half of the trials between the previous study phase (e.g. CUP) and the test phase (e.g. CUPS), while the other half remained identical (Hintzman & Curran, 1997). The logic behind this study is that studied old and similar lure items should be more familiar than new items, and that studied old and similar lures should therefore have similar levels of familiarity. The left-parietal old/new effect was more positive-going for correctly identified old words than plurality reversed similar lures, and ERP waveforms associated with both correctly identified old words and plurality reversed words that were incorrectly classified as old words were more positive at anterior-superior regions between 300 to 500ms compared to new words. This positivity was of the same magnitude for the old words and the similar lures. In keeping with the logic described above, these findings link the mid-frontal ERP old/new effect to familiarity (Curran, 2000).

A similar manipulation using mirror-reversed geometrically similar shapes ("blobs"), and pictures produced similar findings (Curran, Tanaka, & Weiskopf, 2002; Curran & Cleary, 2003). Curran and Cleary (2003) instructed participants to study asymmetric, greyscale line drawings of objects, animals, people and scenes. Participants were also instructed to remember the left/right orientation of the pictures. At test, participants were told an old response should be given to test pictures with the same orientation between study and test, and to give a new response to similar pictures with reversed orientation, as well as to new pictures. In the analysis, participants were divided into two groups according to their ability to discriminate between studied and similar pictures. Both good performers and poor performers showed a mid-frontal ERP old/new effect, and it did not differ in magnitude between the ERPs elicited by studied pictures and orientation reversed pictures that attracted an old response. For the same reasons described for the plurality study (Curran, 2000), these data fit a familiarity account of the mid-frontal old/new effect (although for only a partial replication, see Groh-Bordin, Zimmer, & Mecklinger (2005).

The influence that the perceptual similarity between study and test has on the mid-frontal old/new effect can be understood by looking at the effect in cross-modal recognition memory tasks. The approach in these studies is to vary and/or maintain the same stimulus modality between study and test. If the mid-frontal old/new effect is insensitive to modality changes, the data would suggest that the mid-frontal old/new effect is unrelated to perceptual change and is linked to a more generic retrieval process, of which familiarity is one candidate.

The influence of modality change on the mid-frontal old/new effect is mixed. For example, when all target items varied between study (Auditory) and test (Visually) modality, Curran and colleagues (2001) reported no mid-frontal old/new effect for items attracting old responses. The authors argued that the mid-frontal old/new effect is sensitive to study-test modality, and they also suggested that the mid-frontal old/new effect is an index of 'perceptual' familiarity, perhaps in the form of perceptual fluency, which is sensitive to the physical similarity between study and test items. However, despite a change in study (Auditory) and test (Visual) modality, a study by Nessler and colleagues (2001) in the same year reported the mid-frontal old/new effect for hits and for semantically related lures. The reliable mid-frontal old/new effects in this across modality experiment suggest that the mid-frontal old/new effect is insensitive to the perceptual similarity between study and test items, at least in a task where conceptual information is emphasised (Nessler, Mecklinger, & Penney, 2001).

While these experiments either varied or maintained the study and test modality in separate experiments (Joyce, Paller, Schwartz, & Kutas, 1999; Wilding, Doyle, & Rugg, 1995; Curran et al., 2001), a more direct test was conducted by Curran and Dien (2003), who compared within and across modality effects in the same experiment. In their study, half of the study items were presented visually and the other half were presented auditorally. At test, all items were presented visually. The logic behind this study is as follows. If the mid-frontal old/new effect is related to perceptual similarity mainly, the visually presented study words should produce larger mid-frontal old/new effects than auditorally presented study words. They reported reliable mid-frontal old/new effects for both the within and cross modality conditions, and the ERPs elicited by test words in the visual-visual case were more positive-going than those elicited by test words in the cross-modal case. This is the first study that demonstrated both perceptual and conceptual information are influential in determining the size of the mid-frontal old/new effect. According to some accounts, perceptual overlap between study and test can influence the strength of a familiarity signal, so these findings fit a familiarity account of the mid-frontal old/new effect (Mandler, 1980, Jacoby & Dallas, 1981; Jacoby & Kelley, 1992).

Groh-Bordin and colleagues (2006) also investigated the influence of mismatching perceptual information between study and test. Two classes of visual stimuli were included in the experiment: objects and non-object line drawings. Half of the objects were colour modified between study and test (incongruent) while the other half remained identical (congruent). Both the congruent and incongruent objects elicited reliable mid-frontal ERP old/new effects and the fact that the mid-frontal old/new effect elicited by congruent objects was larger led to the conclusion that some degree of perceptual matching process is also reflected by the mid-frontal old/new effect. In the same experiment, they also investigated the influence of conceptual priming on the familiarity process by using non-object line drawings that did not hold any strong semantic associations. The significant mid-frontal ERP old/new effects for both congruent and incongruent non-objects indicate that the mid-frontal modulation is not restricted to items that hold substantive conceptual content.

While the association between familiarity and the mid-frontal old/new effect is strong, it has been suggested that the effect itself is a reflection of a process occurring downstream of a neural familiarity signal. Tsivillis and colleagues (2001) investigated the effects of context on ERP correlates of recognition memory. Participants were presented with a series of images which captured an object superimposed on a background at study. Subsequently, participants had to discriminate between old and new objects, irrespective of the context information. The test images were in 5 combinations: identical object-context pairs between study and test (same); recombined object and context pairs (rearranged); old object and new context pairs (old/new); new object and old context pairs (new/old); and new object and new context pairs (new/new). Response accuracy was higher for the same than the old/new conditions and it did not differ between rearranged and old/new conditions. Critically, the mid-frontal old/new effect was reliable for correctly recognised "same" and "rearranged" stimuli, but absent for correctly recognised "old/new" stimuli. It was concluded that the mid-frontal effect is not a direct index of familiarity, but instead sensitive to the novelty of stimuli (Tsivilis, Otten, & Rugg, 2001).

Subsequently, Ecker and colleagues (2007) replicated the experiment by Tsivilis and colleagues with an additional manipulation that controlled the level of attention directed to the test object. Ecker and colleagues (2007) compared a no-cue testing group (which was an exact replication of Tsivilis and colleagues (2001)), with a cue testing group in which an additional cue was placed next to the test object to attract attention. They replicated the findings of Tsivilis and colleagues (2001) in the no-cue group, but reported mid-frontal old/new effects for all conditions for the cue group. The authors suggested that when an old/new image is perceived in the no-cue group, attention is paid to both the object and the context, and a new context might produce a novelty signal that interferes and weakens the mid-frontal old/new effect. As a result no or a weak mid-frontal effect is produced. In the cue group, however, attention is directed to the test object, the context is treated as irrelevant contextual information, and therefore the mid-frontal old/new effect remains. The findings therefore suggest that the familiarity process as indexed by the mid-frontal old/new effect is independent of context when attention to the irrelevant aspects of the test stimulus is controlled.

A different experimental approach to the link between the mid-frontal old/new effect and familiarity on recognition memory is to study the effect in a memory task in which participants are instructed to adopt liberal or conservative decision criteria (Azimian-Faridani & Wilding, 2006). The assumption underneath this approach is based on signal detection theory, and the notion that familiarity is a continuous dimension with increases in familiarity strength away from the origin. As discussed in detail in Chapter 1, a criterion must be placed along the familiarity dimension to determine whether a stimulus will receive an old or a new response. Azimian-Faridani & Wilding manipulated the placement of this criterion. They encouraged a conservative response criterion by emphasising old responses and instructing participants to give an old response only when they were confident with their decision. They encouraged a liberal response criterion by emphasising new responses and instructed participants that a new response should be given only when participants were confident with their decision. They predicted that the old responses from the conservative condition would be accompanied by higher levels of familiarity (on average) than old responses from the liberal condition. The link between the mid-frontal old/new effect and familiarity was supported by the finding that the ERPs elicited by hits in the conservative condition were more positive-going than those in the liberal condition. This study provides strong support for the association between the mid-frontal old/new effect and familiarity, and it also demonstrates that the mid-frontal old/new effect behaves in a graded fashion according to the level of familiarity associated with test stimuli.

A further study has also shed light on the graded nature of the mid-frontal old/new effect. Woodruff and colleagues (2006) incorporated confidence measures in a one-stage Remember/Know paradigm. Participants were required to make "Remember" responses for judgments associated with contextual information, and otherwise to use a 4-point high/low confidence old/new scale. The logic of this study is that remember responses are supported by an all or none recollection process, and familiarity is a graded process that varies with the level of confidence in a test decision. Therefore, a neural correlate of recollection should be obtained for remember responses only, and a correlate of familiarity should vary with recognition confidence systematically. Consistent with these predictions, the left-parietal old/new effect was obtained for remember responses, and the magnitude of a (somewhat left-lateralised) mid-frontal modulation co-varied with recognition confidence in a graded manner, with the greatest magnitude for high confidence old and the lowest magnitude for high confidence new responses.

Data relevant to the functional significance of ERP old/new effects also comes from studies with populations other than young adults. Tendolkar and colleagues (1999) tested source memory in controls and a group of patients with Alzheimer's disease. Participants were required to make old/new judgments followed by source retrieval (the colour in which old items were presented at study). Overall recognition memory performance was above chance for both group of participants, however, source memory was severely impaired in the patient group only, which suggests the inability to rely on recollection for memory judgments. Consistent with the behavioural data, the mid-frontal old/new effect was observed for both groups of participants, and the left parietal old/new effect was obtained for the controls only. It has been suggested that Alzheimer patients have preserved familiarity-based recognition memory, along with an impairment in recollection-based memory which is a result of hippocampal atrophy (Tendolkar, Schoenfeld, & Golz et al., 1999; Aggleton & Brown, 1999).

Duzel and colleagues (2001) tested the amnesic patient Jon and two matched controls on a recognition memory task. While response accuracy for Jon and the controls was above chance, Jon had poorer discrimination than the controls. The mid-frontal old/new effect was obtained for Jon and controls; however the left-parietal old/new effect was evident in controls only. Jon has pronounced hippocampal atrophy and behavioural data suggests that his recollective-based but not his familiarity-based memory is impaired.

The findings described above are consistent with a familiarity account of the mid-frontal old/new effect. Some authors, however, have proposed that the mid-frontal modulations are linked to conceptual priming rather than familiarity (Olichney, Van Petten, & Paller et al., 2000; Olichney, Morris, & Ochoa et al., 2001). Olichney and colleagues (2000) tested a group of 12 amnesic patients and their matched controls. At study, both groups of participants were required to judge whether study items were semantically congruent or incongruent with a given category label. They reported impaired memory in the patients relative to the controls, and also failed to find ERP old/new effects in the 300-500ms epoch for the patients. Interestingly, both groups of participants showed an N400-like modulation for incongruent relative to congruent words when they compared first with second presentations. This evidence has been taken as challenging a familiarity account of the mid-frontal effect because patients who are thought to be relatively dependent on familiarity for memory judgments should show an association with the mid-frontal old/new effect. This was not obtained (Olichney et al., 2000; Olichney et al., 2001). The fact that the N400 old/new effect was elicited irrespective of memory retrieval suggests that it indexed some form of conceptual priming, and this has been used as part of an argument that the familiarity interpretation of the mid-frontal old/new effect is incorrect. Paller and colleagues (for example: Yovel & Paller 2004; Voss & Paller, 2007; Voss, Lucas, & Paller, In Press.) have promoted the view that the effect in fact indexes conceptual priming, and this account can accommodate many of the existing findings. Critically, however, it does not provide an adequate explanation for the cross-modal effects described above, and the other demonstrations that merely changing perceptual features between study and test can influence the magnitude of the mid-frontal old/new effect (see in particular the recent study and responses published by Stenberg, Hellman, Johansson, & Rosén

2009). These data points suggest strongly that conceptual priming is too narrow an account for the existing data, and that a process that might be influenced by perceptual as well as conceptual manipulations is a stronger candidate. Familiarity is one such candidate (see Rugg & Curran, 2007, as well as counter points by Yovel & Paller 2004; Voss & Paller, 2007; Voss, Lucas, & Paller, In Press.).

Evidence from Facial Stimuli

This section begins with a brief description of the unique characteristics of faces and the implications of these characteristics for recognition memory. Amongst other evidence, the view that the processing of faces is unique is supported by the classic face inversion effect (Yin, 1969). It has been shown that recognition of upright faces is superior to that for upright objects. Recognition of inverted faces, however, is superior to that for inverted objects. This suggests that the cognitive processes underlying recognition of faces and objects are not entirely the same, because inversion has different effects on these two stimulus types. In addition, Prosopagnosic patients are impaired at recognising faces but commonly are unimpaired at recognising other kinds of visual objects (Duchaine & Nakayama, 2005). This neuropsychological evidence also suggests that the processing of faces and other objects relies upon somewhat different neutral anatomical structures, and possibly different cognitive processes. Brain imaging evidence in which the focus has been on the particular role played by the Fusiform Face Area (FFA) is also consistent with the view that faces are processed somewhat differently from other stimulus types (Kanwisher, McDermott & Chun, 1997). This range of evidence suggests that processing differences that arise due to the unique characteristics of faces might well extend to differences in the way that faces are processed in tasks where long-term memory judgments are required.

A series of ERP experiment conducted in the last few years have employed faces as stimuli in memory retrieval tasks. To anticipate, the question of the nature and number of ERP old/new effects that are elicited by faces does not have a clear answer. One of the goals in this thesis is to attempt to impose some kind of order on this literature. The focus here will be primarily on studies where unfamiliar faces have been employed, because these allow the amount of pre-exposure and knowledge associated with a particular individual to be controlled.

Paller and Colleagues (1999) were among the first to investigate ERP correlates of recognition memory using black and white unfamiliar facial stimuli. The faces they used captured head-and shoulder information against a plain background. At encoding, half of the study faces were paired with a gender matching voice (named faces) that contained name and biographical information associated with the depicted person (e.g. I'm Carol, We were lab partners in Chemistry). The other half (unnamed faces) did not have this information. At test, studied faces were mixed with an equal number of new faces, and participants were instructed to make an old/new judgement to the test faces.

This task was chosen because it was assumed that all correctly identified old faces (named and unnamed faces) should be associated with a similar degree of familiarity because familiarity should only differentiate the old/new status of test items, and thus, they should produce the same magnitude of the mid-frontal old/new effects. They reported reliable old/new differences for named faces only at mid-line electrode locations (except for the Fpz electrode site). Although the task did not separate responses made on the basis of recollection and familiarity, this pattern of findings is inconsistent with what a familiarity account predicts if the mid-frontal old/new effect is a generic index of familiarity.

Contrasting data has been reported by Johansson and colleagues (2004). They investigated the influence of emotional information on recognition memory using the old/new recognition memory paradigm. They reported similar levels of recognition performance for three classes of facial stimuli that were associated with either positive, neutral or negative emotional content (as determined by facial expression). Importantly, reliable old/new effects were present over the anterior scalp in a 380-500ms time window. The effects did not differ as a function of emotion. This study suggests a frontal modulation is insensitive to facial expression, but indexes memory. The authors suggested that it could be functionally linked to familiarity (Johansson, Mecklinger, & Treese 2004).

In another study that explored perceptual fluency, semantic familiarity and recognition-related familiarity for faces, Nessler and colleagues (2005) reported a frontal old/new effect in the 300-450ms time windows for famous and non-famous faces in the recognition memory task, as well as in a task that examined semantic familiarity by contrasting ERP differences between first presentations of famous and non-famous faces (no analysis contrasting the old/new differences between famous and non-famous faces was conducted). For the perceptual fluency task, they obtained a centro-parietal effect between the first presentation of famous and non-famous faces, and they suggested that this component indexes greater perceptual fluency for famous than for non-famous faces.

Although the task designs mean that the possible contributions of recollection and familiarity could not be separated in the above mentioned studies (Johansson et al., 2004; Nessler, Mecklinger, & Penney, 2005), they do provide evidence that recognition memory for faces is associated with a frontal old/new effect around the 300-500ms epoch, and that this modulation is insensitive to the nature of the stimuli (i.e. emotion and fame). In addition, Nessler and colleagues (2005) demonstrated that perceptual fluency for faces is associated with an old/new effect with a centro-parietal maximum. It is at least worth noting the similarities between these effects and those elicited by words (see Rugg et al, 1998).

In some recent studies, a subjective separation of responses and ERPs based upon recollection or familiarity was accomplished in a series of experiments using the source memory approach. In one source memory approach with faces as stimuli, a target face is paired with a piece of autobiographical information at encoding. Correct old judgments to faces that attract either correct or incorrect source judgements might then be taken as responses that either are or are not associated with recollection. In some published studies, a slightly different approach has been taken, which combines both objective and subjective measures that can separate recollection and familiarity. In these studies, three retrieval options were included: source, other-source, and no-source (Yovel & Paller, 2004; Curran & Hancock, 2007; Mackenzie & Donaldson, 2007). Participants were asked to make old/new judgments to test faces, and then to indicate whether they could, (i) remember autobiographical information presented along with the face at study, ii) whether they could remember details other than the autobiographical information, or (iii) whether no contextual information could be remembered. When participants made response (i) they were then asked to provide the relevant autobiographical detail. For these studies, it was assumed that recollection of task-relevant detail served as the basis for the *source* option, *other-source* indicated non-criterial recollection and that the no-source option indicated that the initial old judgment was based upon a familiarity process. These studies and their findings are critical in the context of this thesis, as they provide the starting point for the empirical work reported here.

In an influential experiment, Yovel and Paller (2004) examined the phenomenon of the "butcher-on-the-bus". This is based on Mandlers (1980) argument that seeing a familiar person in an unfamiliar situation, such as seeing your butcher on the bus, might lead to a feeling of familiarity without conscious recollection about the details of the person. In this experiment, occupation information was presented auditorily along with target faces. Face/occupation fit judgments were acquired at encoding. ERP data were acquired when participants completed a memory test in which studied faces were intermixed with unstudied faces. Twelve participants made initial old/new judgments, and secondary judgments about the source content as described above were only required for faces judged to be old. ERP waveforms were subsequently formed for correct responses that were separated for the three classes of source judgments (8 participants were included in contrasts involving the other-source option), and new responses (correct rejections). The ERPs were analysed over two time windows: 300-500 and 500-700ms along the midline electrodes.

In the first time window, the ERP old/new effects were broadly distributed and were reliable and equivalent in size for the response categories associated with recovery of source information. There were no reliable old/new effects for no-source judgments. In the second window, ERP old/new effects were reliable for all three options associated with a correct old response, and the effects were larger for the two options associated with the recovery of source information in comparison to the no-source condition. The differences between the effects in the two time windows were also quantitative rather than qualitative, as no evidence for scalp distribution differences was obtained when the old/new effects for correct source judgments were contrasted across epoch. In keeping with the criteria discussed above, these effects can most straightforwardly be linked to recollection. The small old/new effect for no-source judgments in the 500-700ms time window could reflect sub-threshold recollection, or misapplication by participants of the 'other source' option. In summary, the findings of Yovel and Paller (2004) allow only one strong claim, which is that ERPs in a source retrieval task with faces as stimuli index one process that is tied to recollection rather than to familiarity.

A similar paradigm to Yovel and Paller's (2004) was employed by Mackenzie and Donaldson (2007), who used faces with no background information. In addition, the hair around each face was obscured. Mackenzie and Donaldson also reported the outcomes of analyses for the 300-500 and 500-700ms epochs for the same response categories employed by Yovel & Paller (2004).

In the 300-500ms epoch, Mackenzie and Donaldson identified a frontal old/new effect that was reliable (and of the same magnitude) only for the source and other-source categories. At posterior sites, there was an old/new effect that was statistically equivalent for all three options for categories associated with correct old judgments. This posterior effect fulfils the criteria for a neural index of familiarity; hence these data suggest that there are two old/new effects in this time window. The anterior effect indexes recollection, while the posterior effect indexes familiarity. The strength of this argument is weak, however, because there were no reliable differences between the scalp distributions of the three old/new effects in this epoch. In addition, in the absence of data associated with misses, another interpretation of the posterior early effect is that it is simply a repetition effect. This possibility gains support from the finding that, in studies where verbal and facial stimuli were employed, a repetition effect is often observed at central posterior sites in this epoch (For words: Rugg et al. 1998; Azimian-Fardiani & Wilding, 2006; faces: Henson, Goshen-Gottstein, & Ganel et al., 2003; Schweinberger, 1996; Schweinberger & Burton, 2003; Itier & Taylor 2004). It has been proposed that this effect is an index of implicit memory (Rugg, Mark, & Walla et al., 1998).

For the 500-700ms epoch, Mackenzie and Donaldson reported graded old/new effects that were largest for source, then other-source, then no-source. This graded pattern links all of the old/new effects in this epoch to recollection. Mackenzie and

Donaldson also showed that in this epoch there were two separable indices of recollection, because the scalp distribution of the no-source old/new effect differed reliably from the effect for the two categories associated with recovery of source material. The main reason for this distribution difference is an old/new effect that extends to frontal sites for the two with source conditions only.

In summary, the findings of Mackenzie and Donaldson (2007) converge with those of Yovel and Paller (2004), in that the findings in both studies can readily be interpreted as support for the claim that ERPs elicited by faces in source retrieval tasks index processes tied closely to recollection. While Yovel and Paller (2004) demonstrated only one ERP modulation linked to recollection, however, Mackenzie and Donaldson's data argue strongly that at least two distinct ERP modulations elicited by faces are tied to recollection. It remains the case that in neither study is there strong evidence for an ERP index of familiarity.

A similar study with a sample of 24 participants was conducted by Curran and Hancock (2007), who also attempted to separate responses associated with recollection and familiarity for faces. Two principal differences from the above two studies were: 1) the use of a set of highly heterogeneous (colour) photos which contained Caucasian and non-Caucasian faces with external features such as glasses, moustaches, beards and jewelleries; 2) the occupation information that was paired with faces was presented visually directly below the target face, as opposed to being presented auditorily.

For the 300-500ms epoch, Curran and Hancock reported analyses that mirrored those completed by Yovel and Paller (2004) in that they were restricted to frontal regions. There were statistically equivalent old/new effects at frontal sites for old items associated with recovery of source information as well as those associated with the no-source category. Curran and Hancock restricted their mean amplitude analyses to posterior sites in the 500-700ms epoch, where only the correct source judgment categories were reliably different from correct rejections. Thus in comparison to Mackenzie and Donaldson (2007) the authors used a more directed analysis strategy (guided by the findings in studied in which verbal stimuli had been employed), but the key difference is the presence of a reliable anterior old/new effect for faces in the no-source condition in the early epoch. Furthermore, ERPs associated with the "miss" category, which is assumed to be associated with weak familiarity, did not differentiate from correct rejections and were more negative going than hit responses at frontal electrodes. On the basis of these findings, Curran and Hancock suggested that they had obtained for faces a mid-frontal old/new effect, thereby arguing that the effect is a general index of familiarity.

While Curran and Hancock's data provides evidence for the link between familiarity and the mid-frontal ERP old/new effect, one criticism of Curran and Hancock's design stems from the use of a heterogeneous set of pictures. The ethnic background and external features depicted in the photos could in principle serve as non-facial cues that facilitate recognition and that are associated with conceptual categories (e.g. has moustache). It has been argued, therefore, that these kinds of information could be the basis of the frontal effect, in keeping with the argument that conceptual priming is indexed by this ERP effect (Yovel & Paller, 2004; Voss & Paller, 2007; Voss, Schendan, & Paller, In Press).

Hence, despite the highly similar manipulations employed across the three studies, the question of whether ERPs index familiarity, and what forms ERP indices of recollection take, remain controversial. Focusing first on ERP signatures of familiarity, the apparent inconsistencies across studies may be a result of differences in response accuracy (see Curran & Hancock, 2007). One of the arguments put forward by Curran and Hancock is that the null result observed in Yovel and Paller is because the homogeneous set of facial stimuli they used meant that familiarity could be not be relied upon to discriminate old and new faces, and this is reflected in the lower recognition memory accuracy in that study in comparison to Curran and Hancock's study. A summary of response accuracy across the three studies described above is presented in Table 2.1. Memory discrimination is lowest in Yovel and Paller, then Mackenzie and Donaldson, in comparison to Curran and Hancock's study. Therefore, one possibility for the absence of the mid-frontal old/new effect as an index of familiarity in the two former studies is the similarity between levels of familiarity strength for old and new items in the experiments. According to this view, a neural index of familiarity in the form of the mid-frontal old/new effect is more likely to be obtained when response accuracy is comparable to that obtained by Curran and Hancock.

Table 2.1. Response accuracy (old/new discrimination) in the three critical studies (Yovel & Paller, 2004; Mackenzie & Donaldson, 2007; Curran & Hancock, 2007).

		Yovel & Paller	Mackenzie & Donaldson	Curran & Hancock
Overall Recognition Performance				
	Hits	0.65	0.73	0.81
	False Alarms	0.12	0.20	0.10
	Discrimination	0.53	0.53	0.71

Overview

The literature review in this chapter has summarised evidence for the main ERP old/new effects that are linked to recognition memory when verbal material was used; this is the case in the majority of the published studies. The primary goal in this thesis is to investigate the sensitivity of ERPs to the processes that support memory for faces, to establish the functional significances of ERPs elicited by faces, and as a result develop an understanding of how memory for faces is supported. This will be accomplished in a series of studies that systematically delineate the contributions of recollection and familiarity during retrieval using the same stimulus set (unfamiliar faces). The paradigms employed in this thesis are those that have been employed widely using verbal materials, and are ones in which recollection and familiarity have been separated successfully.

Critically, in the key experiments described above, target faces were paired with autobiographical information. It is difficult, therefore, to make any claims about ERP indices of recollection for faces, as the content that defined whether recollection occurred was autobiographical. This concern does not apply to any indices of familiarity elicited in response to faces that were obtained in these studies, but given the equivocal evidence for ERP indices of familiarity for faces, in combination with the ambiguities concerning ERP correlates of recollection for faces, it is uncontroversial to state that further investigations of the sensitivity of ERPs to memory processes linked with faces are required to address these issues. The tasks employed in the experiments in this thesis were designed with this concern in mind, and emphasise processing of information associated directly with faces throughout. At issue are the sensitivities of ERPs to processes supporting memory for faces, and the insights they provide into how memory for faces is accomplished.

Chapter Three: Electrogenesis of Event-Related Potentials

The Electroencephalogram (EEG)

In 1929, Berger reported a series of rhythmic voltage oscillations from electrodes placed on the surface of the scalp. The spontaneous neural activity recorded at the scalp is termed the Electroencephalogram (EEG). This electrical activity is generated from millions of neurons and summated to form measurable electrical potentials that can be recorded at a distance. The part of the EEG that is triggered by the presentation of a stimulus such as a word or a face is referred to as an event-related potential (ERP) (Picton, Lins, & Scherg, 1995).

ERPs have been paired with behavioural measures to investigate psychological questions. A typical behavioural measure reflects the sum of numerous cognitive processes, often making it inadequate in isolation for answering questions concerning a certain stage of cognitive processing. ERPs can be utilized in this regard, because the technique allows the brain activity associated with cognitive functions to be recorded with temporal resolution at the millisecond level.

The temporal resolution of ERPs is superior to that of functional magnetic resonance (fMRI) and positron emission tomography (PET). The temporal resolution of PET and fMRI is limited by the sluggish nature of the haemmodynamic response, which makes using this technique a challenge when studying cognitive and neural processes that are separated by only a few hundred milliseconds (e.g. Johnson et al., 2008). However, ERPs have low spatial resolution compared to other neuroimaging techniques, in particular PET or fMRI. This is because it is difficult to infer neural sources from scalp-recorded data. Because of these properties, ERPs have been used primarily in experiments where the interest is in cognitive functions rather than on the neuroanatomical structures that support those functions.

Neuronal Activity

The brain and the surrounding tissue comprise conductive media that allow electrical current generated inside the brain to pass through and propagate to the scalp. The conductivity of the brain, however, varies across different tissues and across the thickness of the skull. These factors mean that electrical activity generated in the brain is distorted to some degree by the time it reaches the surface of the scalp. This is one reason why the spatial resolution provided by EEG is limited.

When neurons are at rest, spontaneous background neural activity occurs. When neurons are activated, action potentials and post-synaptic potentials are generated. This results in potential differences between the basal and the apical parts of neurons; and this in turn allows neurons to carry a signal over a distance. Action potentials are all-or-none discrete changes in voltage that are initiated at the cell body of an axon and progress to its terminal where the release of neurotransmitters into the synaptic cleft takes place. Postsynaptic potentials are graded potentials that occur instantaneously when the neurotransmitters bind to the receptors on the membrane of the postsynaptic cell, causing the ion channel to open or close and thereby altering the membrane potential.

Because the brain is a conductive medium, this activity can be recorded by electrodes placed either locally in the intercellular space (intracranially) or on the surface of the scalp. EEG is a record of the net flow of electrical potentials generated intra-cranially. In the simplest circumstance, EEG can be recorded by placing a pair of electrodes at different points on the surface of the scalp in order to measure the electrical potential difference between the two locations. The recorded potentials are usually small in magnitude; the amplitude varies from approximately +/- 100 microvolts. Not all activity generated in the brain can be recorded at the scalp, however. This is because there are several factors related to the electrogenesis of scalp-recorded activity.

Electrogenesis

Action potentials are generally undetected at the scalp due to the physical arrangement of the axons, and because each firing burst lasts about a millisecond. In contrast, postsynaptic potentials last from tens to hundreds of milliseconds, making them detectable from a distance (from the cellular source to the scalp). As a result, the electrical activity recorded by EEG is due to postsynaptic potentials mainly.

Electrogenesis occurs at two levels: in individual neurons and across groups of neurons (Coles & Rugg, 1995). When a postsynaptic excitatory potential stimulates a neuron, it generates a local electromagnetic field or dipole with a negative potential called a "sink" and a positive potential called a "source". The same phenomenon also occurs at the level of large populations of neurons, and the scalp recorded activity typically reflects the summation of this activity (Allison, Wood & McCarthy, 1986).

Not all active neuronal populations, however, generate activity that can be recorded at a distance. This is because scalp-recorded EEG can only index activity from "open field" configurations (Wood, 1987; see Figure 3.1). In these configurations, neurons are oriented perpendicularly to the surface of the scalp. Under these conditions, the dipoles from these neurons will summate and propagate along the potential gradient, producing a dipolar field with positive and negative current flows that are recordable at the scalp. In addition, for activity to be recordable at a distance, the neurons in an open field configuration must fire in synchrony. Because of such criteria for the recordable signal, it is believed that the neocortex is the primary source of scalp recorded ERPs, since 70% of pyramidal cells in the neocortex are in open field configurations (Nunez, 1981).

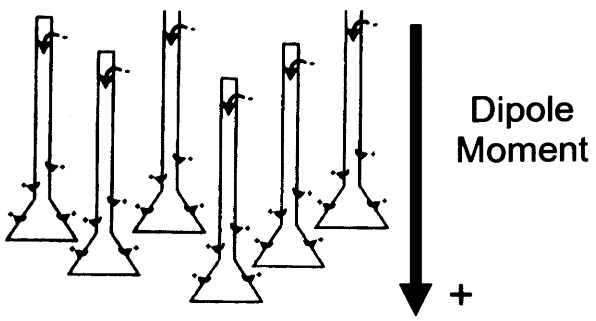


Figure 3.1. Open field source configuration. Adapted from Kutas and Dale (1997).

In contrast, if neurons are oriented randomly in "closed field" configurations (Wood, 1987; see Figure 3.2), then the neural activities will be cancelled out by each other under conditions when groups of neurons have their cell bodies centrally distributed with outward-facing dendrites, or when parallel neurons have opposite orientations. Both of these arrangements cause the positivity from one neuron to be cancelled by the negativity from an adjacent neuron. Complete cancellation occurs when individual dipoles are 180 degrees from each other, and some cancellation occurs at 90 degrees (Luck, 2005). Such arrangements will not produce potential fields that are recordable from the scalp. Other physical properties such as the number and shape of neurons also influence the recorded potential (Wood, 1987). These observations emphasise that ERPs provide only a selective measure of neural activity, and that the absence of measurable neural activity at the scalp does not imply the absence of neural activity intra-cranially.

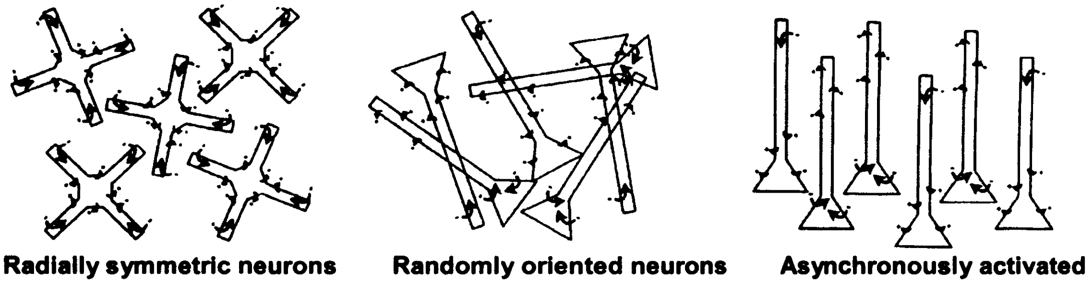


Figure 3.2. Examples of self-cancelling or closed field source configurations. Adapted from Kutas and Dale (1997).

In addition to geometric configuration and electrical conductance variations, the distance between the source of neural activity and the scalp electrodes also influences the recorded neural activity. This is because the strength of the electrical field decays with increasing distance from the source, hence EEG is less sensitive to neural activity generated from deep than from shallow sources.

Another consequence of these considerations concerning electrogenesis is that the scalp-recorded activity at a given location does not necessarily reflect the neural activity directly underneath that scalp location, but instead may reflect the net activity from several distinct and spatially distributed sources. Such summation is linear and occurs instantaneously. It is therefore not straightforward to infer the neural generators of scalp-recorded activity, and this is because of the so-called "inverse problem". The inverse problem is that, for any given pattern of electrical activity on the outside of a sphere, there is an infinite combination of internal generators that might be responsible. Because of the inverse problem, it is widely accepted that ERPs have very limited spatial resolution and are not suitable in isolation for identifying neural generators of activity that is recorded at the scalp.

Recording Electromagnetic Signals of the Brain

Electrodes, Electrode Placement and Sites, and Procedures

The scalp recorded ERP signal of interest is small in comparison to various forms of noise. As a result, several procedures are commonly employed to extract signals and minimise noise. The most widely used electrodes for recording EEG are the non-polarisable silver/silver chloride (Ag/AgCl) type. They are recommended as they produce minimal distortion to the recorded signal and record very slow potential changes reliably (Kutas, 1997; Picton, Bentin, & Berg et al., 2000). In typical current procedures, each recording electrode is connected to an elastic electrode cap, which is tightly affixed to the scalp. Each electrode cup is typically filled with electrolytic jelly, which acts as a conductive media between the scalp and the electrode metal. The electrodes are affixed to the scalp according to a common system, the most widely used of which is the standard 10-20 international system (IS) introduced by the International Federation of Electroencephalography (Jasper, 1958). This system ensures that electrodes are positioned in fixed locations on the scalp regardless of the shape and size of the head (see Figure 3.3). This method of standardised measurement of locations on the scalp allows comparisons of the electrophysiological data across participants and across experiments.

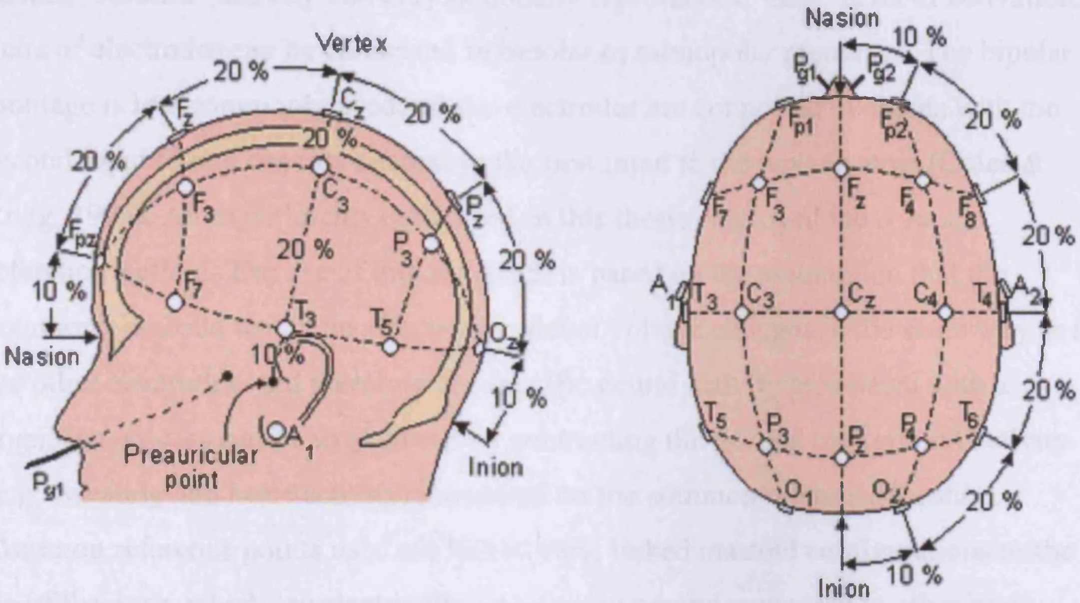


Figure 3.3. 10-20 International System (Jasper, 1958). Location divisions based on an iterative subdivision of arcs on the scalp starting from craniometric reference points: Nasion (Ns), Inion (In), Left (PAL) and Right (PAR) pre-auricular points. Figure taken from www.bci2000.org

Spatial Resolution of EEG

Spatial resolution at the scalp is determined by the number of electrodes used; and this is mainly dependant on the needs of the experiment. Currently, electrode caps can accommodate up to 256 or more channels, and this allows high-density recordings. The ERP data can be used to form brain maps which provide an estimate of the scalp distribution of the activity derived from the available data points across a particular latency range (Perrin, Pernier, Bertrand, & Giard, 1987; Perrin, Pernier, Bertrand, & Echallier, 1989).

Data Recording

Methods of Referencing

Typically, ERPs are recorded from a high-density array of electrodes and compared against a common reference electrode (Picton et al., 2000). This is an arbitrarily chosen 'baseline' activity that only notionally represents a "zero" level of activation. Pairs of electrodes can be connected in bipolar or monopolar montages. The bipolar montage is less commonly used; all the electrodes are connected in chains with the second input to one channel becoming the first input to the next channel (Coles & Rugg, 1995). All experiments conducted in this thesis employed the common reference method. The use of this approach is based on the assumption that the common electrode would be affected by global voltage changes in the same way as all the other electrodes, and therefore the specific neural activity associated with a cognitive process can be worked out by subtracting the general background activity (e.g. sweating and heart activity) measured on the common reference location. Common reference points used are linked ears, linked mastoid configurations or the tip of the nose, which are electrically (relatively) neutral compared to other brain activities (Picton et al., 2000). It is important to note that different reference methods or reference points can give rise to different patterns of brain activity, and it is essential to take account of the referencing method while comparing different data sets.

A/D Conversion and Sampling

Scalp-recorded neural signals are passed through an amplifier in order to select activity from the appropriate frequency range and to increase output magnitudes. Analog filtering is often done at the time of amplification. The output analog signals are then converted into digital form via the analog-to-digital (A/D) converter to facilitate data analysis. The rate of A/D conversion is referred to as the "sampling rate"; it determines the number of samples recorded in a given interval and this determines the temporal resolution in the waveforms. The sampling interval is the time difference between successive sampling points. The sampling rate used is determined by the purpose of the study: if the signal of interest contains high frequency brain activity, a high sampling rate (e.g. 1000Hz) is needed in order to capture the full range of signal. Typically, in ERP studies a frequency range of 0-100Hz captures the activity of interest and a conservative sampling rate between 200 and 500Hz is often employed.

Baseline Correction and Filtering

The on-going EEG signals are then broken down into discrete ERP epochs time-locked to a stimulus (trigger), and the epochs include a short duration baseline (~100-200ms) before the trigger to allow for baseline correction. The baseline correction procedure is commonly employed to control the influence of pre-stimulus electrical activity on post-stimulus activity. The mean level of pre-stimulus activity (for all electrodes individually) over the selected time period is subtracted from the signal at all time points. Hence, any constant amplitude differences in the pre-stimulus and post-stimulus level will be removed, while task-related as well as stimulus-generated activation will be retained (Wilding, 2006).

Each extracted ERP contains a signal of interest and other artefacts, such as eye movements and muscle activity. The signal of interest is usually small (0.1 to 5 μV) in comparison to the artefacts (50 to 100 μV), therefore several signal extraction procedures are employed in order to extract the signal of interest. The ERP data is often passed through a band-pass filter that consists of a high-pass and a low-pass filter; this ensures that signals of interest are retained while some artefacts are filtered out. High-pass filters filter out frequencies below the cut-off point, whereas low-pass filters filter out frequencies above the cut-off point. As a guideline, a high-pass filter is often set to 0.1-1Hz, whereas the low-pass filter is set to 30-100Hz. The filtering process can be carried out at the same time as amplification and/or off-line.

Signal Extraction

Signal Averaging

Signal averaging is the fundamental method used to obtain ERPs with a good signal-to-noise ratio. This method relies on the assumption that the signal of interest is invariant across trials, whereas sources of noise vary randomly. As a result, noise should reduce with averaging while the signal of interest should remain. Based on this assumption, the background EEG noise can be improved considerably by averaging a sufficiently large number (usually at least 16) of individual artefact-free time-locked epochs of EEG. The averaging is performed for each point of the digital value for each electrode site, and the signal-to-noise ratio increases by a factor equal to the square root of the number of trials summed and averaged (Luck, 2005).

Signal-averaging, however, suffers from two main disadvantages. Firstly, by averaging all trials any graded property in mental processes across trials is ignored. Secondly, the averaged ERP waveform might have no resemblance to individual trials. This could be as a result of "latency jitter", where the onset latency and/or the duration of an ERP signature vary in time across a number of trials (Donchin, Karis, & Bashore, et al., 1986). Also, in some cases, ERP signatures may be present in only a proportion of trials in an average, for example, when forced-choice procedures are employed and when trials are separated according to decision outcome. Under these circumstances, the averaging technique will provide an unrepresentative average of the activity on individual trials.

Artefacts

Rejecting trials with artefacts off-line prior to ERP analysis has been used widely to increase the signal-to-noise ratio. Electrophysiological artefacts are signals unrelated to the brain activity associated with the task. They can be divided into external and internal (physical) artefacts. The external artefacts occur outside of the participant's control; they include alternating current which has the same frequency range as the mains voltage supply or switching artefacts which are rapid discharge spikes associated with switching electrical equipment. On the other hand, internal artefacts occur inside participants, and the most common physical artefacts are body movements, eye blinks and eye movements. The ERP waveform elicited by eye movements and the ERP signals of interest occur in the same frequency range and one solution to this problem is to discard ERP epochs that are contaminated by eye movements. Alternatively, it is possible to estimate and algorithmically correct the impact of eye movements in order to retain more data (Coles & Rugg, 1995). In order to implement either of these approaches, electro-ocular artefacts (EOG) are recorded from electrodes placed close to the eyes in order to monitor their effect on the ERP (Naatanen & Picton, 1987).

Interpretation of ERP Results

Descriptions of ERPs

ERP modulations are often described in terms of their polarity and serial order (i.e. P1, N2), or the polarity and peak latency (i.e. P200) from the onset of stimulus presentation. In addition, recording from a range of electrodes enables a description relating to the spatial distribution over the scalp (i.e. P300). With such a systematic description system, ERP signatures can be communicated across experiments, integrated with other ERP data, and can in principle be used as a covert physiological marker for the engagement of cognitive processes (Otten & Rugg 2004). ERP modulations are often referred to as components. The issue of components is addressed below, and is followed by a description of two influential components. They are described here because they have a spatial distribution, time course and series of antecedents that mean that they are relevant to the ERP modulations that are described in the experiments reported later in this thesis.

ERP Components

At present, there is still no single consensus on how an ERP component is defined. Broadly speaking, there are "physiological" and "functional" approaches. The physiological approach implies that ERP components are defined in terms of the neural generators or the sources within the brain (Näätänen & Picton, 1987), whereas the functional approach implies that the sources contributing to the ERP waveform are irrelevant, and what is important are the functional processes that are associated with the ERP component (Donchin, 1981). The most common approach to ERP components now is based on both functional importance and the anatomical sources, hence an ERP component has a circumscribed scalp distribution and a circumscribed functional significance based on its behaviour in particular conditions (Donchin, Ritter, & MaCallum, 1978).

P300

This component is also referred to as P3. Because of its relatively large amplitude (compared to other ERP components) of around 5-20uV, it is one of the most studied ERP components. It was first reported by Sutton and colleagues (1965). This modulation is highly sensitive to stimulus probability, and the effect was first observed in a now well-established "oddball" paradigm (Donchin et al., 1978), in which a series of sounds consisting of a frequent and a rare tone are presented to participants. The P3 modulation is larger for the rarer frequency, and the P3 amplitude depends upon the relative rarity of the infrequent stimulus (Donchin & Coles, 1988; Coles, Henderikus, & Smid et al., 1995). It has been proposed that the P300 effect is related to stimulus evaluation time (Donchin & Coles, 1988), as onset latency correlates with reaction time. The P3 component is also separated into P3a and P3b (alternatively, frontal P300 and parietal P300), each with functionally distinct characteristics. In general, it is a positive-going modulation with onset latency between 300 and 900ms post-stimulus and is maximal over fronto-central (P3a) and centro-posterior (P3b) electrode locations (Donchin & Coles, 1988; Hillyard & Kutas, 1983; Hillyard, Squires, Bauer & Lindsey, 1971; for review see Coles, Gratton & Fabiani, 1990). The P3a component has a strong association with attention during task processing, whereas P3b is linked to stimulus evaluation and context updating (Donchin & Coles, 1988; Hillyard & Kutas, 1983). In general, the P3 is larger for task-relevant than for task-irrelevant stimuli, and is also correlated with response confidence: stimuli to which confident responses are made elicit larger P3s.

N400

This component is a negative-going waveform with an onset latency between 300 and 600ms and maximal amplitude over central-parietal scalp. The N400 is related to language comprehension and priming. This component was first reported by Kutas and Hillyard (1980) in an experiment that involved participants reading out sentences in which the last word of the sentence was semantically congruent or incongruent with words preceding it. The N400 is larger for semantically incongruent than for congruent words. The N400 is also related to repetition: primed items - both verbal and non-verbal – elicit a larger N400 than unprimed items (Coles & Rugg, 1995;

Barrett & Rugg, 1990). It has been suggested that this component indexes processes that facilitate the integration and/or assessment of semantic information (Kutas & Hillyard, 1980; Schweinberger & Burton, 2003). In addition, it is thought to reflect the difficulty with which a current stimulus can be integrated into the preceding context (Kutas & Federmeier, 2000).

Functional Interpretations of ERP Effects

This section will outline how inferences can be drawn from ERP data before going into details of ERP analysis strategies that are commonly employed. A central assumption for the functional interpretation of ERPs is the distinction between qualitative and quantitative differences in the data. Qualitative differences between electrical activities imply that at least partially non-overlapping brain regions and therefore functionally different cognitive processes are involved in the experimental conditions (Donaldson, Wilding & Allan., 2003; Wilding, 2006). In contrast, only quantitative differences in the data indicate the same neural structures and therefore the same cognitive processes are engaged, albeit perhaps to different degrees in the experimental conditions.

Analysis and Rescaling of ERP Data

Quantitative differences are commonly assessed by comparing mean amplitude measures at particular locations of interest. To assess whether qualitative differences are present, the common method is to submit the ERP data to a rescaling procedure prior to analysis. Rescaling ERP data is employed to remove overall amplitude differences between conditions of interest yet retain differences between the scalp distributions (McCarthy & Wood, 1985). Any reliable effects involving the factors of condition and electrode location observed in the analysis of rescaled data indicate scalp distribution differences between conditions (for an extended commentary and some reservations, see Urbach & Kutas, 2002; 2006).

Two rescaling methods have been used widely; they are the vector length method (Urbach & Kutas, 2002) and the max-min method (McCarthy &Wood, 1985).

The approach in the first method is to calculate the common rescaled 'vector length' (the divisor) from all electrodes and, for each condition separately, divide each amplitude value at each electrode by the vector length. The vector length increases as overall amplitudes increase, and as a result this approach minimises overall amplitude differences between conditions of interest. This method has been recommended in some ERP data acquisition guidelines (Picton et al., 2000), but this method can produce false positive results when in fact no scalp distribution differences exist (Urbach & Kutas, 2002; Wilding, 2006).

In the second (max-min) method, the amplitudes for all electrodes are rescaled against the maximum and minimum amplitudes from the same set of data. The data are thus transformed into a range of normalised amplitudes falling between 0 and 1. While this method does not suffer from the same drawbacks as the vector-length method, it is prone to false negative results when in fact scalp distribution differences exist (Haig, Gordon, & Hook, 1997; Wilding, 2006). There are good reasons for employing rescaling methods when the intention is to make inferences about when functionally distinct neural and cognitive processes are involved in different experimental conditions (Wilding, 2006). This is a central goal in this thesis, and in the experiments that are described, the max-min method is employed for rescaling data.

Chapter Four: General Methods

Introduction

The recording and analysis strategy common to all experiments will be outlined in this chapter. The specific procedures for each experiment will be presented in the introduction and method sections for the relevant chapters. The experiment stimuli were similar across all experiments, however an additional modification was implemented for the encoding tasks in experiments 3-5. Two sets of ERP recording parameters were used, because 2 different acquisition systems were employed. Experiments 1, 2 and 5 used one set and experiments 3 and 4 used another. To facilitate comparisons across experiments, the data analysis strategy was broadly consistent for all experiments.

Participants

Participants were Caucasian right-handed English speakers with normal or corrected-to-normal vision. The age range was from 18 to 30. They were students from Cardiff University and informed consent was obtained from all of them prior to each experiment. None were taking medication for epilepsy, depression or anxiety at the time of testing. They were each paid £7.50/hour for their participation.

Stimulus Materials

Stimuli employed in all experiments consisted of front-view unfamiliar faces. They were all images of young to middle age Caucasian males and females. The images were of faces similar to those that would be encountered on a daily basis. The faces had neutral emotion and did not carry distinctive external accessories. All faces were standardized black-and white images (400 x 500 pixels) containing head-and-shoulder information with minimal background. Examples of the faces are shown in Appendix A. Experiment 1 also employed verbal material (visually presented words), and details about these stimuli are provided in the Methods section for Experiment 1.

Stimulus Presentation

All facial stimuli were presented visually against a white background on a computer monitor located 1 meter from participants. Faces subtended maximum visual angles of 5.6° (vertical) and 4.2°(horizontal). For all experiments, faces presented at test were displayed for a duration of 300ms.

Experiment Structure

For all experiments, there were several study-test blocks. Construction of the blocks and the specific response requirements will be described in the method sections in each of the experiment chapters. The old/new status of the stimuli was counterbalanced in all experiments, so that all items were presented as old as well as new stimuli equally often across participants. The order of study-test block presentation was balanced across participants: half of the participants performed the first half of the study-test blocks first whereas the other half of the participants performed the second half first. The old/new status of the items and the sequence of the study-test block presentations produced 4 study-test lists in each experiment. For responses, common to all experiments is that the hands designated to old and new responses were counterbalanced: half of the participants used the left hand for old responses, whereas the remainder used the right hand. The order of stimulus presentation within each study and test block was randomly determined for each participant by the stimulus presentation software.

Experiment Procedures

Participants were verbally informed about the capping procedure for the ERP set up and the procedure for the experiment before they gave informed consent. They also received a written information letter that they were given time to read. They were fitted with the electrode cap prior to the start of each experiment. The capping procedure started with skin preparation by applying the electrode skin preparation cream using a cotton bud to the skin area where the electrodes would be attached. This is the recommended procedure to reduce electrical impedance levels at the skin and remove artifacts (Picton et al., 2000). The electrode impedance level for each electrode was reduced to below 5Ω prior to the start of recording. Participants were seated in a sound-attenuated recording booth, situated approximately one meter away from the computer monitor. They read through an instruction sheet and the experiment procedure was also explained verbally at the start of the experiment. Each experiment started with a short practice session (half of the size of one of the actual study-test blocks), and care was taken to ensure participants fully understood the task instructions. Short breaks of approximately 1-2 mins were given after each study-test block; a 5 mins break was given after participants completed half of the experiment.

ERP recording

As mentioned above, EEG data were recorded from 2 acquisition systems at test. Experiments 1, 2, and 5 were recorded from System 1, which involved acquisition from 25 silver/silver chloride scalp electrodes; experiments 3 and 4 were recorded from System 2, which involved acquisition from 32 electrodes. All electrodes were embedded in an elastic cap and located at midline sites (Fz, Cz, Pz, **Oz**) and left/right hemisphere locations (FP1/FP2, F7/F7, F5/F4, F3/F2, **F1/F2**, T7/F8, C5/C6, C3/C4, **C1/C2**, T5/T6, P5/P6, P3/P4, **P1/P2**, O1/O2) (seven additional electrodes used in System 2 are shown in bold). The electrode sites were based on the International 10-20 system (Jasper, 1958) (see Figure 4.1). For both systems, electro-oculogram (EOG) was recorded from electrode pairs placed above and below the left eye and on the outer canthi.

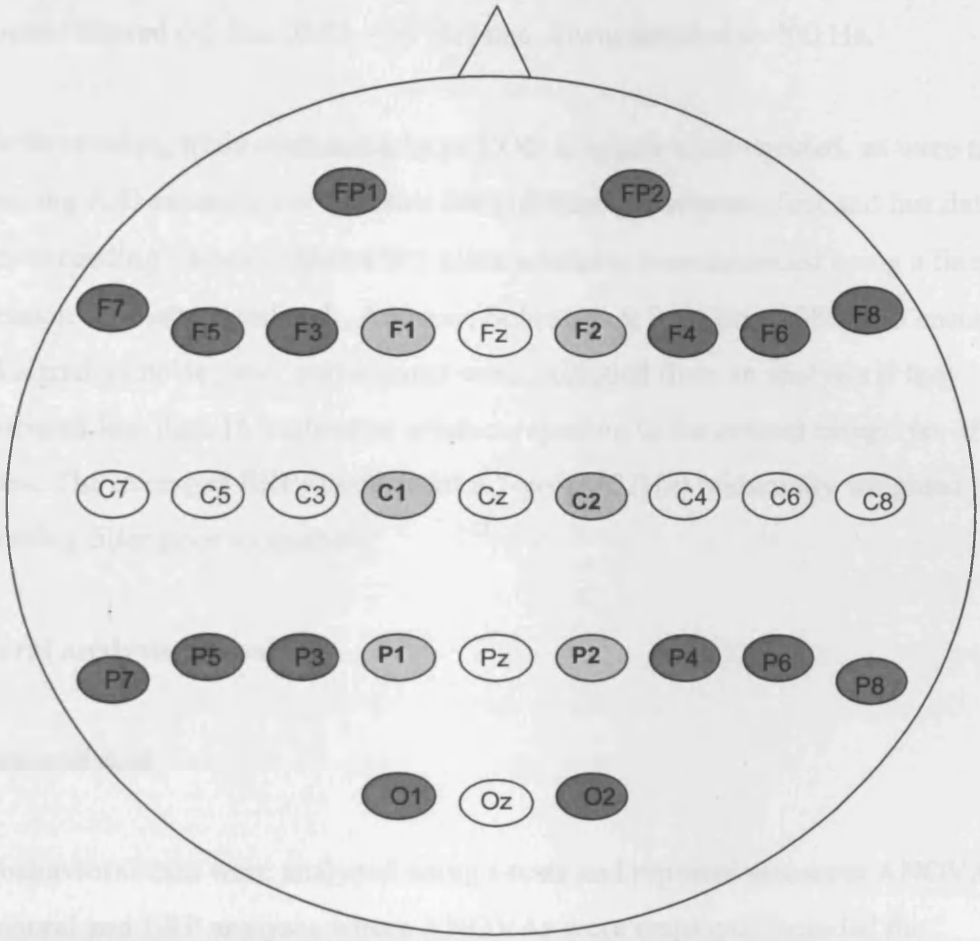


Figure 4.1. International 10/20 system (Jasper, 1958). All electrode locations that were employed in the recording of the ERPs. Additional electrodes in system 2 are coloured in light grey. Dark grey coloured sites represent electrodes that were selected for the global ERP analyses (see below).

For System 1, EEG and EOG were recorded at 200Hz with a bandwidth of 0.03-40Hz (-3 dB). Impedances were maintained below 5kΩ. EEG was recorded referenced to Fz. For System 2, EEG (range DC-419 Hz; sampling rate 2048 Hz) was acquired referenced to linked electrodes located midway between POZ and PO3/PO4. For both systems, EEG was re-referenced computationally off-line to a linked mastoid reference into baseline corrected epochs of 1280ms (256 data points), each including a 100ms pre-stimulus baseline, relative to which all post-stimulus amplitudes were measured. The data from Fz were reclaimed in System 1. For System 2, data was high-pass filtered off-line (0.03 – 60 Hz) and down-sampled to 200 Hz.

For both systems, trials containing large EOG artefacts were rejected, as were trials containing A/D saturation or baseline drift (difference between first and last data point) exceeding ±80μV. Other EOG blink artefacts were corrected using a linear regression estimate (Semlitsch, Anderer, Schuster, & Presslich, 1986). To ensure a good signal-to-noise ratio, participants were excluded from an analysis if they contributed less than 16 trials after artefact rejection to the critical categories of interest. The averaged ERPs underwent a 7-point (22Hz) binomially weighted smoothing filter prior to analysis.

General analysis procedures

Behavioral data

The behavioral data were analyzed using t-tests and repeated measures ANOVAs. All behavioral and ERP analyses where ANOVAs were employed included the Greenhouse-Geisser correction for non-sphericity when necessary (Greenhouse & Geisser, 1959).

ERP data

The mean amplitudes of the ERP data were compared between response categories of interest over 4 time windows (300-500, 500-700, 700-900, and 900-1100ms). Mean amplitudes were computed with reference to the mean amplitude of the 100ms pre-stimulus baseline. The initial analyses for all experiments were performed on a montage of 16 electrode locations: left/right prefrontal sites (FP1/FP2), left/right frontal (F7/F8, F5/F6, F3/F4), left/right parietal (P7/P8, P5/P6, P3/P4), left/right occipital (O1/O2). This montage of electrodes was divided into four equal clusters: left anterior (FP1, F7, F5, F3), right anterior (FP2, F8, F6, F4), left posterior (O1, P7, P5, P3), right posterior (O2, P8, P6, P4). The initial global ANOVAs included factors of response category, anterior/posterior dimension, left/right hemisphere, and site (see Figure 4.1).

In cases when ANOVAs revealed reliable effects involving response category with more than 2 levels, they were followed up by all possible paired contrasts. Corrected degrees of freedom and F-values are shown in the main body of text and tables. Only reliable effects involving the factor of response category are reported.

Focused analyses

Directed analyses at specific scalp locations were conducted in order to determine the sensitivity of ERPs to recollection and familiarity when faces are the test stimuli (see Introduction, in particular, pages 59-65). The sites at which these analyses were conducted were determined, for each experiment, by the outcomes of the higher-level analyses. The response categories that were included in these directed analyses varied according to the particular designs of the individual experiments.

Topographic analyses

These analyses assessed (i) whether there were differences between the scalp distributions of the ERPs for particular contrasts; and (ii) whether the distributions of the ERP old/new effects for a given contrast changed over time. The topographic analyses were conducted on the 16 electrode sites from which the initial ERP analysis was carried out. Prior to the analysis, the ERP data were range-normalized using the Max-Min method proposed by McCarthy and Wood (1985) on the full montages in order to remove amplitude differences between conditions. This allows claims about differences between scalp distributions when interactions involving scalp locations remain when rescaled data are analyzed (McCarthy & Wood, 1985; Urbach & Kutas, 2002; Wilding, 2006).

Tables, figures and scalp topographies

The tables for the critical behavioral data are presented in the relevant results sections. In all experiments, the ERP results of the ANOVAs involving the factor of response category are shown in table form. The tables display corrected degrees of freedom, F-values and p-values. In all ANOVA tables, p-values greater than 0.1 are denoted as ns. (non-significant), all p-values of 0.1 or less are presented, and p-values of 0.05 or less are shown in bold text. All tables except for behavioral data, ERP waveforms, scalp maps and additional materials are presented at the end of each experiment chapter. The scalp maps shown are computed from the difference scores obtained via the subtraction of the mean amplitude for one critical condition from another (e.g. hits minus correct rejections).

Chapter Five: Experiment 1 - Recognition Memory for Faces and Words

Introduction

Dual-process models state that two functionally distinct processes support recognition memory: recollection and familiarity (Mandler, 1980; Jacoby, 1983; Yonelinas, 1994). Recollection is associated with the recovery of contextual information from episodic memory, and familiarity is regarded as a feeling that an item has been encountered previously but does not entail the retrieval of contextual information. ERP studies in which words have been the test stimuli have provided strong evidence in support of dual-process accounts. As reviewed in previous chapters, two ERP old/new effects have been identified, and these have functional properties that suggest they are correlates of recollection and of familiarity.

ERP studies where test stimuli were not words have, however, provided several indications that not entirely the same ERP old/new effects are observed when test stimuli differ. It is arguably unsurprising that ERP old/new effects will differ according to the content of information that is retrieved (Johnson, Minton, & Rugg, 2008: for relevant fMRI studies, see Chapter 2), but the current ERP literature is also ambiguous concerning whether ERPs for non-verbal stimuli do in fact index recollection and familiarity, and if they do, whether these indices are the same ones that are observed in studies where verbal material has been employed. These observations are particularly true in the case of studies where faces have been employed as the test stimuli.

One of the aims in this thesis is to provide a detailed investigation of the sensitivity of ERPs to memory processes that support judgments about faces and facial features. In this regard, Experiment 1 is a baseline study that was designed to provide a direct comparison of the ERP old/new effects that are elicited by faces and words in order to begin to address the question of whether the same ERP old/new effects - hence comparable retrieval processes - are engaged in the two cases.

Methods

Participants

There were thirty-five participated in the study. Data from 11 participants were discarded due to insufficient trials (< 16) in at least one of the critical conditions (see below) following artifact rejection. The mean age of the remaining twenty-four participants was 21 (ages 18-25, 1 male).

Stimuli

The stimuli were 200 faces and 200 words (for examples of faces see Appendix A). Words were all concrete nouns selected randomly from a list of 720 words with a frequency range of 1-10/million, and were presented in black letters with the font size of 36. The word list contained no words that denoted names or occupations. The experiment comprised 10 study-test blocks. Half contained faces, the remainder words. Each study phase contained 16 targets and 8 distracters. The 16 targets were presented in the centre of the screen. Distracters were presented on the left or right of fixation (4 on each side in each study phase). In this and in subsequent experiments, distracters were presented at study only, their purpose being twofold: to encourage participants to attend to visual information on each trial, and to provide a means of controlling levels of response accuracy on subsequent tests. Test phases each contained 32 items, comprising the 16 studied targets and 16 new items. A total of 8 counterbalanced combinations were formed following the procedure described in the General Methods Chapter, see page 80.

Procedure

Study and test trials started with an asterisk displayed centrally for 1000ms, followed by a 100ms blank screen. Words and faces were presented for 300ms. All stimuli were followed by a blank screen lasting the length of time the participant took to respond plus 1500ms before presentation of the asterisk signaling the onset of the next trial. A three-way location response was required in study phases; respond with left and right index fingers to stimuli presented on the left/right of fixation, with a thumb press for items presented centrally. For test trials a binary old/new judgment was required. The thumb used for the centre study judgments, and the hands used for the old/new test judgments, were balanced across participants. Study-test blocks alternated between faces and words, with half of the participants starting with a face block. The sequences of item presentation in each study and test phase were determined randomly for each participant. EEG was recorded with recording parameter 1 (see General Methods Chapter, page 82).

Results

Behavioral Data

Table 5.1 shows the mean probabilities of correct responses to old and new items separately for faces and for words. Standard deviations are in brackets. Discrimination measures [p(hit) – p(false alarm)] (see Snodgrass & Corwin, 1989) were above chance for both stimulus types (Faces = 0.38: $t(23)=12.24$, $p<0.01$; Words = 0.61: $t(23)=16.36$, $p<0.01$), and discrimination was superior for words ($t(23)=7.59$, $p<0.01$).

Table 5.1. Proportions of old and new faces and words attracting correct responses. Standard deviations are in brackets.

	Item status	
	Old	New
Face p (correct)	0.67 (0.13)	0.70 (0.15)
Word p (correct)	0.76 (0.17)	0.85 (0.13)

Table 5.2 shows the mean RTs for correct responses to old and new items separately for faces and words. A two-way ANOVA with factors of stimulus type (Faces, Words) and response (Hits, Correct Rejections) revealed a main effect of stimulus type ($F(1,23)=32.23$, $p<0.01$), as well as a main effect of response ($F(1,23)=8.01$,

p<0.01). These indicated that RTs were faster for words than faces, and that correct old responses were faster than correct new responses.

Table 5.2. The reaction times (RTs) for old (hits) and new (correct rejections) items attracting correct responses for faces and words. Standard deviations are in brackets.

	Old	**New**
Face	1240 (187)	1311 (193)
Word	1136 (158)	1167 (174)

Electrophysiological Data

ERP Analyses

The initial analyses focused on the old/new effects for faces and words separately. These were followed by contrasts between ERP difference scores obtained by subtracting mean amplitudes associated with the ERPs elicited by correct rejections from those for hits for faces and for words. The analyses were conducted for the following latency intervals: 300-500, 500-800, and 800-1100ms. These latency ranges are commonly used in ERP memory retrieval studies for words (Curran 1999, Azimian-Faridani & Wilding, 2006; Woodruff et al., 2006). The electrodes and factors in the initial ANOVA were those introduced in the General Methods Chapter. To reiterate, they encompassed 16 electrodes at anterior and posterior sites (left anterior: FP1, F7, F5, F3; right anterior: FP2, F8, F6, F4; left posterior: O1, T5, P5, P3; right posterior: O2, T6, P6, P4). The analyses included the factors of response category (two levels), anterior/posterior dimension (two), hemisphere (two) and site (four).

Mean trial numbers contributing to the ERPs for hits and correct rejections were: for faces: 26 (range = 16 to 46) and 27 (16 to 60); for words: 31 (16 to 63) and 32 (16 to 71). All of the outcomes of the ERP analyses are presented in Tables 5.3, and are described below. Only results involving response category are shown in the tables, and in the text below only the highest order interactions involving this factor will be discussed.

Figure 5.1 and 5.2 show the grand averaged ERPs elicited by hits and correct rejections for faces and for words (see also Figure 5.3 below). The grand averaged waveforms for faces show that the waveforms for hits are more positive-going than those for correct rejections from approximately 200ms at anterior electrodes and from approximately 300ms over the posterior scalp. The positive-going old/new effects are most prominent along the midline and are somewhat left-lateralized from 500 to 800ms. The two waveforms converge subsequently. The grand averaged waveforms for words show that the waveforms for hits become more positive-going from approximately 200ms across most electrodes, and these differences remain largest along the midline as well as over the left-parietal scalp from approximately 400 to 800ms. From 800ms onward, the effects become most prominent over right anterior regions. These patterns can be observed in Figure 5.4, which shows the scalp distributions of the face and word old/new effects in the form of scalp maps for the epochs over which the data were submitted to analysis (300-500, 500-800 and 800-1100ms).

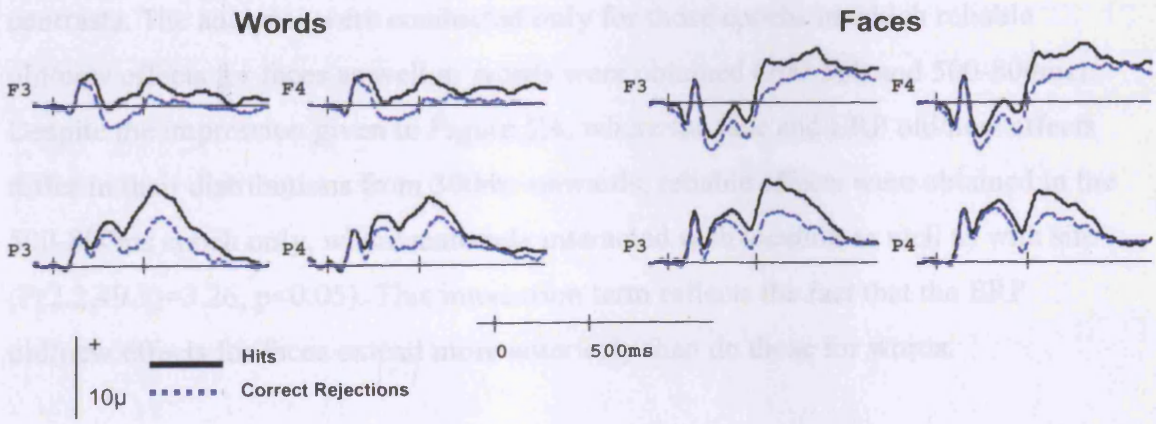


Figure 5.3 Grand averaged event-related potentials elicited by hits and correct rejections for words and faces. Data are shown for 4 superior electrodes (F3, F4, P3, P4). (n=24)

Face Old/new Effects:

Table 5.3 shows that the positive-going ERP old/new effects for faces were reliable from 300-800ms. An interaction between category and site was obtained in the 300-500ms epoch, reflecting the fact that the old/new effects are largest at sites closest to the midline (see Figure 5.3). The three-way interaction between category, location and hemisphere in the following epoch reflects the left-lateralization of the old/new effects over posterior scalp, alongside a less lateralized effect over anterior scalp. In the final epoch, a marginally significant interaction between category and hemisphere provides some indication that the old/new effect in this epoch is left lateralized.

Word Old/new Effects:

For all epochs, the three-way interactions between category, location and site reflect changes in the distribution of the word old/new effects over time. From 300-500ms, and from 800-1100ms, the three-way interaction reflects the anterior superior maximum of the word old/new effect (see Figure 5.3). The same interaction term in the 500-800ms epoch reflects the posterior superior maximum of the effect.

Contrasts between Face and Word Old/new Effects:

Other than the fact that materials (2 levels) replaced response category, all factors in these analyses across stimulus type were identical to those described in the preceding contrasts. The analyses were conducted only for those epochs in which reliable old/new effects for faces as well as words were obtained (300-500 and 500-800ms). Despite the impression given in Figure 5.4, where the face and ERP old/new effects differ in their distributions from 300ms onwards, reliable effects were obtained in the 500-800ms epoch only, where materials interacted with location as well as with site ($F(2.2,49.9)=3.26$, $p<0.05$). This interaction term reflects the fact that the ERP old/new effects for faces extend more anteriorly than do those for words.

Topographic Analyses:

The same analysis was computed on re-scaled data followed the procedure outlined in the General Methods Chapter, page 85, in order to enable an interpretation of the ERP data that avoids confounding amplitude and shape differences between the face and word ERP old/new effects observed in the 500-800ms epoch. The same three-way interaction term between material, location and site was obtained in the analysis of rescaled data ($F(1.7,39.4)=4.92$, $p<0.05$), thereby licensing the claim that qualitatively different old/new effects were associated with faces and with words in this epoch.

The across epoch analyses were conducted separately for each material type in order to explore changes in the scalp distributions of the old/new effects over time. In the case of faces, these analyses were conducted for the 300-500 and 500-800ms epochs. For the analyses for words, the 800-1100ms epoch was also included.

This analysis revealed that the scalp distribution for the face old/new effect did not change reliably over time. Across the 300-800ms epochs, a reliable four-way interaction between epoch, location, hemisphere and site was obtained for words ($F(1.9, 44.6)=3.91$, $p<0.05$). This interaction reflects the fact that the old/new effect has a more left-lateralized posterior distribution in the later than in the earlier epoch. Across the 500-1100ms epochs, a reliable interaction between epoch, location, and site was obtained ($F(2.0,46.7)=5.31$, $p<0.01$), indicating the old/new effect in the 800-1100ms epoch extends to a greater degree over the anterior superior, as well as prefrontal sites relative to the effects in the earlier epoch (see Figure 5.4)

Face Old/new Effects Separated According to Response Accuracy:

Old/new discrimination was superior for words than for faces. It is possible, therefore, that the qualitative differences between the face and the word old/new effects in the 500-800ms epoch are a reflection of the greater difficulty of the face task. In order to assess this possibility, the 24 participants were separated into two groups. The *similar* group consisted of the 12 participants for whom old/new discrimination was most similar for faces and words (Discrimination scores were: Faces: 0.43 and Words: 0.54). The dissimilar group contained participants for whom discrimination was most different (Faces: 0.33 and Words: 0.68). Although discrimination was superior for words in both groups (similar: $t(11)=4.98$, $p<0.01$; dissimilar: $t(11)=12.89$, $p<0.01$), the discrimination advantage for words was greater in the dissimilar than in the similar group (0.35 vs. 0.11: $t(22)=6.85$, $P<0.01$). These data were submitted to the same analysis for the material effects described above, but with the additional factor of group. Assuming that neural activity which is sensitive to task difficulty changes with the degree of difficulty, then interactions involving group and location would suggest that relative difficulty contributes to the differences between the face and word old/new effects (for conceptual points and the same logic applied to other ERP data, see Rugg et al., 2000; Rugg & Wilding, 2000; Friedman & Johnson, 2000).

Critically, no reliable effects involving group were obtained in the analyses for the 500-800ms epoch, and the same outcome was obtained in an analysis for the 300-500ms epoch, suggesting that differences in relative difficulty do not contribute to these outcomes. The possible influence of task difficulty was also tested in a second analysis, which was an assessment of whether the anterior element of the old/new effect for faces is related to the greater relative difficulty across participants of the face task. This anterior element was selected as it is the aspect of the data in the 500-800ms epoch which differentiates the face and word ERP old/new effects: both effects also extend over (left) posterior scalp regions.

In this contrast, old/new discrimination scores for faces for each participant were correlated with the average magnitude of face ERP old/new effects at sites F3, Fz and F4. These are the sites at which the differences between the old/new effects for words and faces are most prominent. A negative correlation between discrimination accuracy and the magnitude of the face old/new effect at these locations would implicate difficulty in the differences across stimulus type. This view is based on the assumption that, as difficulty increases (as indexed by lower discrimination scores), the degree to which difficulty-sensitive neural processes are engaged also increases. No support for a difficulty account was observed, as a weak positive and non-significant correlation was obtained ($r=0.23$).

Discussion

Behavioral Data

Old/new discrimination was above chance for both faces and words, indicating that participants were able to discriminate between old and new items for each stimulus type. Discrimination was superior for words than for faces. The RT data showed that participants were faster making correct old than correct new judgments. They were also faster for words than for faces, in keeping with the discrimination advantage. This aspect of the behavioral data is consistent with previous studies in which higher response accuracy is typically associated with faster RTs (e.g. Rugg et al., 2000).

ERP data

300-500ms

Reliable old/new effects were largest over superior sites for both stimulus types, but for faces, the effects extended over anterior scalp to a greater degree (Figure 5.4). Despite the apparent maxima differences between these distributions, no reliable differences were obtained in the direct contrast, suggesting that broadly similar old/new effects, and therefore memory processes, were engaged for faces and words.

The old/new effects for words in the 300-500ms epoch resemble those obtained in previous studies. The broad distribution observed here has been shown to have separable anterior and posterior elements when the accuracy of test judgments is taken into account (Rugg, Mark, & Walla et al., 1998). A positive-going posterior old/new effect has been shown to be sensitive only to the old/new status of items, and has consequently been proposed to index implicit memory (Rugg, Mark, & Walla et al., 1998). In contrast, the anterior element is sensitive to memory judgments; it is more positive-going for correctly recognized old items than for correctly rejected new items. Moreover, it is insensitive to manipulations that are thought to influence recollection primarily, such as levels of processing and divided attention (Rugg, Mark, & Walla et al., 1998; Curran, 2004). This ERP old/new effect has been referred to as the mid-frontal old/new effect or the FN400, and has been proposed to index familiarity (Rugg, Mark, & Walla et al., 1998; Curran, 1999, 2000).

500-800ms

The separate old/new effect analyses for faces and words revealed a common posterior positivity for old stimuli. Topographic analyses indicated that the ERP correlates of recognition memory for faces and words also differed qualitatively in this epoch, principally because there was an old/new effect that extended more anteriorly for faces than it did for words. Comparable old/new effects for faces have been observed in previous studies (Curran & Hancock, 2007; Mackenzie & Donaldson, 2007), but in these studies there has not been the opportunity to compare directly effects for words and for faces.

As mentioned in the results section, however, the observed differences between the face and word ERP old/new effects could in principle reflect the differences in behavioral performance for the two stimulus types. Discrimination was superior for words in comparison to faces. One possibility is that participants employed additional processes for the task that was more difficult, and the anterior projection of the old/new effect in the 500-800ms epoch that is pronounced for faces is a reflection of that additional processing.

This interpretation was challenged by the outcomes of two analyses. First, when participants were split into groups where performance for faces and words was either similar or dissimilar, the analysis outcomes gave no indication that relative difficulty differences played a role in the differences between the old/new effects for faces and for words. In a subsequent correlation analysis, the magnitude of the frontal ERP activity that differentiated faces and words did not change in size according to how well participants were able to make accurate face memory decisions. These findings suggest that the difficulty interpretation is unlikely to be an accurate explanation of the reasons for the differences between the face and word old/new effects.

In the 500-800ms epoch, the common posterior positivity for words and faces has been identified as a generic signature of recollection (Rugg & Allan, 2000; Rugg &

Curran, 2007). These effects appear to be left-lateralized for both material types (Figure 5.4), and are likely to be examples of the left-parietal old/new effect in tasks that require explicit memory judgments (e.g. Wilding & Rugg, 1996; Herron & Rugg, 2003, Duzel, Yonelinas, & Mangun et al, 1997; Rugg et al., 2000). Importantly this effect has been also reported in studies employing different material types, including words, faces, pictures, and meaningless line drawings (squiggles) (Curran, 2004; Yovel & Paller, 2004; Tsivilis, Otten, & Rugg, 2001; Groh-Bordon, Zimmer & Ecker, 2006). This aspect of the data suggests that the posterior old/new effect is common to both faces and words, and it is likely to index a recollection process that is independent of the types of materials used. If this is correct, it follows that the greater anterior projection for faces in this epoch indexes a separable effect, which has different functional properties to the posterior element. Alternatively, the face effect in this epoch may be a unitary signature of recollection for faces.

On the basis of the present experiment, however, it is also possible to make functional inferences about the anterior element of the old/new effect for faces in the 500-800ms using the time course information in the electrical record. This frontal effect for faces shares the same time course as the posterior recollection effect (the left-parietal old/new effect); consequently, it is likely to reflect directly the retrieval and/or maintenance of some form of information that is required for faces to a greater extent than those for words (for a similar line of reasoning on content-specific retrieval, see Johnson et al., 2008). This claim is supported by the absence of reliable old/new effects for faces in the subsequent (800-1100ms) epoch, which suggests that this effect is unlikely to index a post-retrieval process: even if such processes overlap in time with the left-parietal old/new effect, it is reasonable to assume that they should extend beyond it (Yick & Wilding, 2008). Functional claims about this frontal old/new effect will be returned to in subsequent chapters.

800-1100ms

No direct contrast between the old/new effects for faces and words was conducted, because only words revealed reliable old/new effects in this epoch. In this epoch, the old/new effect elicited by words resembles those observed previously. The outcome of the analyses indicates the effect was largest over anterior superior electrodes and is largest at right frontal sites (see Figure 5.4). The fact that this old/new effect onsets after and is topographically distinct from the left-parietal old/new effect provides a basis for suggesting that it indexes post-retrieval processes that were engaged for words but not for faces. Although this right-frontal old/new effect is commonly reported in source memory paradigms (Wilding & Rugg, 1996; Allan, Wilding, & Rugg, 1998), the occurrence of this effect has been inconsistently reported in old/new recognition memory studies (e.g. Allan & Rugg, 1997; Rugg & Allan 2000; Rugg et al., 2000). Consequently, it is not possible to make confident claims about reasons why the effect was present here for words only.

Conclusions

The present experiment provides a baseline for subsequent investigations into processes supporting recognition memory for faces. The pattern of data was broadly consistent with previous studies in that common old/new effects that were centrally distributed in the 300-500ms epoch, and extended over the left-parietal scalp in the 500-800ms epoch were observed for faces and for words. The data also shows that not entirely the same ERP modulations were associated with faces and words in the 500-800ms epoch. Memory for faces was associated with an additional frontal modulation that was not present for words.

The absence of a manipulation of recollection and/or familiarity in this experiment, however, means that the functional significances of the common old/new effects can be inferred only tentatively on the basis of appeals to the presence of similar effects in previous studies where ERPs have been separated into categories that are associated either with responses made on the basis of familiarity or recollection. The remaining experiments in this thesis include behavioral manipulations that allow comparable separations, thereby providing means of delineating the functional significances of ERP old/new effects that are elicited when faces are the study and test stimuli.

Table 5.3 (ERP data)

Table 5.3 F-values and significance values for the old vs. new contrasts for faces and words, as well as the comparison between the old/new effects for faces and words over the 300-500, 500-800, and 800-1100ms epochs. Only effects involving response category that were reliable in at least one epoch are shown. RC = response category, AP = anterior/posterior dimension, HM = hemisphere, ST = site. All significant and marginally significant values will be reported (p<0.10), ns. = non-significant (p<.10). All significant effects are shown in bold. Full dfs are shown on the left with epsilon values in brackets alongside each associated F-value.

Faces

	300-500ms	500-800ms	800-1100ms
RC (1, 23)	**17.63, p<0.01**	**34.39, p<0.01**	3.76, p=0.07
RC x HM (1, 23)	ns.	3.16, p=0.09	3.09, p=0.09
RC x ST (3, 69)	**7.47, p<0.01 (0.61)**	**15.40, p<0.01 (0.63)**	ns.
RC x AP x HM (1, 23)	ns.	**8.53, p<0.01**	ns.

Words

	300-500ms	500-800ms	800-1100ms
RC (1, 23)	**30.12, p<0.01**	**13.60, p<0.01**	**8.96, p<0.01**
RC x HM (1, 23)	ns.	3.55, p=0.07	ns.
RC x ST (3, 69)	**15.10, p<0.01 (0.50)**	**7.78, p<0.01 (0.49)**	2.82, p=0.07 (0.73)
RC x AP x HM (1, 23)	ns.	3.26, p=0.08	ns.
RC x AP x ST (3, 69)	**3.75, p<0.05 (0.71)**	**12.98, p<0.01 (0.70)**	**11.97, p<0.01 (0.73)**

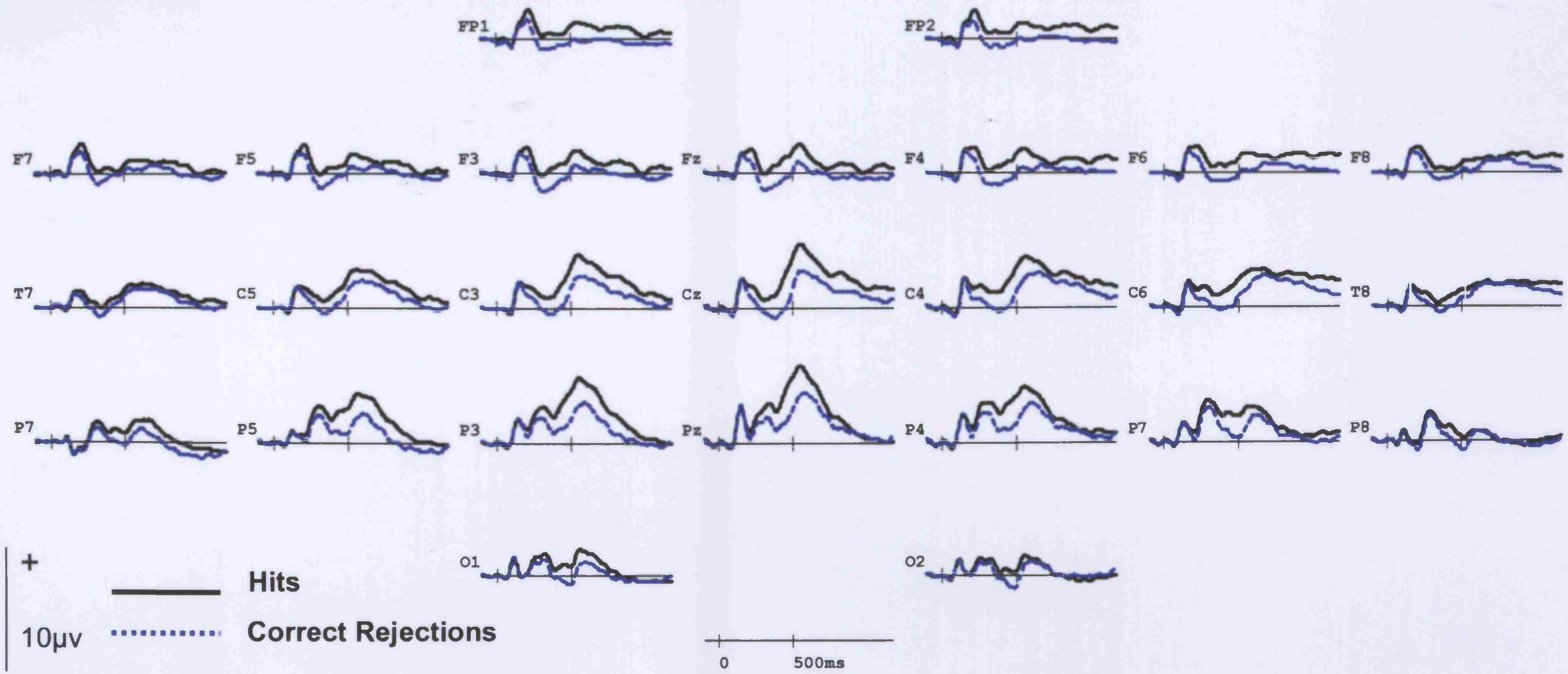


Figure 5.1. Experiment 1 - Grand averaged event-related potentials elicited by hits and correct rejections for **words**. Data are shown for 25 electrodes covering prefrontal (FP1, FP2), frontal (F7, F5, F3, Fz, F4, F6, F8), central (C7, C5, C3, Cz,C4, C6, C8), posterior (P7, P5, P3, Pz, P4, P6, P8) and occipital sites (O1, O2). (n= 24)

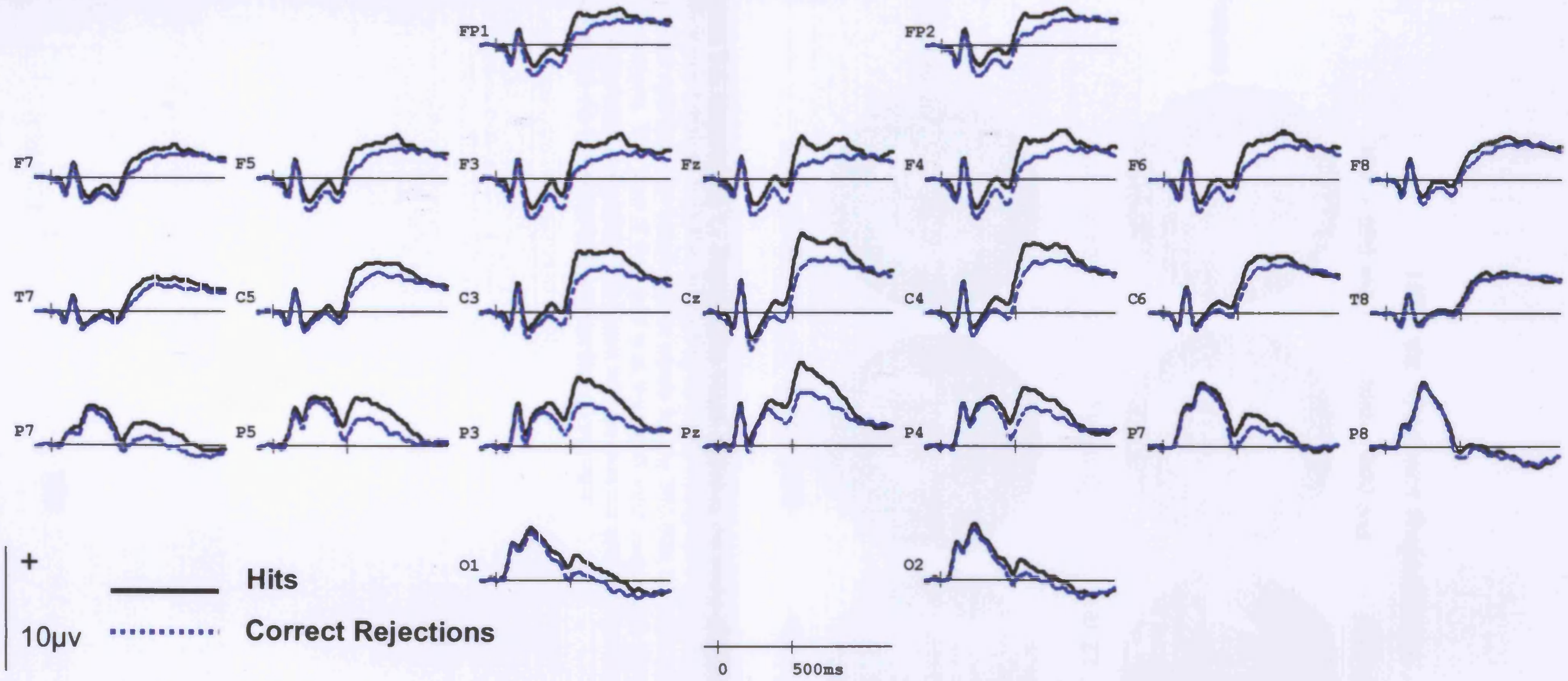


Figure 5.2. Experiment 1 - Grand averaged event-related potentials elicited by hits and correct rejections for **faces**. Data are shown for 25 electrodes covering prefrontal (FP1, FP2), frontal (F7, F5, F3, Fz, F4, F6, F8), central (C7, C5, C3, Cz,C4, C6, C8), posterior (P7, P5, P3, Pz, P4, P6, P8) and occipital sites (O1, O2). (n= 24)

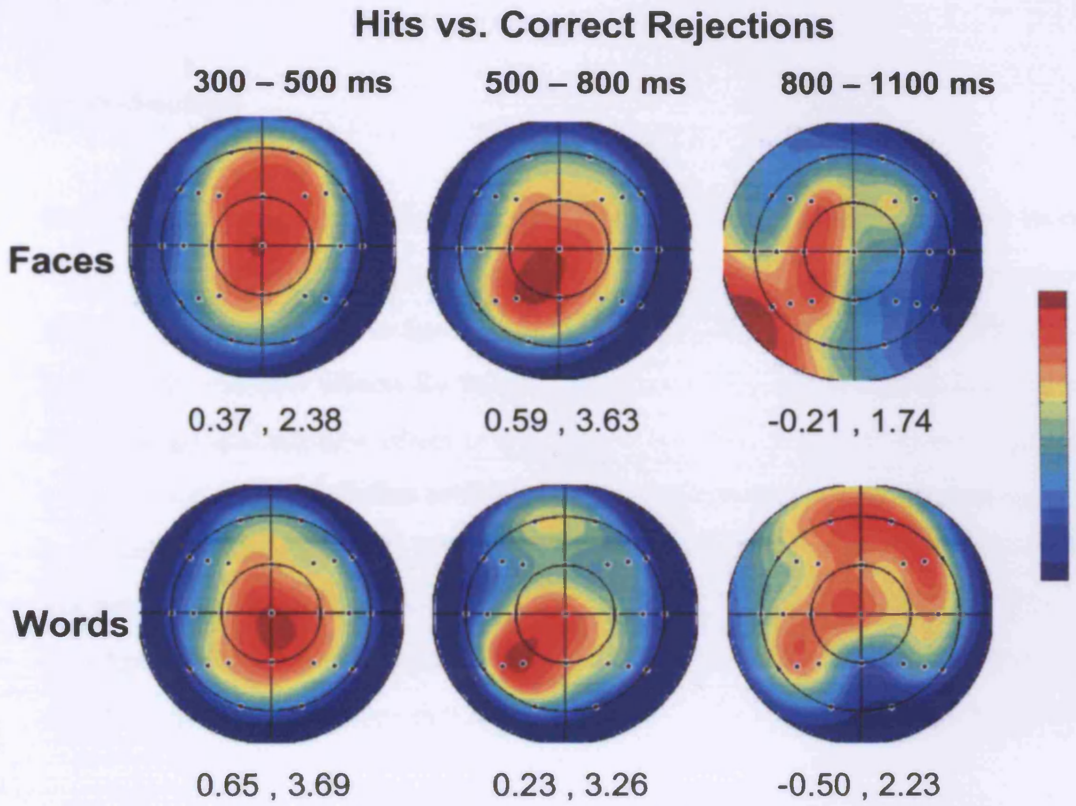


Figure 5.4. Experiment 1 - Topographic maps showing the scalp distributions of the differences between activities evoked by correctly recognized old items and correctly identified new items for faces and for words for the 300-500, 500-800 and 800-1100ms time windows. The front of the head is at the top of each map. Each dot denotes a recording electrode location. The mean voltage maxima and minima for each map can be understood via reference to the colour bar on the right.

Chapter Six: Experiment 2 - Recognition Memory with Confidence Judgments: Part 1

Introduction

Experiment 1 compared directly the neural activity elicited by old and new faces and words that attracted correct judgments in a recognition memory task. It revealed ERP old/new effects common to faces and words: there was no evidence for differences between the old/new effects for faces and words in the 300-500ms epoch, and a common parietal old/new effect in the 500-800ms epoch. Based on previous research, a frontal positive modulation in the 300-500ms epoch has been identified as a neural index of familiarity (Curran 1999; Curran 2000), whereas a left-parietal modulation has been identified as an index of recollection (Allan, Wilding, & Rugg, 1998; Rugg & Allan, 2000). The findings in Experiment 1 support the view that ERPs index common retrieval processes that support recognition memory for faces and words.

In addition, there were reliable differences between the ERP old/new effects for faces and words. These also occurred in the 500-800ms time window, where the old/new effects extended to anterior scalp sites for faces to a greater extent than for words. It was proposed that this frontal modulation is likely to index the online recovery of material-specific information that is associated with faces. What may be a comparable face old/new effect has been observed across other studies using facial stimuli (Curran & Hancock, 2007; Mackenzie & Donaldson, 2007), but in none of these studies, including Experiment 1, has it been possible to make strong claims about the precise functional significance of the anterior old/new effect that was present for faces and not for words.

While Experiment 1 provided evidence that there are at least three ERP old/new effects elicited by faces, the findings are only suggestive, and in addition, no direct measures of the kinds of memory processes that support correct judgments were made. The use of an old/new decision requirement only means that it is not possible to determine what contributions, if any, the processes of recollection and familiarity made to memory judgments for faces (and of course for words). The "associative" approach used in previous published studies where faces comprised the test stimuli has yielded inconsistent results (see Chapter 2 for review), and in light of this a different approach is adopted here: one which has been influential in determining the functional significance of ERP old/new effects when words are the test stimuli (Woodruff et al., 2006; Curran, 2004, Azimian-Fardiani & Wilding, 2004).

One way in which this can be accomplished is by requiring confidence judgments as well as recognition memory decisions (see Chapters 1 & 2). According to some accounts (Yonelinas, Otten, Shaw, Rugg, 2005; Woodruff, Hayama, & Rugg, 2006), recollection is viewed as a high threshold process, and therefore recollection will lead, almost entirely, to high confidence old judgments. Judgments made on the basis of familiarity, however, can be associated with a range of confidence levels, because familiarity is assumed to be underpinned by a graded strength signal. For responses given on the basis of familiarity, high confidence old judgments will be associated with a higher level of familiarity strength than will low confidence old judgments. For new responses, by contrast, low confidence new responses will associated with a higher level of familiarity than will high confidence new responses. This rationale is based on the assumption that increases in strength lead to an increase in the likelihood of an old judgment, and low levels of familiarity are the principal source of information that supports new judgments.

The central assumption here is that familiarity strength co-varies with recognition confidence for old and new items systematically, while recollection approximates a step function, with the majority of recollection-based responses attracting high confidence judgments. The present study was designed to investigate the ERP old/new effects that are elicited by faces and to link them to the processes of recollection and familiarity by determining how the effects vary with response confidence. According to a dual-process high-threshold account, ERP old/new effects that are present only for high confidence old responses can be linked to recollection, while effects that vary in a graded manner according to confidence can be linked to familiarity.

In this experiment, participants saw faces in an initial study phase. At test, participants were asked to rate their confidence in old/new recognition memory judgments on a 4-

point scale ranging from 'high confidence old' to 'high confidence new'. This procedure is different from that employed in previous ERP studies in which faces were the test stimuli (Yovel & Paller, 2004; McKenzie & Donaldson, 2007; Curran & Hancock, 2007) where participants were asked to report whether they could remember specific details (such as occupation), or whether recognition memory for a face was accompanied by memory for details. The latter condition was assumed to reflect responses based upon familiarity, but rests on the assumption that all kinds of contextual detail were regarded as being ones that would merit report. In the approach taken here, graded changes in ERP effects with confidence, particularly for new test items, would arguably provide a stronger form of evidence that ERPs index familiarity when faces are the test stimuli.

These observations are particularly pertinent because of evidence that recollection is graded to some extent (Rotello et al., 2005; Yonelinas, 2007; Mickes, Wais, & Wixted, 2009). As a result, graded ERP differences between high and low confidence old responses could be a reflection of graded recollection, rather than familiarity. This observation emphasizes that, to ensure a clear separation between the two processes, it is critical to examine the ERPs elicited by high and low confidence new responses. The neural indices of recollection should be indistinguishable for high and low confidence new responses because no recollection should occur for these judgments. On the other hand, the level of familiarity should be graded and should differentiate between the two classes of new items (greater positivity for low confidence hits relative to high confidence hits). Hence examination of the ERPs elicited by new items and separated according to confidence is critical for functional interpretations of ERP old/new effects in terms of either recollection or familiarity. This separation was not possible in the studies described by Yovel & Paller, 2004) and by MacKenzie & Donaldson (2007).

In addition, the response options in this experiment were different from those in a previous relevant ERP study using verbal materials (Woodruff et al., 2006). In that study, in addition to the 4-point recognition confidence options, a separate "Remember" response was included. The possible advantage of this procedure is that a contrast between items given recollection responses, and those given high confidence old responses, may enable a comparison between recollection and familiarity-based responding in which levels of confidence are matched (see also Yonelinas et al., 2005). The disadvantage of this method is that the signal:noise for individual response categories is reduced because of the use of five response options, rather than the four participants had in the experiments described here.

Methods

Participants

Twenty-four participants took part in the experiment. Data from 8 participants were discarded prior to analysis. Of these 8 participants, 1 failed to follow the instructions provided. The remaining 7 did not contribute sufficient trials (>16) to the critical response categories following artefact rejection. The mean age of the remaining sixteen participants was 21.5 (ages 18-23), 15 of whom were female.

Stimuli

The stimulus set comprised 400 front-view black and white faces. The stimulus set was used to create 10 study-test blocks, each containing 40 items. Within each block, items were separated such that there were 16 critical study items, 8 distracters presented at study only, and 32 test items, comprising an equal number of old (studied) and new (unstudied) items. The distracters are used to form part of the encoding manipulation and they are not re-presented at test. The 16 study items and all test items were presented in the centre of the screen. Distracters were presented on the left or right of fixation (4 on each side in each study phase). The numbers of complete lists and the counterbalancing procedure is provided in the General Methods Chapter, page 80.

Procedure

The sequence of events occurring in the study phase was identical to Experiment 1. A test phase immediately followed each study phase. Each test trial began with an asterisk which was presented for 1000ms and followed by a blank screen for 100ms.

Test items were presented for 300ms and followed by a black screen. Participants had to indicate the old/new status of the test item by pressing one of four keys with the index and middle fingers of both hands. One hand was designated for old responses, the other for new responses. High confidence responses were always made on the outer response keys with the middle fingers, low confidence responses with the inner response keys with the index fingers. The hands used for old and for new responses were balanced across participants. The next test trial began 1500ms after a response was given. EEG was recorded with recording parameter set 1 (see General Methods Chapter, page 82).

Results

Behavioral Data

Table 6.1. Proportions of old and new items assigned to each response option. Standard deviations are in brackets.

	High Confidence Old	Low Confidence Old	Low Confidence New	High Confidence New
Old	0.45 (0.12)	0.25 (0.08)	0.18 (0.08)	0.12 (0.08)
New	0.05 (0.04)	0.19 (0.08)	0.34 (0.14)	0.41 (0.19)

Table 6.1 shows the mean probabilities of high and low confidence old and new responses separated for old and new items. Standard deviations are in brackets. The table shows there are larger proportions of items associated with correct rather than with incorrect old/new judgments. Old/new discrimination collapsed across confidence was computed using the [p(hit) – p(false alarm)] measure. Discrimination (mean = 0.46) was reliably above chance ($t(15)=15.29$, $p<0.01$). The response data for the four response categories were subjected to a repeated measure ANOVA with factors of response category (high confidence old, low confidence old, low confidence new, high confidence new), and item status (old, new). The analysis revealed a reliable interaction between these two factors ($F(2.59,38.9)=78.78$, $p<0.01$). This

interaction results from the fact that the values in Table 6.1 decrease for old items across the high confidence old through to high confidence new response options, while the reverse is true for new items. Figure 6.1 shows the old-new ROC plotted from the 4-point confidence scale using the Yonelinas Microsoft Excel solver. The dual-process model estimates from the solver were as follows: recollection *R*o = 0.33, and familiarity d' = 0.79 (for a formal descriptions of how these estimates are derived, see Yonelinas, 1999).

Figure 6.1. The ROC plots cumulative hit and false alarm pairs on the 4-point confidence rating. The left-post point represents items that received high confidence old responses only.

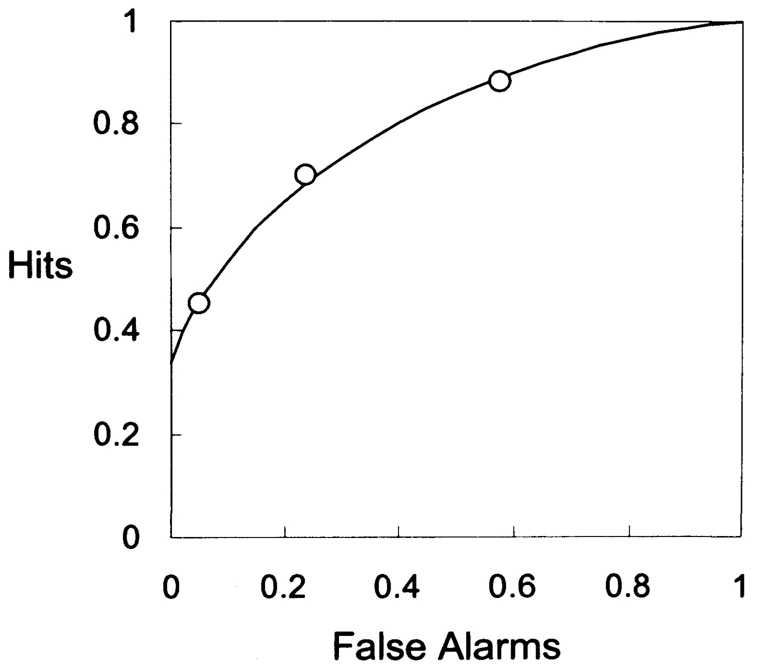


Table 6.2 shows the mean response times (RTs) for old and new items assigned to the four response options. Standard deviations are in brackets. The table shows that faster response times were observed for high relative to low confidence responses, regardless of item status. A repeated measures ANOVA with factors of item status and response category revealed a main effect of category ($F(1.57,23.60)=11.95$, $p<0.01$), although there was also an interaction between this factor and item status ($F(2.06,30.89)=6.02$, $p<0.01$). Follow up analyses revealed that, when high confidence old responses were made, they were faster for old than for new items ($t(15)=3.06$, $p<0.01$). This was not the case for all other classes of response.

Table 6.2. The reaction times (RTs) for old and new items assigned to each response options. Standard deviations are in brackets.

	High Confidence Old	Low Confidence Old	Low Confidence New	High Confidence New
Old	1013 (190)	1384 (341)	1377 (326)	1281 (282)
New	1269 (311)	1316 (259)	1397 (359)	1205 (209)

Electrophysiological Data

ERP Analyses

The principal analyses focused on old and new items attracting correct (old or new) responses, and separated according to confidence (high/low). The initial analyses were conducted for the following latency intervals: 300-500, 500-700, 700-900, and 900-1100ms. These latency ranges have been used in previous memory retrieval studies where faces were the test stimuli and capture the key differences in the experiment reported here (Yovel & Paller, 2004; Curran & Hancock, 2007).

In addition to the factors of response category (four levels), each initial analysis per epoch included the following location factors: anterior/posterior dimension (two), hemisphere (two) and site (four). Reliable effects involving the factor of response category were followed up by all possible paired contrasts across response categories.

Mean trial numbers contributing to the ERPs for high and low confidence hits: 38(range = 18 to 70) and 32 (16 to 78); for high and low confidence CRs: 23 (16 to 47) and 30 (16 to 65). The outcomes of the initial analyses were also used to identify the locations in each epoch where old/new effects were largest. These locations were then submitted to focused analyses, to determine with a good degree of sensitivity whether ERPs elicited by faces in memory tasks index recollection and/or familiarity. These analyses are somewhat exploratory, but are justified given the disparate findings in previous published studies in which faces were the test stimuli in memory tasks (for a detailed review, see pages 59-65 in Chapter 2).

Furthermore, in order to facilitate cross comparisons with the existing literature, two sets of planned analyses from pre-selected electrodes were also conducted. For the old/new effect that has been associated with familiarity in previous studies (the mid-frontal ERP old/new effect), analyses were conducted at three mid-frontal electrodes (F3, Fz, F4) in the 300-500ms epoch. For the effect linked to recollection (the left-parietal ERP old/new effect), analyses were conducted on data from left-parietal electrodes (P3, P5, P7) in the 500-700 and 700-900ms epochs. These electrodes and time windows have been employed in previous studies using primarily verbal materials at test, and links between these effects and the processes of recollection and familiarity have been made (Rugg, Mark, & Walla et al., 1998; Curran, 1999; 2000; see Curran & Hancock, 2007 for evidence employed facial stimuli). All of the outcomes of the ERP analyses are presented in Tables 6.3 – 6.5, and are described below.

Figure 6.2 shows the grand averages associated with hits and CRs, separated for the two confidence levels (see also Figure 6.4 below). Visual inspection of the waveforms shows that, for high confidence responses, the divergences between the waveforms emerge from approximately 200ms post-stimulus and are sustained until the end of the recording epoch, with the ERPs for hits being more positive-going than those for

CRs. The differences are largest at frontal electrode sites across all epochs. By contrast, the ERPs for low confidence hits diverge minimally from the ERPs for low confidence CRs. The scalp maps associated with hits and CRs separated for the two confidence levels is shown in Figure 6.3.

Global contrasts

The initial analyses of the data for each of the 4 categories revealed an interaction between category, location and site in all epochs (see Table 6.3). These outcomes license the subsequent paired contrasts that are described below.

Critical paired contrasts

All of the paired contrasts including high confidence hits revealed reliable interactions between category, location, and site in all epochs, except for the contrast with low confidence CRs in the 900-1100ms epoch only. These interactions reflect the fact that ERPs elicited by high confidence hits are more positive-going than those elicited by low confidence hits, low confidence CRs (except in the 900-1100ms epoch), and high confidence CRs. In each case, these differences are largest at pre-frontal electrodes (see Figure 6.3).

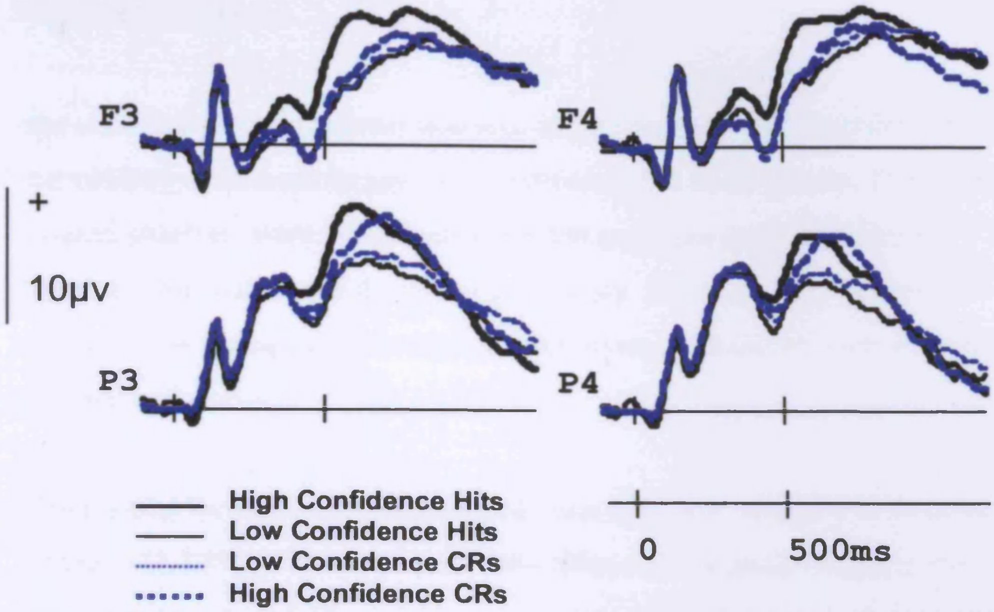


Figure 6.4. Grand averaged event-related potentials elicited by hits and correct rejections that attracted high or low confidence judgments. Data are shown for 4 superior electrodes (F3, F4, P3, P4). (n=16)

There were no reliable effects in the contrasts between the two low confidence response categories for all epochs. For the contrast between the two correct rejection categories, the main effect of category in the 500-700ms epoch comes about because the ERPs elicited by high confidence CRs are more positive-going than those elicited by low confidence CRs. The interaction between category and site approached significance, because this difference is largest at sites closest to the midline. In the 700-900ms epoch, the interaction between category and hemisphere indicates that the greater positivity for high rather than low confidence CRs is largest over the left hemisphere.

The contrast between low confidence hits and high confidence CRs revealed reliable interactions between category and site across the 500-900ms epochs, and the reason for the interactions is because the waveforms for high confidence CRs are more positive-going than the waveforms for low confidence hits. These differences are largest at superior sites.

Focused analyses: 1

The outcomes from the global analyses and paired contrasts described above indicate that old/new effects are largest over prefrontal sites in all epochs. Therefore the focused analyses were conducted at the left and right prefrontal sites (FP1 and FP2) separately for each epoch described previously. In each epoch, the analyses were first completed including all four response categories, with paired contrasts conducted as necessary after this.

These initial focused analyses revealed main effects of category in three epochs (300-500ms: $F(2.2,33.2)=11.83$, $p<0.01$; 500-700ms: $F(2.4,36.0)=11.27$, $p<0.01$; 700-900ms: $F(2.3,34.1)=5.75$, $p<0.01$), and an interaction between category and site in the 900-1100ms epoch ($F(2.6,39.3)=3.80$, $p<0.05$). Follow up analyses for all epochs (see Table 6.4) indicated that the ERPs elicited by high and low confidence CRs, as well as low confidence hits, were all reliably more negative-going than the ERPs elicited by high confidence hits. As indicated by the interaction between category and site, these differences are largest at FP2 for the contrasts between high and low confidence hits across the 700-1100ms epochs, as well as the contrast between high confidence hits and CRs in the 900-1100ms epoch. The only paired contrasts to reveal reliable effects when high confidence hits were not included were between low confidence hits and low confidence CRs. This paired contrast revealed reliable interactions between category and site across the 500-900ms epoch, reflecting a greater positivity for low confidence hits relative to CRs that is larger at FP1 than at FP2. All of these outcomes are shown in Table 6.4.

Focused Analyses: 2

The focused analyses including three mid-frontal electrodes (F3, Fz, F4) in the 300-500ms epoch revealed a similar pattern of results: a main effect of category was obtained in the initial analysis ($F(2.2,33.2)=7.22$, $p>0.05$), and follow-up analyses revealed reliable differences only in the paired contrasts including high confidence hits: low confidence hits ($F(1,15)=30.41$, $p<0.01$); low confidence CRs ($F(1,15)=25.41$, $p<0.01$); high confidence CRs ($F(1,15)=13.79$, $p<0.01$).

The focused analyses including parietal sites (P7, P5, P3) were conducted for two epochs: 500-700 and 700-900ms. Main effects of category were obtained in the initial analyses for both epochs (500-700ms: ($F(2.2,33.2)=9.69$, $p<0.01$); 700-900ms: ($F(2.5, 37.3)=6.12$, $p<0.01$), and an interaction between category and site in the earlier epoch only ($F(2.8,41.3)=5.80$, $p<0.01$).

Follow-up paired contrasts (see Table 6.5) revealed that, in the 500-700ms epoch, the ERPs elicited by high confidence hits were reliably more positive-going than the ERPs elicited by low confidence hits, as well as high and low confidence CRs. The contrast between the two CRs revealed a greater positivity for high relative to low confidence CRs. In each case, these differences were largest at sites closest to the midline (P3) as indicated by the interaction between category and site.

The contrast between high confidence hits and high confidence CRs in the 700-900ms epoch obtained no reliable differences between the two response categories. Similar results were obtained for the high and low confidence hits contrast, except that the interaction term was only marginally significant (also in Table 6.5). An interaction between category and site was obtained for the contrast between high confidence hits and low confidence CRs, indicating the greater positivity for high confidence hits that is largest at P3. There was also a greater relative positivity for high relative to low confidence CRs. Finally, across the two epochs, reliable main effects were obtained for the contrast between low confidence hits and high confidence CRs, with these effects indicating a greater relative positivity for high confidence CRs.

Topographic analyses:

Keeping to the analysis approach outlined in the General Methods chapter, an across epoch analysis was conducted in order to identify any changes in the scalp distributions of the reliable old/new effects. The paucity of reliable old/new effects for low confidence judgments meant that analyses were restricted to high confidence old/new effects only. The analyses were performed on the difference waveforms obtained by the subtraction of high confidence CRs from high confidence hits for all epochs. The rescaled data were analyzed with factors of epoch (300-500, 500-700, 700-900, 900-1100ms) and all the above mentioned factors. The reliable interaction between epoch and site ($F(3.3,48.8)=4.82$, $p<0.01$) provided evidence that the scalp distribution of the high confidence old/new effects changes over time.

To investigate this outcome further, contrasts of temporally successive pairs of epochs were conducted from 300ms onwards. The location factors were identical to those described in the preceding contrasts. There was a significant interaction between epoch and location in the 300-500 vs. 500-700ms contrast ($F(1,15)=4.50$, $p<0.05$). Figure 6.3 shows that the effect in the 300-500ms epoch has a more focal prefrontal distribution than the effect in the 500-700ms epoch. In the second latency contrast, the analyses revealed an interaction between epoch and site ($F(1.2,18.3)=6.87$, $p<0.01$), and the reason for the interaction is because the effect in the 700-900ms epoch has a more diffuse distribution in comparison to the superior maximum of the distribution in the earlier (500-700ms) epoch. These were the only two contrasts in which reliable interactions involving epoch and site were obtained.

Discussion

Behavioral data

By collapsing high and low confidence judgments, the discrimination measure indicated that participants were able to discriminate old from new items at a reliable level. More importantly, the judgments were more accurate when participants made high confidence judgments to both old and new items. Response probabilities decreased from correct and confident through incorrect and confident judgments. The asymmetrical ROC shown in Figure 6.1 is consistent with those observed in most recognition memory studies in which confidence judgments are required (Ratcliff et al., 1992; Yonelinas, 2001; Wixted & Stretch, 2004). According to what is probably the most influential dual-process account of this kind of ROC, the asymmetry comes about because a threshold recollection process increased the proportion of high confidence hits with minimal increases to the proportion of false alarms (Yonelinas, 1999; 2001; 2002).

The inverted U-shape function of the RT data shows that participants were quicker for high relative to low confidence judgments. This pattern of behavioral results is consistent with previous studies in which confidence judgments were acquired; low confidence responses are typically associated with slower RTs (Guest & Wan Laar, 2002; Yonelinas et al., 2005; Woodruff et al., 2006). According to some accounts, items that are closest to a response criterion are likely to elicit either an additional search process that requires longer processing time, or alternatively greater scrutiny before a decision is reached; either of these accounts is consistent with the findings that low confidence responses had longer RTs than did high confidence responses (Juola, Fischler, Wood, & Atkinson, 1971). In addition, RTs for high confidence old responses to old items were markedly faster than those for new items. One explanation for this is that processing fluency benefits from prior exposure, and fluency also contributes to the basis for memory judgments (Mandler, 1980, Jacoby & Dallas, 1981; Jacoby & Kelley, 1992). Regardless of whether this account is correct, however, the overall pattern of behavioral data indicates that the confidence measures employed in this experiment were successful in separating judgments associated with different levels of response confidence.

ERP data

300-500ms

The paired contrasts indicated a greater relative positivity for high confidence hits in comparison to the other three response categories. These categories did not differ from each other reliably. Thus the global analyses revealed no evidence for an effect that behaves as an index of familiarity.

An additional part of the analysis strategy in this experiment comprised focused analyses at the sites where the experiment effects were largest (focused analysis 1). The rationale for this approach was that, given the inconsistent findings in the literature, a directed approach aimed at maximizing the likelihood of aligning ERP effects for faces with either recollection or familiarity was a reasonable one. The focal analysis at (1) the prefrontal electrodes, and (2) the three mid-frontal electrodes, revealed the same patterns of results: a greater relative positivity for high confidence correct old judgments only. None of these differences is consistent with a familiarity interpretation.

The fact that reliable old/new effects were obtained for high confidence judgments only, and that the ERPs elicited by the two classes of CRs did not differ from each other, is consistent with a functional interpretation of the effects in this epoch in terms of recollection, and more specifically of a recollection effect which acts like a threshold process (Rotello et al., 2005; Yonelinas & Park, 2007).

It is also interesting to note that the distribution of the face old/new effects in this epoch did not resemble those obtained in Experiment 1, in which the face effects were broadly distributed. The reason for these differences is unclear, but probably the strongest possibility is that the confidence judgment requirements elicited functionally distinct cognitive processes that are manifested in the scalp recorded ERPs. This line of argument is consistent with findings that frontally distributed old/new effects are typically larger in tasks requiring explicit source judgments than in tasks where only recognition memory judgments are required (Johnson, Kounios, & Nolde, 1996; Senkfor & Van Petten, 1998).

The analysis strategy employed also facilitated comparisons with the existing literature in which verbal materials were the test stimuli; a mid-frontal old/new effect in this time window has been identified as a neural index of familiarity (e.g. Rugg, Mark, & Walla et al., 1998; Curran, 1999, 2000). Accordingly, if this effect is a generic (or at least material independent) index of familiarity, it should be sensitive to the level of confidence associated with test responses to old and new faces (Woodruff et al., 2006). However, the focal analysis at the mid-frontal electrodes revealed no evidence for an index of familiarity; it was simply more positive-going for high confidence judgments to old faces than for all other response categories. This finding suggests, at a minimum, that the effect observed over these mid-frontal sites does not index familiarity for faces. Other implications and proposals are discussed in later chapters.

500-700ms and 700-900ms

A broadly similar pattern of results was obtained in these epochs as in the previous epoch. In the global analysis, the high confidence old/new effects observed in these epochs were largest at prefrontal electrodes, and null results were obtained in the contrasts between low confidence responses, indicating an insensitivity to familiarity strength. In parallel with this, broadly similar results were obtained in focused analysis 1 at the prefrontal electrodes for the two epochs. In addition, the greater positivity for high relative to low confidence hits is also largest at FP2 in the 700-900ms epoch. The main divergence between the results here and in the 300-500ms epoch is for the low confidence ERP old/new effects.

There was a reliable low confidence old/new effect when the analysis was restricted to prefrontal electrodes in the 500-700ms epoch (focused analysis 1). This effect was smaller than the effect for high confidence hits. This pattern is partially consistent with the criterion for an ERP index of familiarity. This interpretation is challenged vigorously, however, by the null results in the contrast between the high relative to low confidence CRs in this epoch (also see focused analysis 1). A correlate of familiarity should differentiate between the two classes of CRs in the main paired contrast, because low confidence CRs are thought to be associated with a higher level of familiarity strength relative to high confidence CRs (Woodruff et al., 2006). Furthermore, the mean amplitudes for the two CRs were numerically contrary to what would be required for an index of familiarity (low vs. high: 500-700ms: 2.91 vs. 3.08; 700-900ms: 5.01 vs. 5.12). In light of these findings, the presence of old/new effects with the prefrontal maximum in these epochs is consistent with the view that the ERPs index a graded recollection process (Rotello, et al., 2005; Yonelinas & Park, 2007).

An ERP index of generic recollection - the left-parietal ERP old/new effect - is typically reported in these time windows when the stimuli are verbal material (Rugg, Mark, & Walla et al., 1998; Curran, 2000). In addition, in Experiment 1 there was evidence for left-lateralized old/new effects for faces (see also Curran & Hancock, 2007). When the analyses were restricted to three left-parietal electrodes (focused analysis 2), the ERPs associated with the high confidence hits had the greatest relative positivity. Thus, while the global analysis indicates the magnitude of the high confidence old/new effect is largest over the prefrontal scalp (see Figure 6.3 in the 500-700ms epoch), the data is broadly consistent with Experiment 1 in that there is at least one ERP old/new effect linked to recollection that extends over frontal and parietal scalp. Another possibility is that there are two recollection-related effects for faces in the 500-700ms time window, one with a parietal focus, the other with a frontal focus. This possibility will be returned to in the discussion below after the consideration of contrasts involving the two classes of CRs.

A departure from the findings in the previous (300-500ms) epoch is the results in two initial contrasts. The first is the contrast involving the two classes of correct rejections, which revealed a greater positivity for high relative to low confidence CR that is largest over superior electrodes. The high versus low confidence CR difference became largest over the left hemisphere in the 700-900ms epoch. The second contrast is between low confidence hits and high confidence CRs. Across the two time windows; there was a greater positivity for new relative to old responses that is largest at superior sites. Common to the two contrasts is that the differences were reliable at parietal sites in both epochs (focused analysis 2).

Overall, the pattern of data obtained over the anterior scalp fits with the criteria for an index of recollection: the ERPs for high confidence hits showed the greatest relative positivity in comparison to the other response types, and the two classes of CRs diverged minimally from each other. In contrast, the functional interpretation of the effects over posterior scalp is less straightforward. Although it is true that the old/new effect was reliable for high confidence judgments only (focused analyses 2), the ERPs elicited by high confidence CRs are also reliably more positivity-going than those for low confidence CRs, which challenges the view that these parietal modulations are a pure index of recollection.

An ERP modulation linked to familiarity should be graded for high confidence old through to high confidence new judgments, so these parietal differences do not behave like an index of familiarity either. The P300 modulation, however, is commonly larger (generally independently of task) for high than for low confidence responses over the parietal scalp, primarily at midline electrodes (Johnson, 1995; Spencer, Vila Abad, &

Donchin, 2000; Curran, 2004; Woodruff et al., 2006). This is the pattern of outcomes obtained in focused analyses 2, where correct high confidence responses were more positive-going than low confidence responses regardless of item status.

In a similar experiment using verbal stimuli, Woodruff and colleagues (2006) contrasted the difference scores obtained by subtracting low from high confidence correct rejections with those obtained for the comparable subtraction for hits. This analysis was performed on rescaled data. They showed that effects for hits were more left-lateralized than the effects for correct rejections over the parietal scalp. They used this finding to argue that the laterality differences reflected the contribution of the left-parietal ERP old/new effect for hits only, and that the differences between correct rejections they observed (greater positivity for high confidence responses) were a manifestation of the P300.

A similar approach was conducted separately for the data for the 500-700 and 700-900ms epochs (unreported in the ERP analysis section above). The difference scores related to hits (subtracting low confidence hits from high confidence hits) and CRs (subtracting low confidence CRs from high confidence CRs) were contrasted along with the factor of category (hits and CRs), and sites from all parietal electrodes (P7, P5, P3, Pz, P4, P6, P8). Only a reliable main effect of category was obtained in the 500-700ms epoch ($F(1,15)=5.69$, $p<0.05$), although the sites at which the differences between these two sets of subtraction scores were largest were P3 and P5.

These data do not, therefore, provide as clean a separation between confidence and memory effects as that reported by Woodruff and colleagues (2006). However, it is probably also premature to claim that no memory related modulation is elicited by highly confidently remembered items over the parietal scalp. High confidence hits were more positive-going than high confidence correct rejections, and the largest difference between these categories at parietal sites was at P3. There is no means within this experiment of determining whether the level of confidence associated with a high confidence judgment to an old or new item is comparable, but in light of the trends described here, perhaps the appropriate claim at this point is that these positive-going parietal effects are some combination of the left-parietal old/new effect and the P300 (see also Herron, Quayle & Rugg, 2003).

900-1100ms

Again, in this epoch the old/new effects were reliable for high confidence judgments only. In contrast to the finding in Experiment 1, in which no reliable old/new effects were obtained for faces after 800ms onward, in the present experiment, the prefrontal old/new effect for high confidence judgments was temporally extended. This effect is likely to reflect retrieval processes that are required to a greater degree in tasks that require more than simple yes/no recognition judgments (Experiment 1). This argument, if correct, suggests this modulation is not related to the on-line recollection of face-related information, because it was absent in Experiment 1. One possible account of this modulation is that it reflects the engagement of post-retrieval processes that are contingent upon recollection (Wilding & Rugg, 1996; Rugg, Otten, & Henson, 2002). The high confidence old/new effect reported in the focused analysis 1 is largest at FP2, and resembles the right frontal old/new effect that is commonly associated with post-retrieval processes (Wilding & Rugg, 1996; Rugg et al., 2000; Cruse & Wilding, 2009).

The across epoch analyses

The across epoch analysis for high confidence judgments provided some support for the view that qualitatively different processes were engaged over time, alongside the fact that the outcomes of the paired analysis showed that the high confidence old/new effects were largest over prefrontal electrodes for all four epochs. The old/new effects had a more focal prefrontal distribution in the 300-500ms epoch relative to the 500-700ms epoch, and this is broadly consistent with the observation that old/new effects extend over posterior scalp in the later of these two epochs more so than in the earlier one (Rugg, Mark, & Walla et al., 1998; Friedman & Johnson, 2000; Curran, 2000). While the old/new effects obtained in these two epochs are readily linked to recollection, the topographic differences indicate that electrophysiologcally and perhaps functionally distant recollection processes were engaged.

Several researchers have proposed that the left-parietal ERP old/new effect is an index of generic recollection processes (Rugg, Mark, & Walla et al., 1998; Rugg & Curran, 2007). One suggestion for the role of the prefrontal maximum effects up to 900ms is that they index the online recovery of face-specific information. The effects may be evident earlier here (in the 300-500ms epoch) than in experiment 1 because the use of confidence judgments may have served as a stronger prompt to recollect face-specific information than the simple old/new recognition judgments required in Experiment 1. How this interpretation links with the preceding observations about effects post-900ms will be returned to later.

Regardless of the accuracy of these suppositions, however, the findings support the claim that at least three qualitatively distinct ERP old/new effects with not entirely overlapping neural generators were engaged when task judgments were likely to be supported by recollection. Refinements of the possible functional roles of these effects will be discussed along with findings from other experiments in subsequent chapters.

Conclusions

High confidence judgments were associated with high memory accuracy and faster RTs relative to low confidence judgments. There was no evidence for any ERP modulation that correlated positively with the level of confidence for old as well as for new items. Thus, the ERP data provide no evidence for a neural index of familiarity when faces are the test stimuli. A corollary to this is that the data also provide no evidence that the mid-frontal old/new effect is a generic index of familiarity. Reliable old/new effects that were largest at prefrontal electrodes were obtained for high confidence judgments only, and these effects can be linked to recollection according to the criteria outlined previously. These data therefore fit to some extent with those of Yovel and Paller (2004), and of Mackenzie and Donaldson (2007), since in neither of those studies was there strong evidence that an index of familiarity was present when faces comprised the test stimuli.

One argument offered by Curran and Hancock (2007) for the findings of Yovel and Paller and Mackenzie and Donaldson is that no evidence for indices of familiarity was obtained in those studies because response accuracy was not particularly high. This argument can be extended to the data reported here, and Experiment 3 represents an attempt to address this concern, by raising response accuracy relative to that obtained in Experiment 2, while keeping all other factors relatively constant.

Table 6.3. F-values and significance values for the initial global and all paired comparisons between the mean amplitudes associated with high confidence hits, low confidence hits, low confidence correct rejection (CR) and high confidence CR response categories over the 300-500, 500-700, 700-900, and 900-1100ms epochs. All terminology and other information as for Table 5.3.

Global Analyses:

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (3, 45)	**7.50, p<0.01**	**17.56, p<0.01 (0.95)**	**6.09, p<0.01 (0.78)**	ns.
RC x AP (3, 45)	**4.15, p<0.05 (0.74)**	**3.96, p<0.05 (0.68)**	**4.22, p<0.05 (0.72)**	**2.70, p<0.01 (0.82)**
RC x ST (9, 135)	ns.	**5.12, p<0.01 (0.43)**	ns.	ns.
RC x AP x ST (9, 135)	**6.62, p<0.01 (0.44)**	**6.27, p<0.01 (0.44)**	**5.09, p<0.01 (0.52)**	**3.46, p<0.01 (0.48)**

All paired contrasts:

High confidence hits vs. High confidence CRs

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 15)	**12.94, p<0.01**	**15.60, p<0.01**	ns.	ns.
RC x AP (1, 15)	**6.90, p<0.05**	**6.93, p<0.05**	**7.48, p<0.05**	**5.529, p<0.05**
RC x HM (1, 15)	ns.	ns.	ns.	3.27, p=0.09
RC x AP x ST (3, 45)	**11.06, p<0.01 (0.63)**	**17.61, p<0.01 (0.66)**	**14.41, p<0.01 (0.66)**	**7.94, p<0.01 (0.72)**

High confidence hits vs. Low confidence hits

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 15)	**24.12, p<0.01**	**43.96, p<0.01**	**18.80, p<0.01**	ns.
RC x AP (1, 15)	**14.57, p<0.01**	**5.20, p<0.05**	ns.	**5.83, p<0.05**
RC x ST (3, 45)	**4.12, p<0.05 (0.70)**	**10.90, p<0.01 (0.60)**	ns.	ns.
RC x AP x ST (3, 45)	**14.56, p<0.01 (0.54)**	**7.20, p<0.01 (0.47)**	**6.65, p<0.01 (0.69)**	**6.65, p<0.01**
RC x HM x ST (3, 45)	ns.	2.90, p=0.06	ns.	ns.

High confidence hits vs. Low confidence CRs

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 15)	**20.22, p<0.01**	**37.90, p<0.01**	**6.28, p<0.05**	ns.
RC x AP (1, 15)	**17.89, p<0.01**	**5.45, p<0.05**	3.87, p=0.07	ns.
RC x ST (3, 45)	**4.48, p<0.05 (0.48)**	**5.82, p<0.01 (0.54)**	ns.	ns.
RC x AP x ST (3, 45)	**15.48, p<0.01 (0.76)**	**17.92, p<0.01 (0.74)**	**13.46, p<0.01 (0.70)**	ns.
RC x AP x HM x ST (3, 45)	2.52, p=0.08 (0.90)	ns.	ns.	ns.

High confidence CRs. vs. Low confidence CRs

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 15)	ns.	**4.71, p<0.05**	ns.	ns.
RC x HM (1, 15)	ns.	ns.	**4.81, p<0.05**	ns.
RC x ST (3, 45)	ns.	2.86, p=0.08 (0.62)	ns.	ns.

Low confidence hits vs. High confidence CRs

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 15)	ns.	**7.84, p<0.05**	**9.26, p<0.01**	ns.
RC x AP (1, 15)	ns.	ns.	4.52, p<0.06	ns.
RC x ST (3, 45)	ns.	**5.26, p<0.05 (0.52)**	**4.62, p<0.05 (0.62)**	ns.
RC x AP x HM x ST (3, 45)	2.78, p<0.08 (0.68)	ns.	ns.	ns.

Table 6.4. F-values and significance values for focused analyses 1 at FP1 and FP2, all paired comparisons between the mean amplitudes associated with high confidence hits, low confidence hits, low confidence correct rejection (CR) and high confidence CR response categories over the 300-500, 500-700, 700-900, and 900-1100ms epochs. All terminology and other information as for Table 5.3.

Focused Analyses 1: All Paired Analyses

		300-500ms	500-700ms	700-900ms	900-1100ms
High confidence hits vs. High confidence CRs	RC (1, 15)	**15.09, p<0.01**	**14.54, p<0.01**	**8.94, p<0.01**	**4.51, p<0.05**
	RC x ST (1, 15)	ns.	ns.	ns.	**9.32, p<0.01**
Low confidence hits vs. Low confidence CRs	RC (1, 15)	ns.	ns.	ns.	ns.
	RC x ST (1, 15)	ns.	**5.05, p<0.05**	**4.58, p<0.05**	ns.
High confidence hits vs. Low confidence Hits	RC (1, 15)	**55.46, p<0.01**	**30.50, p<0.01**	**16.42, p<0.01**	**8.88, p<0.01**
	RC x ST (1, 15)	ns.	ns.	**5.77, p<0.05**	**7.23, p<0.05**
High confidence hits vs. Low confidence CRs	RC (1, 15)	**48.02, p<0.01**	**30.40, p<0.01**	**17.02, p<0.01**	3.85, p=0.07
	RC x ST (1, 15)	ns.	ns.	ns.	ns.
Low confidence hits vs. High confidence CRs	RC (1, 15)	ns.	ns.	ns.	ns.
	RC x ST (1, 15)	ns.	4.48, p<0.06	3.68, p<0.07	ns.

Table 6.5. F-values and significance values for focused analyses 2 at P3, P5, P7, all paired comparisons between the mean amplitudes associated with confidence hits, low confidence hits, low confidence correct rejection (CR) and high confidence CR response categories over the 500-700, 700-900ms epochs. All terminology and other information as for Table 5.3.

Focused Analyses 2: All Paired Analyses – Parietal Sites

		500-700ms	700-900ms
High confidence hits vs. High confidence CRs	RC (1, 15)	3.81, p=0.07	ns.
	RC x ST (1, 15)	**8.75, p<0.01**	ns.
High confidence hits vs. Low confidence Hits	RC (1, 15)	**33.84, p<0.01**	**18.38, p<0.01**
	RC x ST (1, 15)	**6.38, p<0.01**	2.93, p=0.08
High confidence hits vs. Low confidence CRs	RC (1, 15)	**16.76, p<0.01**	ns.
	RC x ST (1, 15)	**23.78, p<0.01**	**3.82, p<0.05**
Low confidence hits vs. High confidence CRs	RC (1, 15)	**6.31, p<0.05**	**14.10, p<0.01**
	RC x ST (1, 15)	ns.	ns.
High confidence CRs vs. Low confidence CRs	RC (1, 15)	**7.88, p<0.01**	**6.95, p<0.05**
	RC x ST (1, 15)	**6.90, p<0.01**	ns.

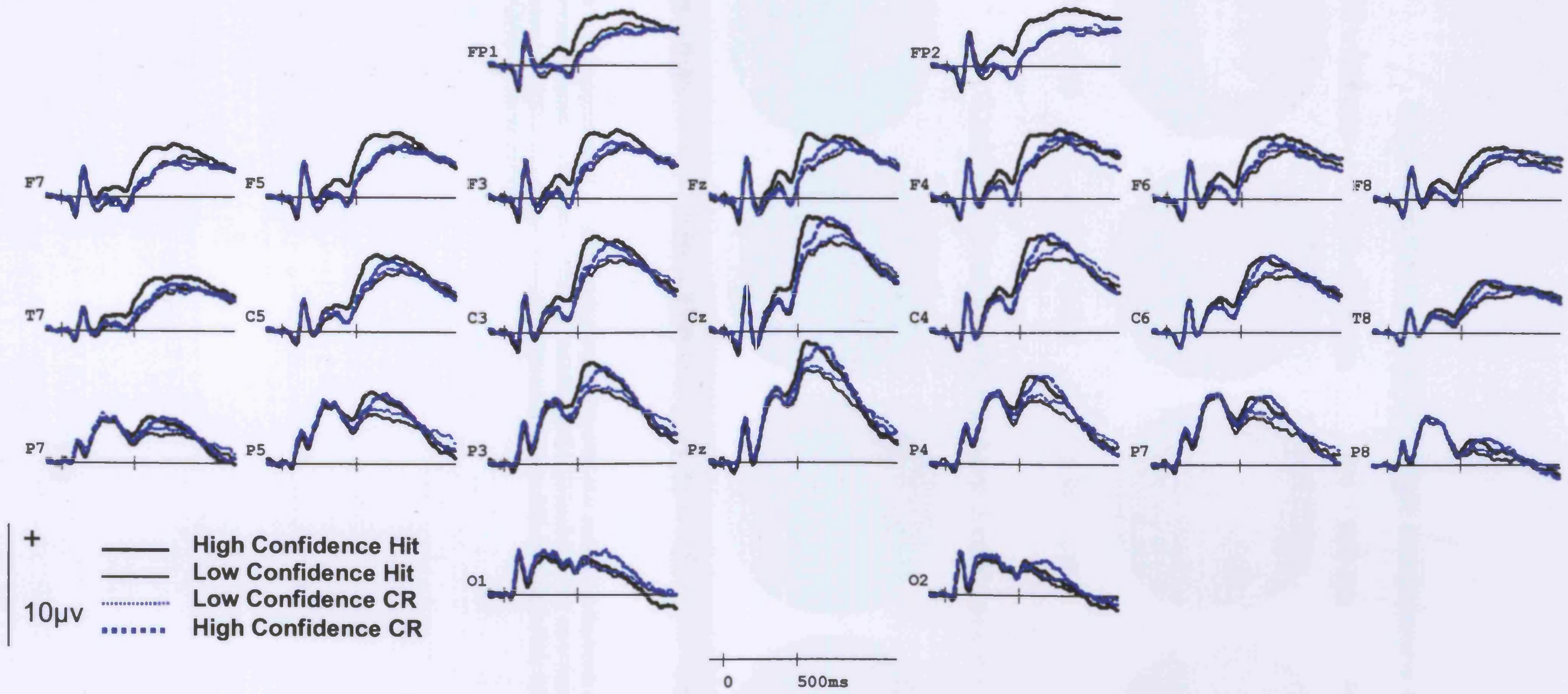


Figure 6.2. Experiment 2 - Grand averaged event-related potentials elicited by hits and correct rejections that attracted high or low confidence judgments. Data are shown for 25 electrodes covering prefrontal (FP1, FP2), frontal (F7, F5, F3, Fz, F4, F6, F8), central (C7, C5, C3, Cz,C4, C6, C8), posterior (P7, P5, P3, Pz, P4, P6, P8) and occipital sites (O1, O2). (n= 16)

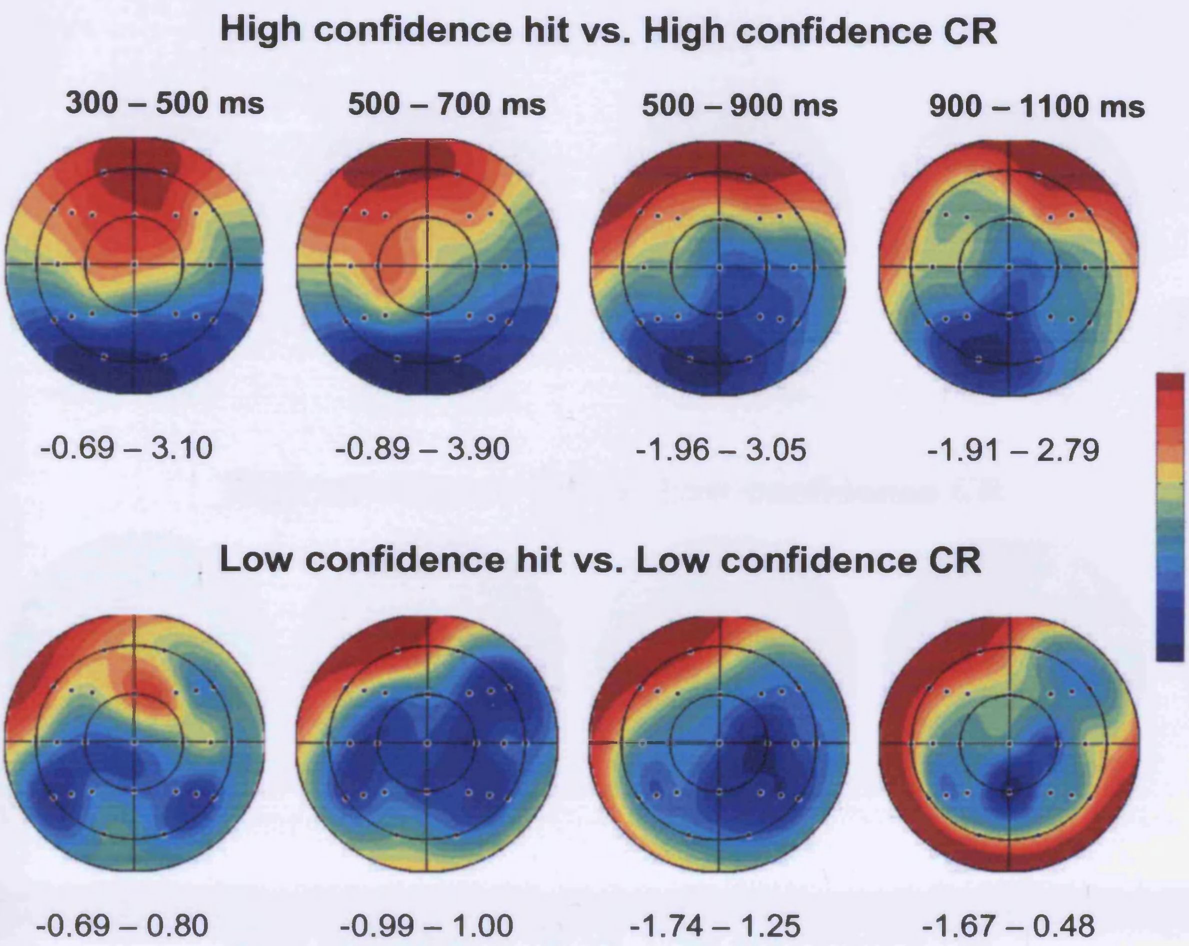


Figure 6.3. Experiment 2 - Topographic maps showing the scalp distributions of the differences between activities evoked by correctly recognized old and new items separated for high and low confidence judgments for the 300-500, 500-700, 700-900 and 900-1100ms time windows.

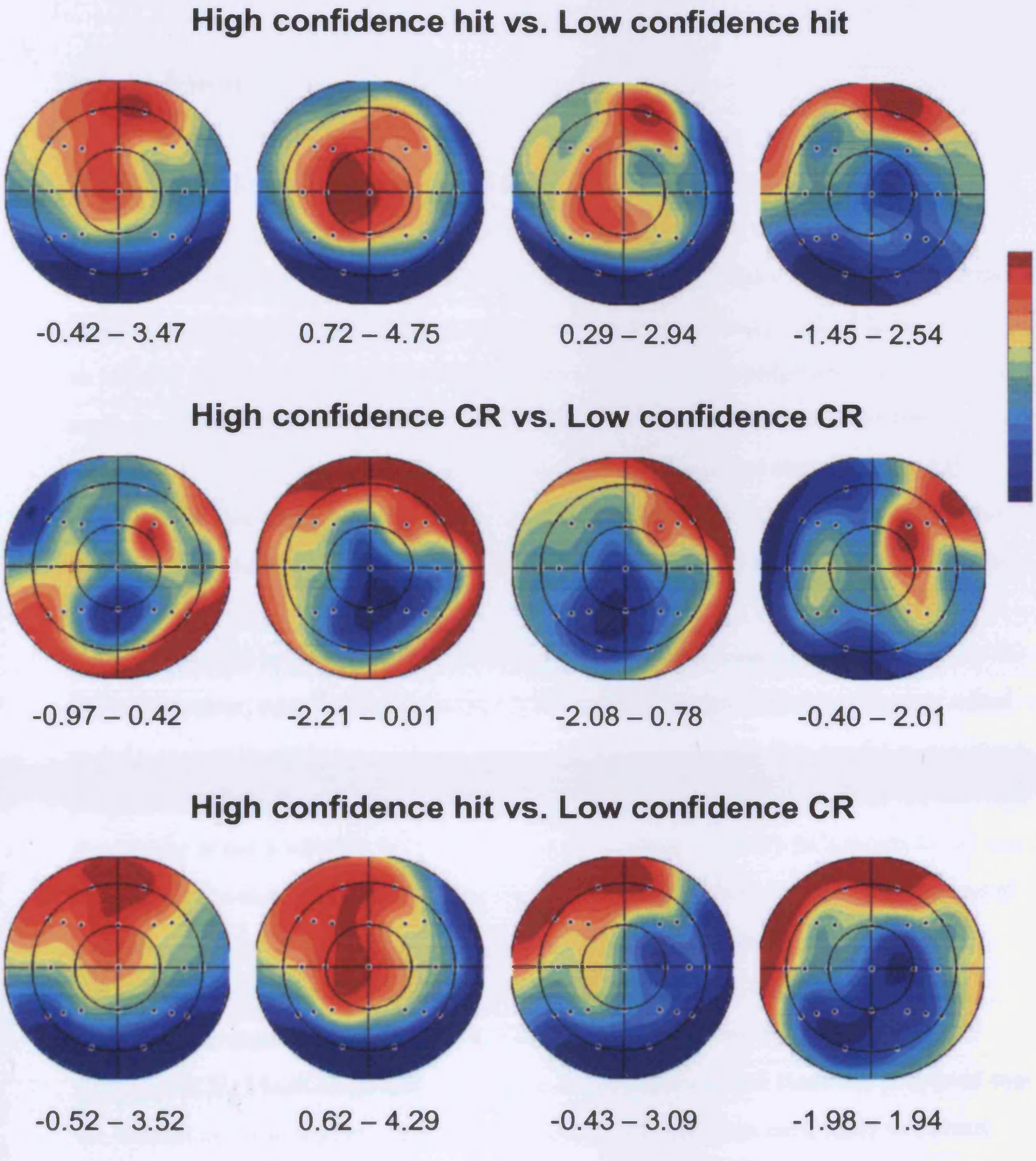


Figure 6.3 (continues). Experiment 2 - Topographic maps showing the scalp distributions of the differences between 3 different contrasts of interests for the 300-500, 500-700, 700-900 and 900-1100ms time windows.

Chapter Seven: Experiment 3 - Recognition Memory with Confidence Judgments: Part 2

Introduction

In Experiment 2, ERPs elicited by old and new faces that attracted high or low confidence ratings were acquired to determine the functional significances of ERP modulations that varied with confidence. The global and focused analyses suggested that the (primarily frontal) old/new effects obtained are strongly linked to recollection, as reliable old/new effects were evident for high confidence judgments only, and there were no reliable differences when contrasting high and low confidence correct rejections. The findings in Experiment 2 provided no evidence that there are ERP modulations that varied with recognition confidence in a more or less linear fashion, thus no evidence for any neural indices of familiarity when faces are the test stimuli.

It is not possible to discount the possibility that ERPs are insensitive to familiarity for faces. However, one other consideration for the null results is that participants relied mainly on recollection for their memory judgments, and those low confidence correct judgments reflected weak recollection. This dependence could stem from the fact that familiarity is not a reliable process for face recognition memory judgments in the task because of the complexity of the stimuli. Common to all faces is a similar configural structure, thereby in principle making all faces share a similar level of baseline familiarity strength. A similar argument has been made by Curran and Hancock (2007), when considering the reasons for the results reported by Yovel and Paller (2004), and by MacKenzie and Donaldson (2007). Curran and Hancock proposed that the stimuli in these studies were not sufficiently distinct from each other to permit familiarity to be used as a reliable basis for test judgments. This argument is supported by the fact that Curran and Hancock did observe an effect that acted as an index of familiarity (for review, see page 469 in Curran & Hancock, 2007) in a task where more distinctive stimuli were employed, and in which discrimination was higher than in the studies reported by Yovel and Paller and by MacKenzie and Donaldson. In light of these considerations, in Experiment 3 different encoding parameters were employed in order to increase discrimination (Yonelinas & Jacoby, 1995; Rugg, Mark, & Walla et al., 1998).

The main purpose of Experiment 3 was to generalise the findings in Experiment 2 and to assess some of the possibilities discussed above. Towards this end, the short stimulus presentation time (300ms) employed in Experiment 2 was changed to a longer stimulus presentation time of 2000ms at study. The intention was to increase the opportunity for participants to encode unique facial features (Vilberg et al., 2006; Vilberg & Rugg, 2009). In addition to this change, there was a change to the encoding task, which was designed to direct attention toward internal facial features. How this was accomplished is described in the methods section below. The overall intention behind these manipulations was to increase the likelihood of observing an ERP correlate of familiarity in the ERPs acquired at the time of retrieval.

Methods

Participants

Twenty-nine took part in the experiment. Data from 13 participants were discarded prior to analysis. These participants did not contribute sufficient trials (>16) to the critical categories following artefact rejection. The remaining participants had a mean age of 20 (range 18 - 30), 5 of whom were male.

Stimuli

The stimulus set comprised 360 front-view black and white faces. Each image was used in two forms, consisting of complete and incomplete images. To form the incomplete stimuli, all stimuli were randomly divided into 4 facial feature groups (left eye, right eye, nose, and mouth). Each incomplete stimulus for each feature group was formed by inserting a white block to obscure the allocated facial part (see Appendix A).

The block structure repeated the one used in Experiment 2, except only 4 distractors were used in each study phase. The experiment consisted of 10 study-test blocks. Each block contained 20 study items that were separated into 16 target items, 4 distracters that were presented at study only, and 32 test items, comprising an equal number of old (studied) and new (unstudied) items. Each study and test phase contained an equal number of male and female faces. In addition, within each study phase, the four possible occlusions occurred equally often for male and female faces.

At encoding, target items were presented for a duration of 2000ms, while distractors were presented for 300ms. The use of distracters was to ensure participants were maintaining attention throughout the study phase and they are not re-presented at test. Test items consisted of complete stimuli only. The counterbalancing procedure followed the one described in the General Methods Chapter, page 80.

Procedure

The sequence of events prior to the presentation of the stimuli in the study-and-test block was identical to that in Experiment 2. During study phases, participants were instructed to indicate the part of the facial feature (left eye, right eye, nose, and mouth) that was obscured by the white block (see Appendix A for examples of occlusions). The complete target or distractor item was displayed in the centre of the screen for either 2000ms or 300ms, respectively. The complete target or distractor was immediately followed by the corresponding incomplete stimulus for 100ms, which was in turn followed by a blank screen. A four-way feature location response was required. The response requirement was to press the left-most key for left eye occlusions and the right-most key for right eye occlusions with the index fingers. Nose occlusion required a left thumb response, while mouth occlusion required a right thumb response. This response requirement was identical for all participants. After a location response was given, the next study trial began following a 1500ms blank screen. Test phases were identical to those in Experiment 2. EEG was recorded with recording parameter 2 settings (see General Methods chapter, page 82).

Results

Behavioral Data

Table 7.1. Proportions of old and new items assigned to each response option. Standard deviations are in brackets.

	High Confidence Old	Low Confidence Old	Low Confidence New	High Confidence New
Old	0.53 (0.12)	0.26 (0.09)	0.16 (0.07)	0.06 (0.04)
New	0.04 (0.06)	0.17 (0.09)	0.34 (0.13)	0.37 (0.11)

Table 7.1 shows the mean probabilities of old and new items assigned to high and low confidence old and new responses. Standard deviations are in brackets. The table shows that old items were more likely to be assigned as old items, while the reverse is true for new items. The discrimination measure [p(hit) – p(false alarm)] collapsed across confidence (mean = 0.50) was reliably above chance ($t(21)=12.74$, $p<0.01$). A repeated measures ANOVA with factors of response category (high confidence old, low confidence old, low confidence new, and high confidence new), and item status (old, new) revealed a reliable main effect of category ($F(1.95,29.28)=4.76$, $p<0.01$), and an interaction with status ($F(2.33,34.91)=103.20$, $p<0.01$). For the same reason as in Experiment 2, this interaction results from the fact that the proportions of correct responses, for both old and new items, show a diminution from correct high confidence through to incorrect high confidence responses (see Table 7.1). Figure 7.2 shows the old-new ROC plotted from the 4-point confidence scale using the Yonelinas Microsoft Excel solver. The dual-process model estimates from the solver were as follows: recollection *R*o = 0.32, and familiarity *d'* = 1.25 (for a formal descriptions of how these estimates are derived, see Yonelinas, 1999).

Figure 7.2. The ROC plots cumulative hit and false alarm pairs on the 4-point confidence rating. The left-post point represents items that received high confidence old responses only.

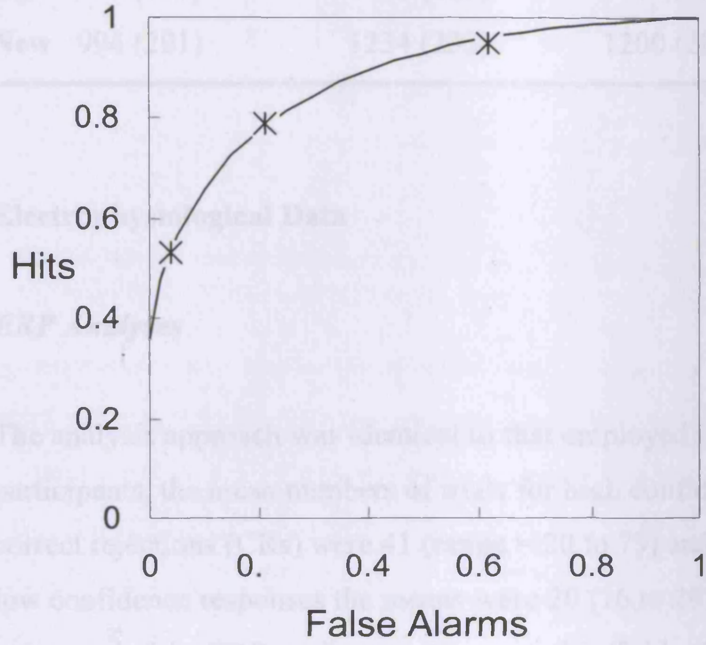


Table 7.2 shows the mean response times (RT) for old and new items assigned to the four response categories. Standard deviations are in brackets. The table shows faster response times for high relative to low confidence responses for both old and new items. The repeated measures ANOVA with factors of item status and response category revealed a main effect of status ($F=(1,15)=5.18$, $p<0.05$) and its interaction with response category ($F=(1,15)=9.79$, $p<0.01$). Follow up analyses revealed that the reason for the interaction is because the RTs for high confidence old responses made to old items were significantly faster than high confidence old responses made to new items ($t(15)=2.36$, $p<0.05$). This is not the case for other response categories.

Table 7.2. The reaction times (RTs) for old and new items assigned to each response option. Standard deviations are in brackets.

	High Confidence Old	Low Confidence Old	Low Confidence New	High Confidence New
Old	917 (101)	1171 (187)	1174 (222)	1051 (203)
New	994 (201)	1234 (233)	1200 (204)	1055 (135)

Electrophysiological Data

ERP Analyses

The analysis approach was identical to that employed in Experiment 2. For all participants, the mean numbers of trials for high confidence hits and high confidence correct rejections (CRs) were 41 (range = 20 to 79) and 28 (16 to 57) respectively; for low confidence responses the means were 20 (16 to 29) and 28 (16 to 51). All of the outcomes of the ERP analyses are presented in Tables 7.3 – 7.5, and are described below.

Figures 7.3 and 7.4 show the grand averages and scalp maps associated with hits and CRs separated for the two confidence levels. For high confidence responses, the old/new divergence starts from approximately 200ms onward, with the waveforms elicited by high confidence hits becoming more positive-going than those elicited by high confidence CRs. These effects are broadly distributed along the anterior-posterior dimension until approximately 700ms. From approximately 700ms onwards, the old/new differences are somewhat restricted to left anterior and central electrodes. Around the same latency range, a reversed old/new effect can be seen at occipital electrodes. This pattern of activation is sustained until the end of the epoch. For low confidence responses, the ERP waveforms diverge minimally from each other in the first 700ms after stimulus presentation. After this, the ERPs elicited by low confidence CRs become more positive-going than those elicited by low confidence hits at central and posterior superior electrodes. There is some evidence for a positive-going old/new effect from 900ms onward at right frontal and prefrontal electrodes.

Global contrasts

The initial analyses comparing all 4 response categories revealed an interaction between category and site in the first two epochs. In the subsequent epochs, interactions between category and location were obtained (see Table 7.3). These outcomes permitted the subsequent paired contrasts that are described below.

Critical paired contrasts

A category by site interaction was obtained in all paired contrasts involving high confidence hits in the first two epochs. These interactions arise because of the greater relative positivity for high confidence hits at superior sites (see Figures 7.3 & 7.5). The comparison between high confidence hits and CRs revealed an interaction between category and location in the last two epochs, and the same interaction was reliable for the contrast between high confidence hits and low confidence CRs in the last epoch only. These interactions reflect the fact that the ERPs elicited by high confidence hits are more positive-going than those elicited by CRs over anterior scalp, while the effects reverse polarity over posterior scalp.

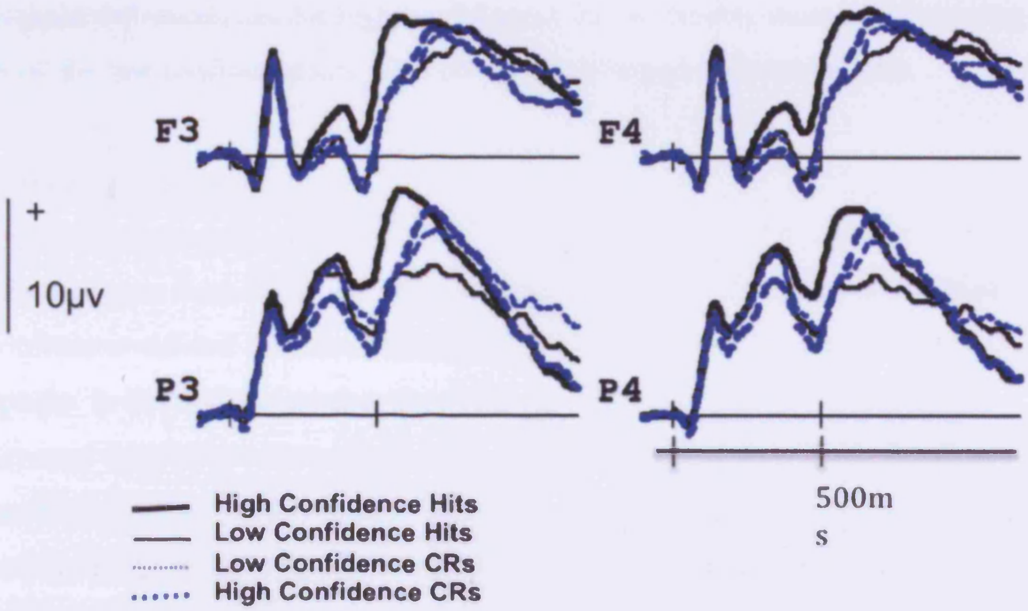


Figure7.5 Grand averaged event-related potentials elicited by hits and correct rejections that attracted high or low confidence judgments. Data are shown for 4 superior electrodes (F3, F4, P3, P4).

For the contrast between the low confidence hits and CRs, there were no reliable effects or interactions involving the factor of category in the first two epochs. ERPs elicited by low confidence CRs are more positive-going than those elicited by low confidence hits from 700-900ms and in the last epoch, the category by location interaction mirrors the effect obtained in the high confidence old/new contrast. Positive-going old/new effect over anterior scalp, with a polarity reversal over posterior scalp.

For the contrast between high and low confidence CRs, an interaction between response category and site was obtained in the 300-500ms epoch, indicating a greater positivity for low confidence CRs relative to high confidence CRs that is largest at sites closest to the midline (see Figure 7.5 above). In the final epoch, an interaction between category and hemisphere was obtained, indicating a greater relative positivity for low than for high confidence CRs that is largest over the left hemisphere.

For the contrast between low confidence hits and high confidence CRs, the only reliable interaction was between category and location in the 500-700ms epoch, because the waveforms for high confidence CRs are reliably more positive going than those for low confidence hits. This difference is largest at posterior sites.

Focused analyses: 1

The outcomes from the global analyses described above indicated that the high confidence old/new effects were largest over superior electrodes in the first two epochs. In the last two epochs, the effects were largest over anterior scalp and reversed in polarity over posterior scalp. The focused analyses were therefore conducted at four superior sites (F3, F4, P3, P4) with factors of location (2 levels), and hemisphere (2) in the first two epochs. In the last two epochs, analyses were conducted separately for the anterior and posterior scalp sites separately (anterior: FP1, F7, F5, F3, FP2, F8, F6, F4; posterior: O1, P7, P5, P3, O2, P8, P6, P4), with factors of hemisphere (2) and site (4). To reiterate the analysis strategy employed in Experiment 2, in each epoch, the analyses were first completed including all four response categories, with paired contrasts conducted as necessary after this.

The initial focused analyses revealed reliable main effects in the 300-500ms ($F(2.2,33.2)=10.16$, $p<0.01$) and 500-700ms ($F(2.6,39.1)=20.92$, $p<0.01$) epochs. Follow up paired analyses revealed that the ERPs elicited by high confidence hits are reliably more-positive going than the ERPs elicited by all other response categories in both epochs. In the 300-500ms epoch, ERPs elicited by low confidence CRs are more positive-going than those elicited by high confidence CRs. In the 500-700ms epoch, the low confidence hits were more negative-going than were high confidence CRs. These statistical outcomes are shown in Table 7.4.

In the 700-900ms epoch, the initial analyses revealed a significant main effect over the posterior scalp only ($F(2.3,34.4)=5.53$, $p<0.01$). The follow-up analyses revealed a reliable main effect of response category, indicating the old/new effects for the high and low confidence judgments were reversed in polarity (high confidence: $F(1,15)=6.22$, $p<0.05$; low confidence: $F(1,15)=10.59$, $p<0.01$). No reliable main effects or interactions were obtained in the following epoch.

Focused analyses: 2

The focused analyses at the three mid-frontal electrodes (F3, Fz, F4) in the 300-500ms epoch revealed a reliable main effect in the initial analysis ($F(2,7,39.9)=13.86$, $p<0.01$). Follow up paired analyses revealed a greater positivity for high confidence hits relative to low confidence hits ($F(1,15)= 19.60$, $p<0.01$), low confidence CRs ($F(1,15)=29.92$, $p<0.01$), and high confidence CRs ($F(1,15)=35.86$, $p<0.01$).

The second half of the focused analyses including parietal sites (P7, P5, P3) was conducted for two epochs: 500-700 and 700-900ms. Main effects of category were obtained in the initial analyses for both [500-700ms: ($F(2.4,35.4)=9.48$, $p<0.01$); 700-900ms: ($F(2.2,32.5)=3.32$, $p<0.05$)].

In the 500-700ms epoch, follow-up analyses revealed reliable interactions between response category and site for all paired contrasts including high confidence hits. The greater relative positivity for high confidence hits is largest at P3 in all cases. In the 700-900ms epoch, when low confidence hits are contrasted with high and low confidence CRs respectively, reliable main effects were obtained. In both cases, the ERPs for low confidence hits were more negative-going. These outcomes are shown in Table 7.5.

***Topographic analyses*:**

Two sets of analyses were conducted on rescaled data. First, an across epoch analysis was conducted to identify changes in the scalp distributions of the high confidence old/new effects from 300-1100ms, and the low confidence old/new effects from 700-1100ms. These old/new effects separated according to confidence were reliable in the foregoing analyses for these time windows.

The analyses were performed on the difference waveforms obtained by the subtraction of high confidence CRs from high confidence hits for all epochs, and the subtraction of low confidence CRs from low confidence hits for the last two epochs. The rescaled data were analyzed with factors of epoch (4 and 2 levels for the two confidence types respectively), along with the above mentioned location factors. The analyses revealed no reliable effects in any of the contrasts.

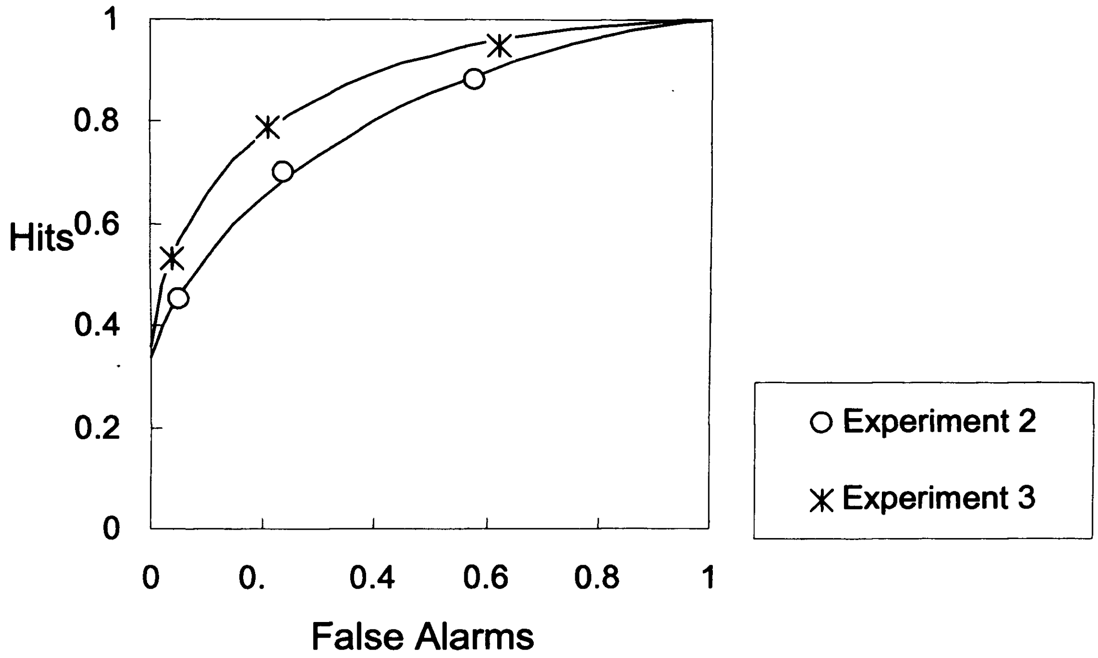
The second part of the analysis contrasted the high and low confidence old/new effects in the 700-900 and 900-1100ms epochs. This part of the analysis investigates whether the old/new effects engaged for high and low confidence responses were neurally distinct. Again, no reliable effects were obtained in either epoch.

Discussion

Behavioral data

The overall pattern of accuracy data was broadly consistent in terms of shape with that in Experiment 2. The discrimination measures collapsed across the level of confidence were reliably above chance, and high confidence judgments to both old and new items were more accurate than were low confidence judgments (see Table 7.1). Importantly, the task changes at encoding in comparison to Experiment 2 increased overall discrimination accuracy markedly (Experiment 2: 0.46 vs. Experiment 3: 0.57). This was carried almost wholly by a higher proportion of high confidence old judgments (Hits: 0.45 vs. 0.53). As suggested previously, high confidence old responses are likely to be made on the basis of a recollection process according to the high-threshold dual-process signal detection model (Yonelinas, 2002). The dual-process estimates of recollection and familiarity showed that the encoding manipulation increased only the likelihood of familiarity based responding in comparison to the findings in Experiment 2. Figure 7.5 shows that the ROCs for the two experiments cross the y-axis at the same point (Experiments 2 & 3: *R*o = 0.33 & 0.32). This point is assumed to index the estimate for recollection (Yonelinas, 1999). The ROC for Experiment 3, however, is pushed further to the upper left corner than in Experiment 2, suggesting that familiarity is available to a greater degree in Experiment 3. The extent to which dual-process or competing univariate signal detection models (Wixted & Stretch, 2004) provide a more accurate interpretation of the current data is retuned to in the General Discussion. Irrespective of this issue, however, it is uncontroversial to claim that response accuracy and some form of memory strength was higher in Experiment 3 than in Experiment 2.

Figure 7.5. The ROC plots cumulative hit and false alarm pairs on the 4-point confidence rating separated for Experiments 2 and 3. The left-post point represents items received the high confident old response.



High confidence judgments were associated with quicker RTs relative to low confidence judgments, with the RTs overall showing an inverted U-shape function (Guest & Wan Laar, 2002; Yonelinas et al., 2005; Woodruff et al., 2006). In addition, the RTs for high confidence old responses were quicker than all other responses to old and new test items, and high confidence old responses to old items were significantly faster than the RTs for new items. The averaged RTs for old and new items collapsed across the response categories were quicker in the present experiment than in Experiment 2 (old/new: Experiment 2: 1239/1247 vs. Experiment 3:1078/1121). This is consistent with the view that higher memory accuracy is typically associated with faster RTs (Rugg et al., 2000; Paller & Kutas, 1992).

ERP data

300-500ms

The global analysis revealed a greater positivity for high confidence hits relative to the other three categories: low confidence hits, low confidence CRs, and high confidence CRs. These differences were largest at sites along the midline, as reflected in the outcomes from the two focused analyses over superior electrodes (focused analysis 1), and the mid-frontal electrodes (focused analysis 2). In these analyses, the ERPs elicited by the other three response categories did not differentiate from each other in the paired contrasts. The only exception is in the high and low confidence CRs contrast in the global analysis and focused analysis 1, where there was a greater positivity for low confidence CRs relative to high confidence CRs that was largest at sites closest to the midline. The fact that these two response categories were more negative-going than the ERPs elicited by high confidence hits provides some evidence that these ERPs are sensitive to familiarity.

If this is correct, then the reliable differences between the two classes of CRs arise because low confidence CRs are associated with higher memory strength relative to the high confidence CRs (for a similar line of evidence, see Azimian-Faridani & Wilding, 2004). As described previously, familiarity correlates with the level of recognition confidence for old, as well as for new items. This data point could be taken as a strong support for the familiarity account because of its ability to differentiate between new items that attracted high and low confidence responses correctly. Challenging to this view, however, is the fact that the ERPs for low confidence hits and CRs differed minimally from each other. The familiarity interpretation predicts that low confidence hits should have a higher level of memory strength than low confidence CRs, and the neural index of familiarity should be sensitive to such differences. This outcome was not obtained. The results are at least suggestive, however, not least because familiarity was increased by the encoding manipulation, and it may be that the way in which (on average) participants employed the scale was that there was insufficient distance (hence familiarity strength) between low confidence old and new responses to differentiate between them in the electrical record. The reason that there is some differentiation between high and low confidence

CRs responses in this experiment and not in Experiment 2 could be explained by the differences between familiarity used for memory judgments. This is partially consistent with Curran and Hancock's (2007) view that enhanced memory performance increases the likelihood of eliciting a detectable familiarity signal.

500-700ms

The effects in this epoch mirror those obtained in the preceding epoch, except that there were no differences between the ERPs elicited by high and by low confidence CRs. In addition, high confidence CRs were reliably more positive-going than low confidence hits over parietal sites in both the global analyses and focused analysis 2. The effects in this epoch depart from those in Experiment 2 in terms of the distributions of effects as well. The high confidence old/new effects are more broadly distributed over anterior-posterior scalp, in contrast with the prefrontal maximum in Experiment 2.

While the behavioural data indicates that comparable recollection estimates were obtained between experiments 2 and 3, it is not straightforward to explain why the putative ERP index of recollection – the left-parietal ERP old/new effect – was markedly larger in Experiment 3 than in Experiment 2. As mentioned previously, the left parietal old/new effect has a strong association with recollection (Smith, 1993, Wilding & Rugg, 1996; Rugg, Mark, & Walla et al., 1998; Curran, 2004; Curran & Hancock, 2007). However, the ROC data shows that the estimate for recollection under dual-process model assumptions did not increase markedly across experiments. It has been reported that increasing the duration for which items are studied increases both recollection and familiarity, but markedly more so for the former process (Yonelinas, 2002; Vilberg & Rugg, 2009). Critically, however, this pattern has not been shown before for faces, so there is no strong reason to question the reliability of the finding reported here.

It is not possible to rule out an explanation for these differences based upon the fact that different participants completed each experiment. It is also noteworthy, however, that the behaviour and the ERP data are compatible with a univariate signal-detection model as well as a dual-process model, where the parietal component reflects a "strong" memory process that is thought to generate the majority of high confidence old responses. The challenge for this account, however, is the fact that low confidence correct old judgments did not generate a reliable left-parietal old/new effect. Stronger evidence for a univariate account would have stemmed from the demonstration of a graded parietal effect.

One way of reconciling these findings with a dual-process account is to argue that the manipulation in Experiment 3 increased the strength of recollection for items above the threshold at which a high confidence judgment was made, but why this would not result in an increase in the estimate of recollection remains unclear. Primarily, as discussed in Experiment 2, parietal old/new effects in this time period might receive a contribution from the P300 modulation, which is sensitive to response confidence and has a Pz maximum (Woodruff et al., 2006). Is it possible to consider the reasons for the disparities across experiments in terms of changes in the P300? If the encoding manipulation in Experiment 3 increased relatively selectively the confidence with which high confidence old judgments were made, this would go some way to explaining the differences across the two studies. There is no means of assessing this possibility directly, however.

700-900ms and 900-1100ms

In a departure from the findings in Experiment 2, reliable differences between the two classes of correct low confidence judgments were obtained from 700ms onward. Broadly similar patterns of high and low confidence old/new effects were obtained in these two epochs: in both cases, the global analyses demonstrated that the ERPs for hits are more positive-going over anterior scalp, and become more negative-going over posterior scalp relative to CRs (see Figure 7.4). Broadly similar patterns of ERP effects have been reported in previous studies in which verbal materials were employed and source retrieval judgments were required (Wilding & Rugg, 1997; Mecklinger, 2000; Cycowicz, Friedman & Snodgrass, 2001; Johansson & Mecklinger, 2003; Herron, 2007).

As previously noted, no reliable old/new effects were obtained in the 800-1100ms epoch in Experiment 1, and as observed in the discussion for Experiment 2, the present finding is consistent with the view that old/new effects in these time windows are less likely to be observed in simple old/new recognition memory paradigms, perhaps because the processes these late ERPs operate on recovered information, and this kind of post-retrieval processing is required to a greater degree in source memory tasks (Wilding & Rugg 1996, 1997; Experiment 2). It is interesting to note that, despite the absence of reliable old/new effects for low confidence judgments across the 300-700ms epoch, there were reliable effects after this time. This finding suggests that these late processes are not tied to a particular process that can support test judgments, nor to the level at which these processes were engaged. An extended discussion related to the functional significance of these modulations will be presented in the general discussion after findings from other studies have been reported.

Conclusions

Experiment 3 employed the same logic as in Experiment 2 with regard to the test analyses. The experiment was designed to encourage superior memory for test stimuli in comparison to Experiment 2. This was achieved by using longer stimulus presentation durations and different task requirements at study. Behavioural data indicated that overall recognition memory accuracy increased in Experiment 3, and while this was due mainly to an increase in the proportion of high confidence old responses, *R*o and *d'* estimates linked the superior response accuracy to familiarity.

Consistent with the findings in Experiment 2, the old/new effects between 300 and 700ms were only elicited for high confidence judgments, supporting the view that these effects are associated with recollection. A larger parietal old/new effect was elicited in the 500-700ms epoch for high confidence judgments in comparison to Experiment 2, and there is no ready explanation for this finding from a dual-process perspective if the effect indexes recollection and dual-process ROC estimates of recollection are accurate. There was some evidence that an ERP modulation was sensitive to recognition confidence in the 300-500ms epoch, providing some support for the view that ERPs contain a neural index of familiarity for faces. From 700ms onward, a common positive-going frontal old/new effect was associated with high and low confidence judgments, supporting that view that they are unlikely to relate to memory retrieval processes that directly influence retrieval success.

In combination, the findings from Experiments 2 and 3 suggest that when old/new discriminations are separated for high and low confidence, there is no convincing ERP evidence that recognition confidence responses are made on the basis of familiarity. The subsequent experiments in this thesis employ a different paradigm that provides a subjective basis for separating for recollection and familiarity, and to determine how related ERP modulations vary accordingly.

Table 7.3. F-values and significance values for the initial global and all paired comparisons between the mean amplitudes associated with high confidence hits, low confidence hits, low confidence correct rejections (CRs) and high confidence CRs response categories over the 300-500, 500-700, 700-900, and 900-1100ms epochs. All terminology and other information as for Table 5.3.

Global Analyses:

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (3, 45)	**7.71, p<0.01 (0.68)**	**14.58, p<0.01 (0.78)**	ns.	ns.
RC x AP (3, 45)	ns.	ns.	**4.21, p<0.05 (0.84)**	**4.49, p<0.01 (0.80)**
RC x ST (9, 135)	**4.11, p<0.01 (0.52)**	**6.19, p<0.01 (0.63)**	ns.	ns.

All paired contrasts:

High confidence hits vs. High confidence CRs

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 15)	**25.30, p<0.01**	**17.56, p<0.01**	ns.	ns.
RC x AP (1, 15)	ns.	ns.	**9.80, p<0.01**	**5.37, p<0.05**
RC x ST (3, 45)	**11.61, p<0.01 (0.74)**	**7.32, p<0.01 (0.89)**	ns.	ns.

High confidence hits vs. Low confidence hits

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 15)	**10.61, p<0.01**	**29.53, p<0.01**	3.33, p=0.09	ns.
RC x AP (1, 15)	ns.	**5.11, p<0.05**	ns.	ns.
RC x ST (3, 45)	**4.48, p<0.01 (0.86)**	**13.35, p<0.01 (0.82)**	2.54, p=0.07 (0.93)	ns.

High confidence hits vs. Low confidence CRs

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 15)	**16.69, p<0.01**	**47.92, p<0.01**	ns.	**7.83, p<0.01**
RC x ST (3, 45)	**5.04, p<0.01 (0.86)**	**10.58, p<0.01 (0.87)**	ns.	ns.

Low confidence hits vs. Low confidence CRs

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 15)	ns.	ns.	**6.61, p<0.05**	ns.
RC x AP (1, 15)	ns.	ns.	ns.	**7.24, p<0.05**

Low confidence hits vs. High confidence CRs

	300-500ms	500-700ms	700-900ms	900-1100ms
RC x AP (1, 15)	ns.	ns.	**11.30, p<0.05**	ns.
RC x AP x ST (3, 45)	ns.	ns.	2.85, p<0.06 (0.85)	ns.

High confidence CRs vs. Low confidence CRs

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 15)	**5.47, p<0.05**	ns.	ns.	3.71, p=0.07
RC x HM (1, 15)	ns.	ns.	3.49, p=0.08	**5.39, p<0.05**
RC x ST (3, 45)	**4.46, p<0.01 (0.81)**	ns.	ns.	ns.
RC x AP x HM x ST (3, 45)	ns.	2.80, p=0.06 (0.85)	ns.	ns.

Table 7.4. F-values and significance values for focal analyses 1 at four superior electrodes (F3, F4, P3, P4), all paired comparisons between the mean amplitudes associated with high confidence hits, low confidence hits, low confidence correct rejections (CRs) and high confidence CRs response categories over the 300-500, 500-700 epochs. All terminology and other information as for Table 5.3.

Focused Analyses 1: All Paired Analyses

		300-500ms	500-700ms
High confidence hits vs. High confidence CRs	RC (1, 15)	**34.60, p<0.01**	**22.10, p<0.01**
High confidence hits vs. Low confidence Hits	RC (1, 15)	**15.86, p<0.01**	**46.62, p<0.01**
High confidence hits vs. Low confidence CRs	RC (1, 15)	**15.24, p<0.01**	**58.59, p<0.01**
Low confidence hits vs. High confidence CRs	RC (1, 15)	ns.	**4.65, p<0.05**
High confidence CRs vs. Low confidence CRs	RC (1, 15)	**7.53, p<0.05**	ns.

Table 7.5. F-values and significance values for focal analyses 1 at P3, P5, P7, all paired comparisons between the mean amplitudes associated with confidence hits, low confidence hits, low confidence correct rejections (CRs) and high confidence CRs response categories over the 500-700, and 700-900ms epochs. All terminology and other information as for Table 5.3.

Focused Analyses 2: All Paired Analyses – Parietal Sites

		500-700ms	700-900ms
High confidence hits vs. High confidence CRs	RC (1, 15)	**11.51, p<0.01**	ns.
	RC x ST (1, 15)	**4.27, p<0.05**	ns.
High confidence hits vs. Low confidence Hits	RC (1, 15)	**19.91, p<0.01**	ns.
	RC x ST (1, 15)	**5.20, p<0.05**	ns.
High confidence hits vs. Low confidence CRs	RC (1, 15)	**18.07, p<0.01**	ns.
	RC x ST (1, 15)	**4.84, p<0.025**	ns.
Low confidence hits vs. Low confidence CRs	RC (1, 15)	ns.	**9.69, p<0.01**
	RC x ST (1, 15)	ns.	ns.
Low confidence hits vs. High confidence CRs	RC (1, 15)	ns.	**4.89, p<0.05**
	RC x ST (1, 15)	ns.	ns.

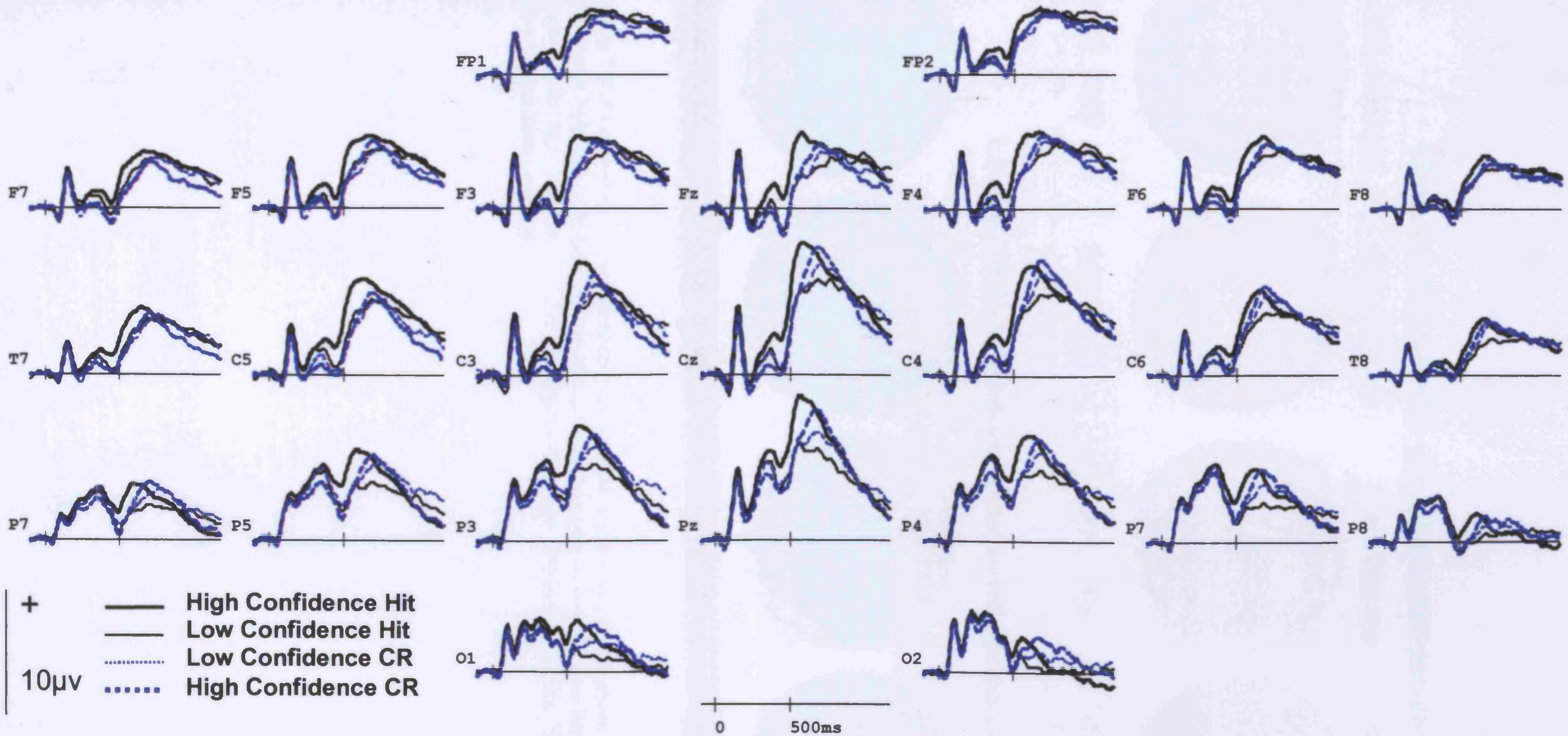


Figure 7.3. Experiment 3 – Grand averaged event-related potentials elicited by hits and correct rejections attracted high or low confidence judgments. Data are shown for 25 electrodes covering prefrontal (FP1, FP2), frontal (F7, F5, F3, Fz, F4, F6, F8), central (C7, C5, C3, Cz,C4, C6, C8), posterior (P7, P5, P3, Pz, P4, P6, P8) and occipital sites (O1, O2). (n= 16)

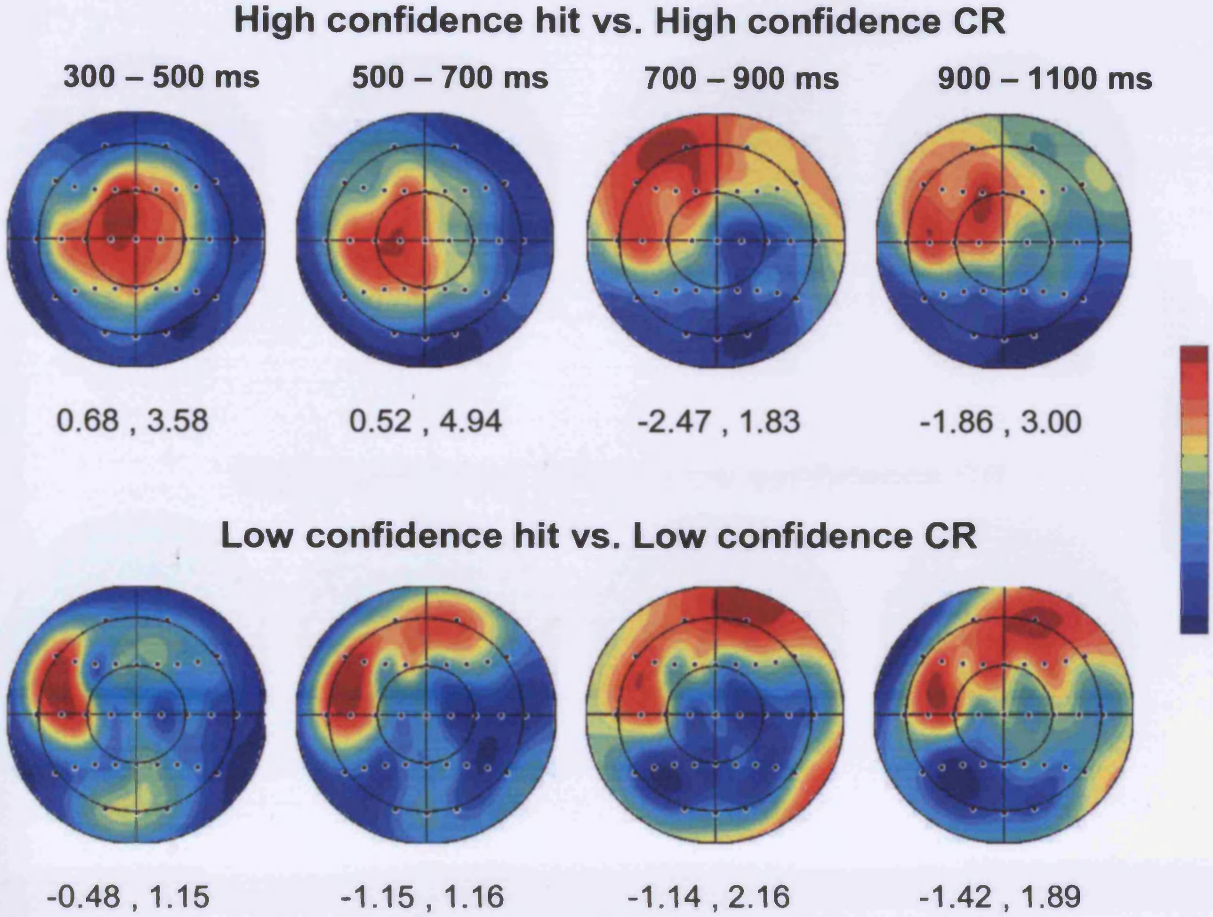


Figure 7.4. Experiment 3 - Topographic maps showing the scalp distributions of the differences between activities evoked by correctly recognized old and new items separated for high and low confidence judgments for the 300-500, 500-700, 700-900 and 900-1100ms time windows.

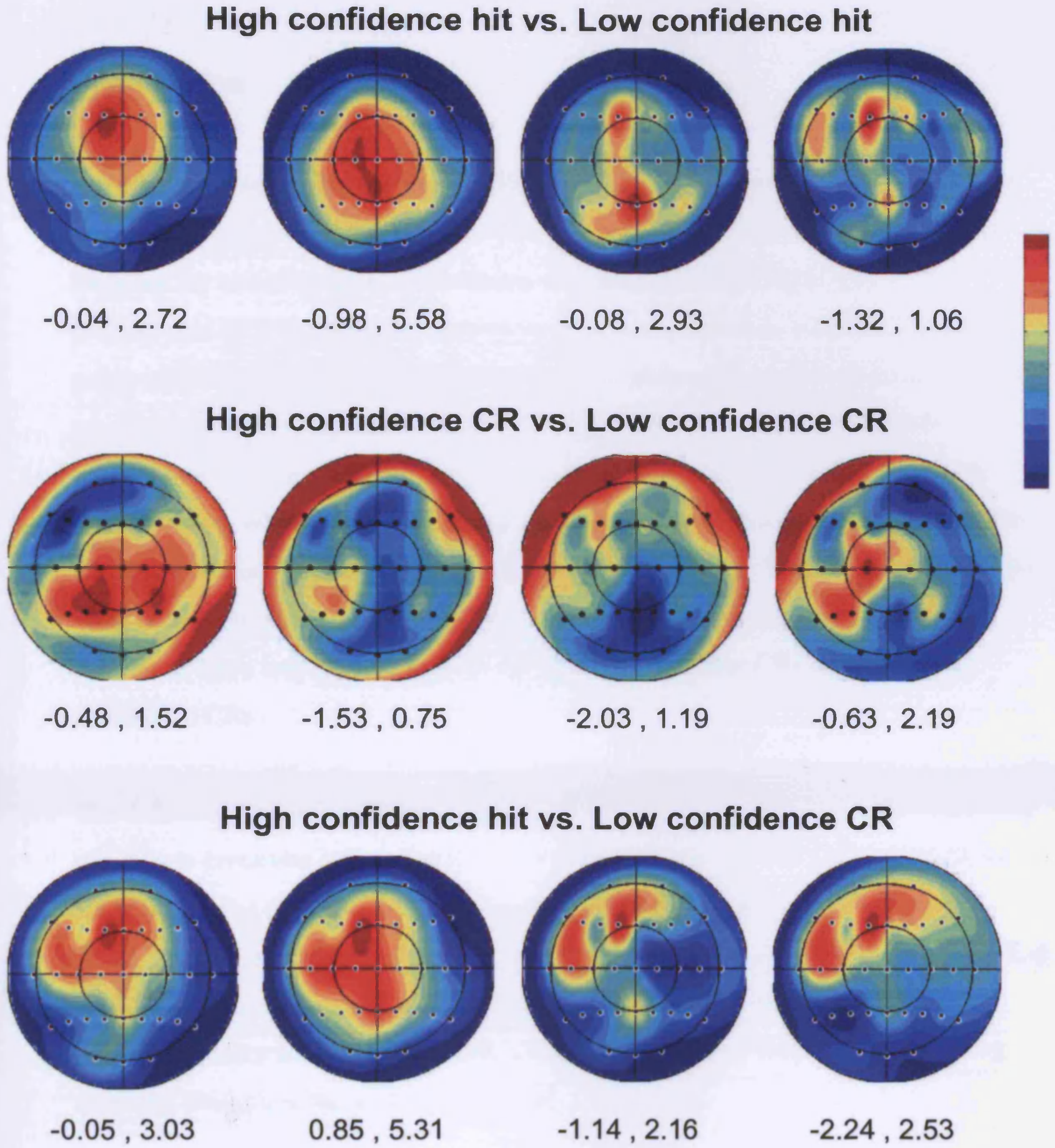


Figure 7.4 (continues). Experiment 3 - Topographic maps showing the scalp distributions of the differences between 3 different contrasts of interests for the 300-500, 500-700, 700-900 and 900-1100ms time windows.

Chapter Eight: Experiment 4 - Source Memory for Face Details: Part 1

Introduction

Experiments 2 and 3 showed that the ERP modulations elicited in paradigms where confidence judgments were acquired behaved as indices of recollection; no strong evidence for neural indices of familiarity was obtained. This claim stems from findings that ERP modulations elicited by high confidence hits were more positive-going relative to the activity elicited by low confidence hits and by all (high and low confidence) correct responses to new test faces. The ERPs elicited by correct rejections and low confidence hits did not differ from each other substantively in Experiment 2. When familiarity-based memory was increased in Experiment 3, there was some evidence that a superiorly distributed effect in the 300-500ms epoch might index familiarity, because it differentiated between the two classes of correct rejections: there was a greater positivity for low confidence CRs relative to high confidence CRs.

The following two experiments in this thesis were completed to assess the sensitivity of ERPs to processes supporting memory judgments using a different manipulation, thereby offering the opportunity to provide converging evidence pointing to the sensitivity of ERPs to familiarity and recollection for faces. In Experiments 2 and 3, it was assumed that recollection resulted principally in high confidence judgments, while familiarity was associated with a range of confidence judgments, depending upon the strength of the underlying signal.

In the following experiments, a different means of separating responses based upon familiarity and those based upon recollection was employed. The "source memory" approach has been used often to separate neural correlates of recollection and familiarity (see Chapter 2 for a detailed discussion of the relevant literature). In this approach, participants are asked to make old/new judgments to test items, and (either jointly or afterwards) a source judgment. The premise underlying this design is that items attracting correct source judgments are associated with recollection, whereas items identified correctly as old that attract incorrect source judgments are responses based upon familiarity. The underlying processes contributing to correctly recognised old items that attract incorrect source judgments can be questioned, however, based on the fact that "non-criterial recollection" – that is, recollection of details other than those required for the source judgment - might occur (Yonelinas & Jacoby, 1996). So in principle, neural activity common to old items that attract correct and incorrect source judgments might index non-criterial recollection, rather than familiarity. This issue is returned to after the results of experiments 4 & 5 are presented.

One of the arguments made in preceding chapters is that, for the investigation of neural processes supporting memory for faces, the stimuli and tasks used should relate as much as possible to information about faces, rather than, in the case of autobiographical information, different kinds of content that have been linked with faces (see Yovel & Paller, 2004; Curran & Hancock, 2007; Mackenzie & Donaldson, 2007). In keeping with this view, the present experiment was designed using a source memory paradigm that encouraged participants to focus on information about faces. Source information was manipulated by obscuring internal facial feature information at study. In each study phase, a white bar was inserted to obscure either one eye or the mouth. At test a facial feature response (indicating which feature had been obscured at study) was required following an initial old/new response. This response manipulation allows the separation of ERPs into three categories: hit/hit (correctly identified old and correct source), hit/miss (correctly identified old and incorrect source), and correct rejection. The hit/hit category presumably contains a reasonably high proportion of responses that are associated with recollection of feature information (source). The hit/miss category may reflect old/new responses made on the basis of familiarity, and may also contain trials on which non-criterial recollection occurred.

ERP old/new effects associated with recollection of task relevant information, therefore, should be larger for the hit/hit than the hit/miss category. For a neural index of familiarity, the magnitude of the effect should not be sensitive to source accuracy, only to the old/new status of the test items; therefore this modulation should be comparable in magnitude for both the hit/hit and hit/miss response categories (Wilding & Rugg, 1996).

Methods

Participants

Thirty participants took part in the experiment. Data from 14 participants were discarded, 5 participants had insufficient trials (<16) in at least one of the critical categories following artefact rejection (for criteria see below), and the remaining 9 participants were unable to perform the feature selection task above a set criterion (conditional probability of a hit/hit response falling above 0.60). The remaining mean age of the remaining participants was 21 (age range 18-28), 5 of whom were male.

Stimuli

The stimulus set comprised 360 faces. Each image was used in two forms, comprising complete and incomplete images. To form the incomplete stimuli, all stimuli were randomly allocated into 1 of 2 facial feature groups (eye or mouth). Stimuli in the eye group were further divided into two to form the left eye and the right eye group. Each incomplete stimulus was formed by inserting a white block to obscure the relevant facial part (see Appendix A).

The experiment consisted of 8 study-test blocks. Each block contained 20 study and 40 test trials, the test trials comprising the studied faces and an equal number of new faces. Each study and test phase contained an equal number of male and female faces. In each study phase, half of the stimuli had the mouth obscured; the remainder had one eye obscured. Block order was balanced, with one block containing study stimuli with the left eye and the mouth obscured, followed by a block containing study stimuli with the right eye and the mouth obscured. Within each study phase, the two possible occlusions had an equal likelihood of occurrence for male and for female faces. The counterbalancing procedure followed the one described in the General Method Chapter, page 80.

Procedure

In the study phases, each trial began with an asterisk (*) that was displayed in the centre of the screen for 1000ms. A 100ms blank screen then intervened, after which a complete stimulus was displayed in the centre of the screen for 2000ms. The stimulus was immediately followed by the corresponding incomplete stimulus for 100ms. This was followed by a blank screen lasting the length of time the participant took to respond plus 1500ms before presentation of the asterisk signaling the onset of the next trial. A binary feature location response was required; half of the participants responded with the left index finger to stimuli with an eye obscured and responded with the right index finger for the mouth. This correspondence was reversed for the remaining participants.

A test phase immediately followed each study phase. Each test trial began with an asterisk which was presented for 1000ms and followed by a blank screen for 100ms. Test items were presented for 300ms and followed by a blank screen lasting the length of time the participant took to respond plus 1500ms. Participants were required to indicate the old/new status of the test item using a binary response. For half of the participants, the left thumb was designated for old responses, the right thumb for new responses. This mapping was reversed for the remaining participants. Once the old/new response was given and the 1500ms blank period had ended, a question mark (?) was presented lasting the length of time the participant took to make the second judgment. This was a location judgment, which required participants to indicate the location of the white bar (eye/mouth) that had obscured a facial feature at encoding. The keys used for eye/mouth responses were the same as those used for those responses in the study phase. When a new response was made at test, a second key press when the question marks came up initiated the next trial. The hands used for the eye/mouth response at study, as well as the old/new response at test, were counterbalanced across participants to create a total of 4 study-test response combinations. EEG was recorded with recording parameter 2 (see General Methods Chapter, page 82).

Results

Behavioural Data

Table 8.1 displays the mean probabilities (and SDs) of correct and incorrect old/new judgements for old and new test faces, as well as the mean and conditional probabilities of correct and incorrect source judgments for faces judged correctly to be old. Old/new discrimination measure [p(hit) – p(false alarm)] collapsed across source accuracy was above chance ($t(15)=20.72$, $p<0.01$). The conditional probability of a correct source judgment for faces judged correctly to be old was also above chance (mean=0.66: $t(15)=30.52$, $p<0.01$).

Table 8.1. Mean probabilities and standard deviations (SD) of correctly identified old and new faces, and the conditional probabilities for correct old responses that attracted correct and incorrect source judgments.

P(Hit)	0.79 (0.07)
P(CR)	0.84 (0.09)
Conditional P(Hit/hit)	0.66 (0.09)
Conditional P(Hit/miss)	0.34 (0.09)

Table 8.2 displays the mean RTs (and SDs) for initial old/new judgments to new and old faces, and the mean RTs for correct initial judgments separated according to subsequent source accuracy. A repeated measures ANOVA with factors of accuracy and old/new status collapsing across source accuracy revealed a reliable main effect of old/new status($F(1,15)=10.42$, $p<0.01$), as well as an interaction between this factor and accuracy ($F(1,15)=12.85$, $p<0.01$). The reason for the interaction is because the RTs for incorrect new responses were slower than for correct old responses ($t(15)=2.88$, $p<0.01$), for incorrect old responses ($t(15)=4.05$, $p<0.01$), and for correct new responses ($t(15)=5.01$, $p<0.01$). A separate set of analyses was conducted for

correct old responses separated for source accuracy. Responses associated with incorrect source judgments were significantly slower than responses associated with correct source judgments ($t(15)=3.03$, $p<0.01$), as well as correct new responses ($t(15)=2.170$, $p<0.05$). The RTs for correct source judgments and correct rejections did not differ reliably.

Table 8.2. Mean reaction times and standard deviations (SD) of initial old/new judgments. Hits are separated according to the source accuracy.

Hits	1196 (255)
CR:	1084 (293)
Miss:	1180 (370)
FA	1443 (486)
Hit/hit:	1166 (243)
Hit/miss:	1227 (273)

Electrophysiological Data

ERP Analyses

The principal analyses focused on correct new responses (CRs) and correct old responses separated according to source accuracy (correct = hit/hit; incorrect = hit/miss). For all 16 participants, the mean numbers of trials for the hit/hit, hit/miss and correct rejection (CR) response categories were 33 (range = 17 to 47), 21 (16 to 27), and 48 (28 to 68). For the main analysis, 16 electrode sites from an equal number of left and right frontal and parietal locations were selected (left anterior: FP1, F7, F5, F3; right anterior: FP2, F8, F6, F4; left posterior; O1, T5, P5, P3; right posterior: O2, T6, P6, P4). The analyses included factors of response category (3 levels), anterior/posterior dimension (2), hemisphere (2), and site (5).

Figures 8.1 and 8.2 show the grand averages and scalp maps elicited by the hit/hit, hit/miss, and CR response categories. The old/new effects for the hit/hit and the hit/miss response categories start from approximately 300ms post-stimulus. These effects are largest over superior sites up to approximately 750ms. The waveforms for the hit/hit and hit/miss response category differ minimally in the 300-500ms time window. The waveform for the hit/hit category became more positive-going than the hit/miss category from 500ms onwards, where both waveforms are more positive-going than CRs. This graded pattern of effects becomes largest at prefrontal and frontal electrodes from 700ms and continues until the end of the recording epoch.

The ERP analyses were divided into 3 main sections, containing the global, focused and topographical analyses. The analyses were conducted for the 300-500, 500-700, 700-900, and 900-1100ms epochs. These latency intervals were selected based on visual inspection of the old/new effects obtained in this experiment (see Figure 8.1) and the overall analysis strategy for the experiments reported in this thesis (see General Methods). Following the strategy in Experiments 2 and 3, the initial analysis contained the factors of response category (three levels) and the above mentioned location factors per epoch. Subsequent analyses following any reliable main effects and/or interactions involving category were conducted for the three possible paired comparisons between the ERPs associated with the hit/hit, hit/miss and correct rejection response categories. The outcomes of these analyses were used to identify the locations in each epoch where old/new effects were largest. These locations were then submitted to focused analyses (focused analysis 1), to maximize the opportunity to determine whether ERPs elicited by faces in memory tasks index recollection and/or familiarity. Focused analysis 2 was directed at specific memory modulations that have been associated with recollection and familiarity in previous studies. These focused analyses were conducted at three mid-frontal electrodes (F3, Fz, F4) in the 300-500ms epoch. Analyses were also conducted from left-parietal electrodes (P3, P5, P7) in the 500-700 and 700-900ms epochs (Rugg, Mark, & Walla et al., 1998; Curran, 1999, 2000). Finally, in the previous experiment chapters, a frontal modulation was consistently elicited in the 500-700ms epoch; therefore a focal analysis was also conducted at the three mid-frontal electrodes (F3, Fz, F4) in the 500-700ms epoch. The final analysis section explores any differences between the scalp topographies of the hit/hit and hit/miss ERP old/new effects, as well as changes in these effects over time.

Global contrasts

The initial analyses of the data for each of the 3 categories revealed an interaction between category, location and site in the 300-500ms epoch, an interaction between category and site in the 500-700ms epoch, and interactions between category and hemisphere for the entire epochs. These outcomes license the subsequent paired contrasts which are described below. Table 8.3 displays the outcomes of the analyses for the global and follow-up paired comparisons between the ERPs associated with the hit/hit, hit/miss, and CR response categories.

Critical paired contrasts

Hit/hit vs.CR

The initial ANOVA for this comparison revealed a significant interaction between category, location and site in the 300-500ms epoch (see Figure 8.3). The interaction term indicates a greater positivity for hit/hit compared to CR that is largest at anterior-inferior and prefrontal electrode sites. In the 500-700ms epoch, the category by site interaction indicates that the magnitude of the old/new effect increases along the inferior-superior dimension. The analyses revealed a reliable category by hemisphere interaction in the 700-900ms epoch, and the same interaction term approached significance in the preceding time window. These interactions indicate that the old/new effect is left-lateralized. The analyses also revealed a significant interaction between category and location in the 900-1100ms epoch, indicating a larger positive-going effect over anterior than over posterior scalp. In addition, interactions between category, location and site approached significance in the last two epochs, because the old/new effects tend to be largest over prefrontal scalp.

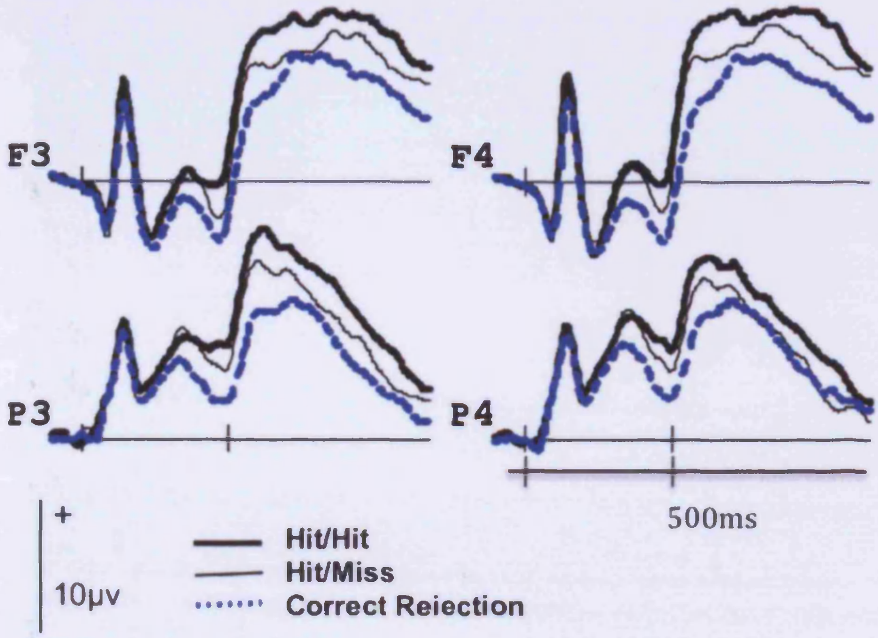


Figure 8.3 Grand averaged event-related potentials elicited by hit/hit, hit/miss and correct rejection. Data are shown for 4 superior electrodes (F3, F4, P3, P4). (n=16)

Hit/miss vs.CR

The analyses gave rise to reliable interactions between category and hemisphere in all epochs. These interactions indicate a greater positivity for hit/miss relative to CR that is largest over the left hemisphere. A reliable interaction between category and site was obtained in the 500-700ms epoch, reflecting the fact that the magnitude of the old/new effect increases along the inferior-superior dimension. A trend for an interaction between category, hemisphere and site in the 700-900ms epoch indicates that the old/new effect tends to be largest over left superior scalp. In the last epoch, the analyses also revealed a category by location interaction, because the old/new effect is largest over anterior scalp.

Hit/hit vs. hit/miss

The analyses revealed significant interactions between category, location, and site in all epochs except from 500-700ms, where the term approached significance. There were also interactions between category and hemisphere in all epochs except for the 700-900ms period. These interactions arise because the greater positivity for the hit/hit relative to hit/miss ERPs is broadly right lateralized, and the difference between conditions is largest at prefrontal electrode sites.

Focused analyses: 1

The outcomes from the global analyses described above indicate that the old/new effects for the hit/hit and hit/miss response categories were broadly similar, but larger for the hit/hit category. Therefore the electrode selection for these focused analyses was based on the outcomes of the hit/hit old/new effect analyses. The analyses were first completed including all three response categories, with paired contrasts conducted as necessary after this. The electrode selections for each epoch are described below and the outcomes of the analyses are shown in Table 8.4. In the first epoch, the focused analyses were conducted at anterior inferior and prefrontal electrodes (F7, FP1, FP2, F8) with factors of hemisphere (2 levels) and site (2). In the second epoch, the focused analyses were conducted at four superior sites (F3, F4, P3, P4) with factors of location (2) and site (2). In the third epoch, the analysis was conducted at left hemisphere electrodes (FP1, F7, F5, F3, O1, P7, P5, P3) with factors of location (2) and site (4). In the final epoch, the effects were conducted over anterior scalp, including all frontal electrodes from which ERPS were acquired (FP1, F7, F5, F3, FP2, F8, F6, F4) with factors of hemisphere (2) and site (4). The initial focused analyses revealed reliable main effects of category in all epochs, and an interaction between category and hemisphere in the first epoch only. The outcomes of all paired analyses separately for each epoch are reported below and shown in Table 8.4.

In the first two epochs, reliable main effects were obtained in all paired contrasts, indicating reliable positive-going old/new effects for both the hit/hit and hit/miss response categories. The effects are reliably larger for the hit/hit category in both epochs. In addition, the effects are right lateralized in the 300-500ms epoch, as indicated by the interaction between category and hemisphere. The hit/miss vs. CR contrast revealed an interaction between category and hemisphere in the 300-500ms epoch, and a category by location interaction in the 500-700ms epoch. The effect in the earlier epoch indicates that the old/new effect is larger at electrodes over the left hemisphere, while the effect is largest over anterior electrodes in the later epoch. No reliable effects were obtained in the hit/miss vs. CR contrast in the 700-900ms epoch, whereas reliable main effects indicated a greater positivity for hit/hit relative to hit/miss and CR. The old/new effect for the hit/hit category in this epoch is also largest at FP1, as indicated by the three way interaction between category, hemisphere and site. In the final epoch, reliable but statistically equivalent old/new effects were obtained for both the hit/hit and hit/miss categories.

Focused analyses: 2

The outcomes of these analyses are shown in Table 8.5. The first of these focused analyses for three mid-frontal electrodes (F3, Fz, F4) was conducted for two epochs: 300-500 and 500-700ms.The initial focused analysis for the three responses in the two epochs revealed main effects of category, and subsequent paired analyses revealed that main effects of category were reliable for all contrasts involving CR. No reliable differences between the hit/hit and the hit/miss old/new effects were observed in the 300-500ms epoch. A marginally significant main effect for the hit/hit vs. hit/miss contrast was obtained in the 500-700ms epoch, indicating that the frontal old/new effect for hit/hit tends to be larger than that for hit/miss.

The second half of the focused analyses involving parietal sites (P7, P5, P3) was conducted for two epochs: 500-700 and 700-900ms. Main effects of category were obtained in the initial analyses for both epochs and an interaction between category and site was obtained in the first epoch only. In the subsequent paired analyses, the hit/hit vs. CR comparison gave rise to a significant main effect of response category in both epochs, and a response category by site interaction in the first epoch, because the hit/hit effect is largest at P3. There was a reliable hit/miss old/new effect in the first epoch only.

For the contrast between the hit/hit and hit/miss response categories, a reliable main effect of category is obtained in the 700-900ms epoch, reflecting a greater positivity for the hit/hit relative to the hit/miss category. The interaction term between category and site approached significance across the 500-900ms epochs, the reason for the interaction is that the old/new effect associated with the hit/hit category appears to be larger than that associated with the hit/miss category, primarily at sites P5 and P3.

Topographic analyses

This analysis was designed to compare the hit/hit-CR and hit/miss-CR differences across time (see Figure 8.2). These differences were reliable for both the hit/hit and hit/miss categories for all epochs in the foregoing (un-rescaled data) analyses. The topographic analyses included factors of response category (2 levels), epoch (2 levels: 300-500 vs. 500-700; 500-700 vs. 700-900, and 700-900 vs. 900-1100ms), as well as all other location factors described above. The only reliable interaction was in the first latency range, which comprised an interaction between category, location, and site ($F(1.9,28.5)=7.38$, $p<0.01$). The reason for the interaction across the two epochs is because there is a common old/new for the two categories at posterior sites, but the effects a anterior sites project forward markedly more for the hit/hit than the hit/miss category.

Discussion

Behavioural data

Participants were able to discriminate old from new faces at a reliable level when source judgments were collapsed across accuracy. When correctly identified old responses were separated for correct and incorrect source judgments, the conditional probability data demonstrated that participants were able to make reliably more correct than incorrect source judgments. While the RTs for old responses associated with correct source judgments did not differ from those for correct rejections, they were faster than old responses associated with incorrect source judgments. Overall, the behavioural data indicates that participants were able to recover the source information in this task on a reasonable proportion of trials, and it is also consistent with findings that old responses associated with subsequent correct source judgments are generally faster relative to old responses associated with incorrect source judgments (Wilding & Rugg, 1996). It is likely that the latter response category requires a greater degree of monitoring prior to responding relative to the former category, as the task relevant information retrieved is likely to be more impoverished (Henson, Rugg, Shallice, & Dolan, 2000). It may also be the case, however, that the time course of retrieval of (probably impoverished) information is slower on trials that elicit a hit/miss response.

ERP data

The use of this paradigm was based on the assumption that an ERP index of familiarity would be common for old faces that attracted either correct or incorrect source judgments, but that correct source judgments could only be supported by recollection, so an ERP index of recollection would comprise larger effects for correct than for incorrect source judgments.

300-500ms

There was a greater relative positivity for hit/hit in comparison to hit/miss which was somewhat right lateralized and maximal at prefrontal electrodes. This effect is thus tied closely to recollection, rather than to familiarity. The distribution of this effect for the hit/hit category is broadly consistent with those obtained in Experiments 2 and 3, therefore one possibility is that the effect reflects the online recovery of face-specific information. In addition, this graded effect was accompanied by evidence for qualitatively different neural activity in the topographic analysis where the hit/hit and hit/miss ERP old/new effects were contrasted. This comes about because the ERPs for the two categories differ minimally at posterior sites, but are markedly more positive-going for the hit/hit category at prefrontal sites. These findings suggest that two sets of generators were engaged differentially during memory judgments that either were or were not accompanied by an accurate source judgment. It is important, however, that focused analysis 2 (that was conducted at three mid-frontal electrodes) revealed no reliable differences between the sizes of the hit/hit and hit/miss old/new effects (see Figure 8.3). The findings from the focused mid-frontal old/new effect analysis in this epoch, and also the similarities between the hit/hit and hit/miss old/new effects at posterior sites (global and topographical analyses) therefore provide some support for the view that ERPs elicited by faces index familiarity and that this index is the mid-frontal ERP old/new effect.

An alternative functional interpretation of these comparable old/new effects is that they are a reflection of non-criterial recollection. According to this account, an effect that is of comparable size for the hit/hit and hit/miss response categories may reflect the recovery of information that can support an old/new judgment but not an accurate source judgment. Hence non-criterial recollection acts like familiarity. As a result, familiarity and non-criterial recollection might be seen as competing accounts for the functional significance of ERP old/new effects that are of equivalent size for hit/hit and hit/miss response categories. This issue will be returned to after a report of the findings in the next experiment.

500-700ms

The same qualitative differences reported above were observed here, and for the same reasons: principally the greater relative prefrontal activity for the hit/hit old/new effect. The outcomes of all focused analyses (at the four superior electrodes, the three mid-frontal electrodes ($p=0.052$), as well as the three parietal electrodes) revealed a greater positivity for hit/hit relative to hit/miss, and both response categories were more positive-going than correct rejections.

These outcomes indicate that the old/new effects in this epoch are sensitive to successful source retrieval. These findings therefore support the view that the observed modulations have a stronger association with recollection than familiarity. The focused analyses at parietal sites revealed a larger old/new effect for hit/hit than for hit/miss. Furthermore, there is evidence that in addition to this parietal modulation that is commonly observed in ERP studies of retrieval in the verbal literature (Rugg, Cox, Doyle, & Wells, 1995; Wilding & Rugg, 1996; Wilding, 2000), a frontal modulation is present. Like the parietal effect, this effect is tied more closely to recollection than to familiarity, and has been observed in previous studies when faces are employed as test stimuli (Experiment 1; Mackenzie & Donaldson, 2007; 2009; see also Yick & Wilding, 2008).

These findings suggest that the frontal component of the old/new effect could reflect additional processes related to recollection for certain stimulus types; in the present context, the retrieval of face-related contextual details that are more available in hit/hit relative to hit/miss responses. Whether this effect is part of a generic signature of recollection for faces (and other complex stimuli) that co-varies with the parietal old/new effect, or there are functionally dissociable components for recollection for a certain stimulus type remains to be determined. In addition, it remains to be determined whether this effect is distinct from the effect that is evident in the preceding epoch at frontal sites and which showed the same functional behaviour. The effect in the later epoch does not appear to be as right-lateralised as the effect in the 300-500ms epoch, but the across epoch analyses did not bear this impression out.

700-900ms and 900-1100ms

The differences between the hit/hit and hit/miss response categories here were broadly similar to those in the preceding epoch, except that the differences were quantitative only. The effects in these epochs reflect primarily a diminishing parietal old/new effect which is larger for the hit/hit than the hit/miss response category, and a right-frontal old/new effect that is equivalent in the two cases. The data in these epochs resemble relatively closely, therefore, the findings in other studies where materials other than faces have been employed and in which source judgments have been made. The data points are consistent with the view that the left-parietal old/new effect is a material- and content-independent index of recollection. The right-frontal effect is likely to be the same effect that has been observed in several previous source retrieval studies (Wilding & Rugg, 1996; Senkfor & Van Petten 1998; Rugg et al., 2000). In some cases, this effect is larger for correct than for incorrect source judgments, whereas in other cases the effect does not honour this separation (for recent discussion, see Cruse & Wilding, 2009; Hayama, Johnson, & Rugg, 2008), as is the case here.

Conclusions

The experiment was designed to identify the neural correlates supporting memory for faces and face features using a source memory paradigm that contained facial stimuli only. At least two modulations were sensitive to the accuracy of the source judgments: a prefrontal modulation in the early epochs (300-700ms) was largest when correct source judgments were made: this effect may be a correlate of recollection that is tied closely to the feature location information that was necessary to make the judgments. In contrast, a more posteriorly distributed modulation was common to both the hit/hit and hit/miss response categories in the 500-700ms epoch, and was sensitive to source accuracy. The correspondence between this effect and the often-reported parietal ERP old/new effect converges on the view that this effect is a relatively generic index of recollection.

The focused analysis at the mid-frontal electrodes in the 300-500ms epoch showed reliable old/new effects that were insensitive to whether task-relevant source information was recovered or not. This provides some basis for the view that ERPs indexed familiarity for faces in this experiment. The link between this effect and familiarity is also strengthened by the suggestive evidence in Experiment 3 where a similar effect was evident. The main limitation of the above experiment, however, is the forced-choice nature of the source memory judgments that followed old/new responses. This design means that a proportion of responses on which correct source judgments were made were not associated with veridical recovery of source information. This introduces potential ambiguities in the functional interpretations of the ERP effects that are common to, or differentiate between, the hit/hit and hit/miss response categories. The next experiment in this thesis was designed to address this issue.

Table 8.3. F-values and significance values for the initial global and all paired comparisons between Hit/Hit-Correct Rejection (CR), Hit/Miss-CR, and Hit/Hit-Hit/Miss over the 300-500, 500-700,700-900, and 900-1100ms epochs. All terminology and other information as for Table 5.3.

Global Analyses:

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (2,30)	**6.56, p<0.01 (0.70)**	**19.81, p<0.01 (0.98)**	**5.98, p<0.01 (0.98)**	**5.16, p<0.05 (0.93)**
RC x AP (2,30)	n.s.	n.s.	n.s.	**5.52, p<0.05 (0.87)**
RC x HM (2,30)	**4.71, p<0.05 (0.84)**	**11.95, p<0.01 (0.98)**	**7.77, p<0.01 (0.96)**	**7.18, p<0.01 (0.95)**
RC x ST (6,90)	n.s.	**14.14, p<0.01 (0.57)**	n.s.	n.s.
RC x AP x ST (6,90)	**2.88, p<0.05 (0.53)**	n.s.	n.s.	n.s.

All paired contrasts:

Hit/Hit vs. CR

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 15)	**19.99, p<0.01**	**44.63, p<0.01**	**8.46, p<0.05**	**8.48, p<0.05**
RC x AP (1,15)	n.s.	n.s.	3.40, p=0.09	**8.25, p<0.05**
RC x HM (1, 15)	n.s.	3.12, p<0.10	**6.87, p<0.05**	n.s.
RC x ST (3, 45)	**2.91, p=0.05 (0.91)**	**11.02, p<0.01 (0.79)**	n.s.	n.s.
RC x AP x ST (3, 45)	**3.76, p<0.05 (0.76)**	n.s.	2.44, p<0.10 (0.75)	2.68, p=0.08 (0.74)

Hit/Miss vs. CR

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 15)	3.79, p=0.07	**9.28, p<0.01**	n.s.	n.s.
RC x AP (1,15)	n.s.	n.s.	n.s.	**15.89, p<0.05**
RC x HM (1, 15)	**7.96, p<0.05**	**22.32, p<0.01**	**15.83, p<0.01**	**14.33, p<0.01**
RC x ST (3, 45)	n.s.	**3.11, p<0.05**	n.s.	n.s.
RC x HM x ST (3, 45)	n.s.	n.s.	2.45, p=0.09 (0.87)	n.s.

Hit/Hit vs. Hit/Miss

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 15)	n.s.	**9.50, p<0.01**	**8.32, p<0.05**	n.s.
RC x HM (1, 15)	**9.70, p<0.01**	**10.35, p<0.01**	n.s.	**5.30, p<0.05**
RC x AP x ST (3, 45)	**5.42, p<0.05 (0.60)**	**2.82,** p=0.09 (0.50)	**3.88, p<0.05 (0.56)**	**3.61, p<0.05 (0.58)**

Table 8.4. F-values and significance values for focused analyses 1 at four anterior inferior and prefrontal electrodes (F7, FP1, FP2, F8) for the 300-500ms; at four superior electrodes (F3, F4, P3, P4) for the 500-700ms; at eight left hemisphere electrodes (FP1, F7, F5, F3, O1, P7, P5, P3) for the 700-900ms, and at eight frontal electrodes (FP1, F7, F5, F3, FP2, F8, F6, F4) for the 900-1100ms epoch. Global analyses and all paired comparisons were conducted between the mean amplitudes associated with Hit/hit, Hit/miss and correct rejection for all epochs. All terminology and other information as for Table 5.3.

Focused Analyses 1: Global Analyses

300-500ms

RC (2,30)	**6.26, p=0.01 (0.79)**
RC x HM (2,30)	**5.13, p<0.05 (0.84)**

500-700ms

RC (2,30)	**24.10, p<0.01 (0.97)**
RC x ST (2,30)	2.70, p=0.09 (0.98)

700-900ms

RC (2,30)	**8.03, p<0.01 (0.93)**

900-1100ms

RC (2,30)	**10.01, p<0.01 (0.85)**

Focused Analyses 1: All Paired Analyses

300-500ms

	HH vs. CR	HM vs. CR	HH vs. HM
RC (1,15)	**14.05, p<0.01**	n.s.	**5.01, p<0.05**
RC x HM (1,15)	n.s.	**13.04, p<0.01**	**6.82, p<0.05**

500-700ms

	HH vs. CR	HM vs. CR	HH vs. HM
RC (1,15)	**56.99, p<0.01**	**13.49, p<0.01**	**8.90, p<0.01**
RC x AP (1,15)	n.s.	**4.71, p<0.05**	n.s.

700-900ms

	HH vs. CR	HM vs. CR	HH vs. HM
RC (1,15)	**18.04, p<0.01**	n.s.	**5.24, p<0.05**
RC x ST (3,45)	n.s.	n.s.	42.54, p<0.10 (0.66)
RC x HM x ST (3,45)	**29.7, p<0.05 (0.66)**	n.s.	32.61, p<0.10 (0.66)

900-1100ms

	HH vs. CR	HM vs. CR	HH vs. HM
RC (1,15)	**14.23, p<0.01**	**7.99, p<0.05**	4.01, p=0.06

Table 8.5. F-values and significance values for focal analyses 2 at F3, Fz, F4 for the 300-500 and 500-700ms epochs, and at P3, P5, P7 for the 500-700 and 700-900ms epochs. Global analyses and all paired comparisons were conducted between the mean amplitudes associated with Hit/hit (HH), Hit/miss (HM) and correct rejection (CR). All terminology and other information as for Table 5.3.

Focused Analyses 2: Global Analyses

Anterior Sites

	300-500ms	500-700ms
RC (2,30)	**14.34, p<0.01 (0.93)**	**32.01, p<0.01 (0.85)**

Parietal Sites

	500-700ms	700-900ms
RC (2,30)	**22.28, p<0.01 (0.81)**	**4.66, p<0.05 (0.89)**
RC x ST (4,40)	**63.03, p<0.05 (0.71)**	**2.88, p<0.05 (0.77)**

Focused Analyses 2: All Paired Analyses

Anterior Sites

		300-500ms	500-700ms
HH vs. CR	RC (1, 15)	**13.38, p<0.01**	**30.82, p<0.01**
HM vs. CR	RC (1, 15)	**4.97, p<0.05**	**8.95, p<0.05**
HH vs. HM	RC (1, 15)	n.s.	4.24, p<0.6

Parietal Sites

		500-700ms	700-900ms
HH vs. CR	RC (1, 15)	**81.00, p<0.01**	**6.81, p>0.05**
	RC x ST (1, 15)	**5.29, p<0.05 (0.89)**	n.s
HM vs. CR	RC (1, 15)	**16.03, p<0.01**	n.s
	RC x ST (1, 15)	n.s	n.s
HH vs. HM	RC (1, 15)	4.24, p<0.6	**4.90, p<0.05**
	RC x ST (1, 15)	3.41, p<0.6	2.96, p<0.8

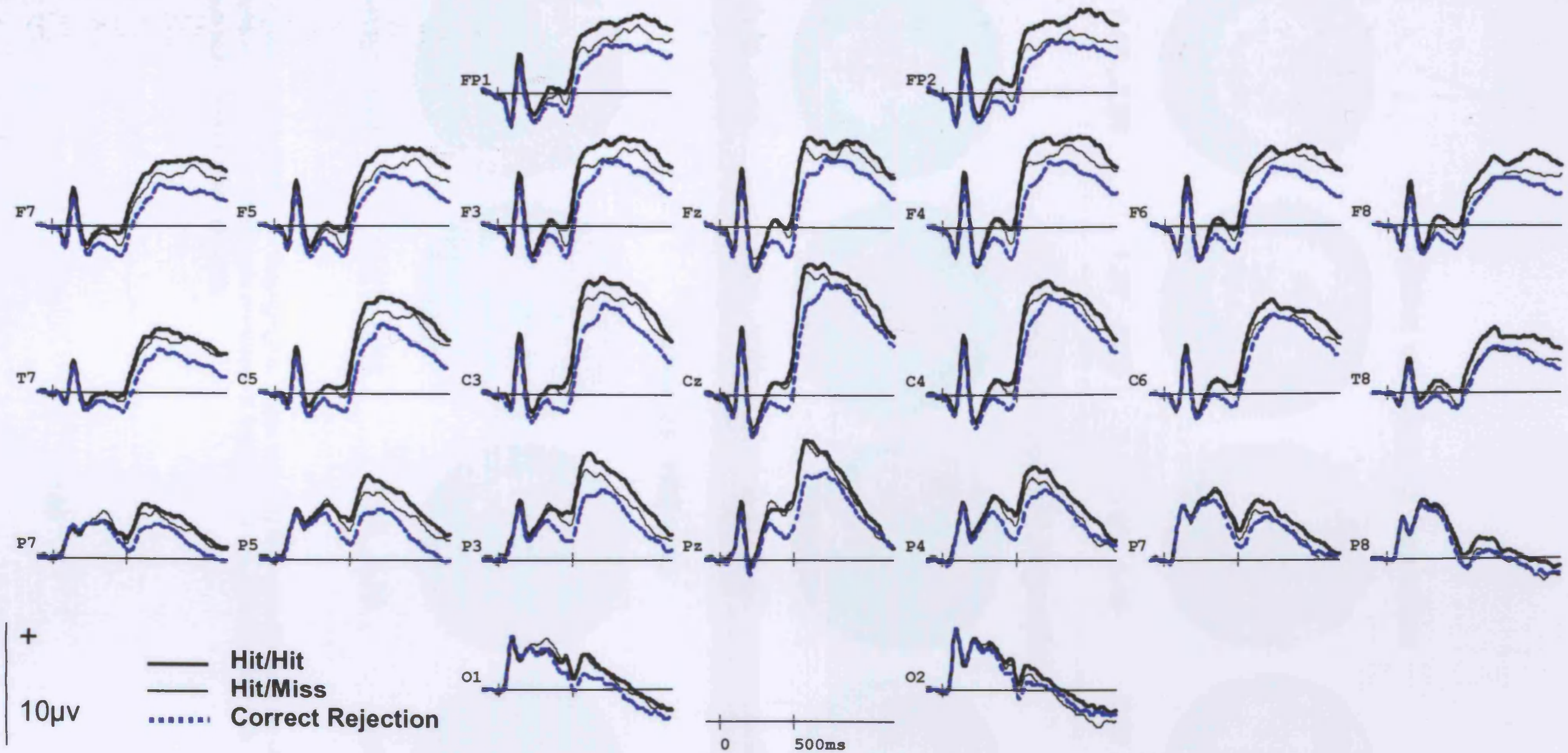


Figure 8.1. Experiment 4 – Grand averaged event-related potentials elicited by hit/hit, hit/miss and correct rejection. Data are shown for 25 electrodes covering prefrontal (FP1, FP2), frontal (F7, F5, F3, Fz, F4, F6, F8), central (C7, C5, C3, Cz, C4, C6, C8), posterior (P7, P5, P3, Pz, P4, P6, P8) and occipital sites (O1, O2). (n= 16)

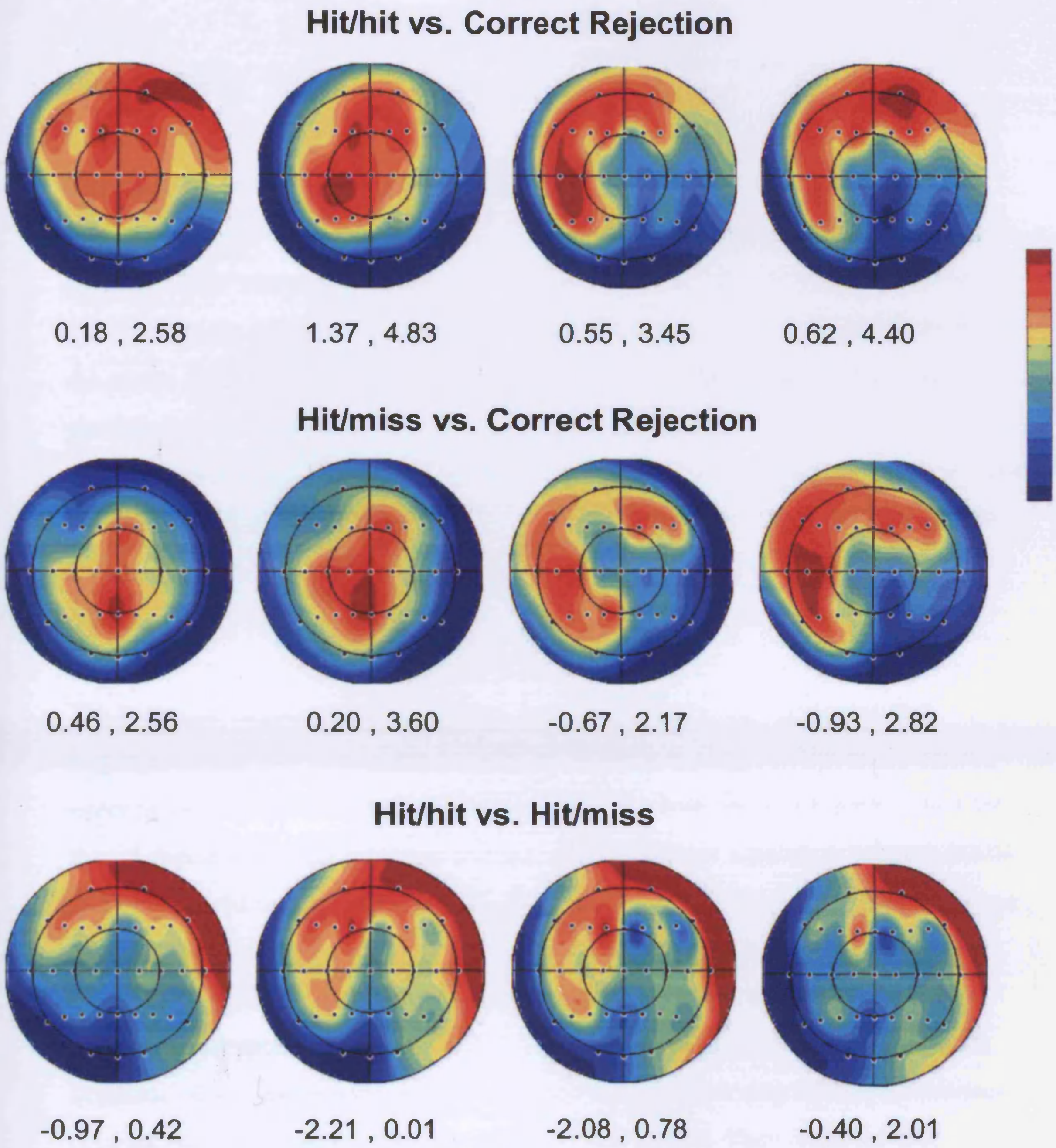


Figure 8.2. Experiment 4 - Topographic maps showing the scalp distributions of the differences between 3 different contrasts of interests for the 300-500, 500-700, 700-900 and 900-1100ms time windows.

Chapter Nine: Experiment 5 - Source Memory for Face Details: Part 2

Introduction

Experiment 4 provided some additional evidences building on the findings in Experiment 3, for a neural correlate of familiarity for faces using a source memory paradigm. ERP old/new effects associated with old items that attracted correct or incorrect source judgments were equivalent in amplitude at the three mid-frontal electrodes in the 300-500ms epoch. Its insensitivity to source memory accuracy provides some support for the view that it is a neural index of familiarity, or alternatively processes linked to non-criterial recollection. The purpose of the present experiment was to generalise the findings of Experiment 4, using a task that provides a more rigorous separation of recognition judgments associated with source recollection.

The paradigm employed in Experiment 4 was structurally very similar to that employed in the first of two experiments by Wilding & Rugg (1996). In the second experiment, they included a 'don't know' option for both the initial old/new and the forced choice source judgment in order to obtain a cleaner separation between hit/hit and hit/miss old/new effects. They reasoned that, because of the forced choice nature of the source decision, a proportion of trials contributing to the hit/hit waveforms were 'lucky guesses'. The presence of these trials (the exact proportion of which would depend upon the level of source accuracy and the number of source options available) would presumably reduce the likelihood of observing reliable differences between the hit/hit and the hit/miss ERPs old/new effects. They reasoned that employing the 'don't know' option was a way of removing these trials from the hit/hit waveforms.

These considerations are relevant here, because they raise the possibility that the reason for statistically equivalent old/new effects for the hit/hit and hit/miss old/new effects is not because the effect indexes a process common to both. Rather, it may be a consequence of the contribution of correct "guess" trials to the hit/hit response category for which little or no source information was available. This possibility was assessed in the present experiment, but rather than using 'don't know' options (Wilding & Rugg, 1996), an additional source response was included. Since only one source response can be correct, this manipulation increases the number of incorrect source responses that can be made. Therefore, when the number of source options is increased, and if participants use all source responses available to them, then the proportion of trials in the hit/hit response category that are 'lucky guesses' will be lower than when only a binary source judgment is required (Experiment 4).

Change to the manipulation used in Experiment 4 will provide a clearer separation of correct old responses based upon veridical source retrieval and those based upon other retrieval processes. If the ERP old/new effects in the 300-500ms replicate the previous findings, they can be linked somewhat more strongly to either familiarity or non-criterial recollection than they can be on the basis of the results in Experiment 4 alone.

Methods

Participants

Twenty-eight took part in the study. Data from 4 participants were discarded prior to analysis because they had insufficient trials (<16) in at least one of the critical categories following artefact rejection. Of those remaining, the average age was 21 (age range 18-29), 2 of whom were male.

Stimuli

The stimulus set comprised 384 front-view black and white faces. Similar to Experiments 3 and 4, each image was used to form a complete and corresponding incomplete stimulus. To form the incomplete stimuli, all stimuli were randomly allocated into 1 of 3 facial feature groups (eye, nose or mouth) and a white block was inserted to obscure the relevant facial part (see Appendix A). Stimuli in the eye group were further divided into two to form a left eye and a right eye group.

The experiment consisted of 12 study-test blocks. Each block contained 16 study and 32 test trials, the test trials comprising an equal number of study (target) and new (unstudied) items. Each study and test phase consisted of an equal number of male and female faces. In each study phase, the 3 possible occlusions had a roughly equal number of occurrences (16 trials: 5: 5: 6). The total number of occlusions and the likelihood of appearance for each feature across all study-test blocks was equivalent. The counterbalancing procedure followed the one described in the General Methods Chapter, see page 80.

Procedure

Participants completed the practice block prior to the actual task. The events occurring in each block were identical to those in Experiment 4, except for the feature response requirements. A three-way feature location response was required; response with the left index finger to stimuli with an eye obscured, a response with the right index finger for nose, and a response with the right middle finger for mouth. The fingers used for feature responses were fixed for all participants. Only the hands used for the old/new response at test were counterbalanced across participants.

Results

Behavioural Data: All participants

Table 9.1 displays the mean probabilities (and SDs) of correct old/new judgements for old and new test faces, and the mean and conditional probabilities of correct/incorrect source judgments for faces judged correctly to be old. Table 9.2 displays the mean probabilities of correct and incorrect source judgments for faces correctly judged old separated according to the correct source at study. Old/new discrimination [p(hit) – p(false alarm)] was above chance for correct old responses collapsed across correct and incorrect source judgments ($t(23)=20.88$, $p<0.01$). The conditional probability was reliably higher for correctly identified old items with the correct source than those responses with an incorrect source decision ($t(23)=4.74$, $p<0.01$). There are 2 incorrect options. For incorrect source judgments, items having the nose covered at study were more likely to be incorrectly associated with the mouth response at test ($t(23) = 2.34$, $p<0.05$); items having the eye or the mouth covered were equally likely to be associated with the other two feature options respectively ($p>0.10$).

Table 9.1. Mean probabilities and standard deviations (SD) of correct initial judgment to old and new faces and the conditional probabilities of correct and incorrect source judgments (collapsed across the two incorrect source judgments) (n=24).

P(Hit)	0.77 (0.07)
P(CR)	0.87 (0.11)
Conditional P(Hit/hit)	0.62 (0.13)
Conditional P(Hit/miss)	0.38 (0.13)

Table 9.2. Probabilities and standard deviations (SD) of correct (shown in bold) and incorrect source judgments for faces judged to be old (n=24).

	Occluded Feature		
Response	Eye	Nose	Mouth
P(Eye)	**0.72(0.09)**	0.18(0.07)	0.13(0.06)
P(Nose)	0.15(0.06)	**0.60 (0.09)**	0.15(0.07)
P(Mouth)	0.13(0.05)	0.22(0.09)	**0.72(0.10)**

Table 9.3 displays the mean RTs (and SDs) for initial old/new judgments to old and new test faces, and the mean RTs for correct initial judgments separated according to subsequent source accuracy. A repeated measures ANOVA revealed a reliable main effect of accuracy ($F(1,23)=28.11$, $p<0.01$), and an interaction between response category and item status ($F(1,23)=16.56$, $p<0.01$). The reason for the interaction is because the RTs for correct new responses were faster than correct old responses ($t(15)=4.71$, $p<0.01$), whereas incorrect new responses were slower than correct old responses ($t(23)=4.20$, $p<0.01$), incorrect old responses ($t(15)=3.41$, $p<0.01$), as well as correct new responses ($t(15)=4.92$, $p<0.01$). A separate analysis conducted for old responses separated for source accuracy indicated that old responses associated with the incorrect source were significantly slower than those old responses associated with correct source judgments ($t(23)=3.13$, $p<0.01$). The two types of old responses were reliably slower than CRs (hit/hit: $t(23)=3.22$, $p<0.01$; hit/miss: $t(23)=5.25$, $p<0.01$).

Table 9.3. Mean reaction times and standard deviations (SD) of initial old/new judgments. Hits are separated according to subsequent source accuracy (n=24).

Hits	1134 (365)
CR:	1063 (306)
Miss:	1211 (352)
FA:	1491 (592)
Hit/hit:	1182 (330)
Hit/miss:	1286 (413)

Behavioural Data: Misses (16 Participants)

For the ERP analyses, the data from a subset of 16 participants who had sufficient trials for misses were submitted to separate behavioural analyses. The behavioural data for the sub-group of participants are shown in Tables 9.4 and 9.5, and were analysed following the same procedure as in the above analyses. Broadly similar patterns of behavioural and RT data was obtained. Discrimination accuracy was 0.63 ($t(15)=21.72$, $p<0.01$), and the conditional probability for a correct source judgments was reliably higher than for an incorrect source judgment ($t(15) = 4.45$, $p<0.01$).

For RTs, there was a reliable main effect of accuracy ($F(1,15)=13.61$, $p<0.01$), as well as an interaction with this factor and item status ($F(1,15)=10.65$, $p<0.01$). The reason for the interaction term is broadly identical to the analyses for all participants. A separate analysis indicate that CRs were faster relative to old responses associated with correct source ($t(15)=3.74$, $p<0.01$), and incorrect source judgments ($t(15)=4.32$, $p<0.01$). For old responses, the RT for correct source judgments is faster than incorrect source judgments ($t(15)=2.35$, $p<0.04$).

Electrophysiological Data

ERP Analyses

The same principal analysis strategy was employed as in Experiment 4. For all 24 participants, the mean numbers of trials for hit/hit, hit/miss and CRs were 42 (range = 18 to 78), 24 (16 to 45), and 68 (17 to 109). For the sub-set of 16 participants for whom there were enough artefact-free trials for analyses involving misses, the mean numbers of trials were 24 (16 to 38) for misses and 79 (30 to 109) for CRs. The outcomes of the ERP analyses for the subset of 16 participants are described below after the results for all 24 participants are presented.

Figures 9.1 and 9.2 show the grand averages and scalp maps elicited by the hit/hit, hit/miss, and CR response categories for all participants. Figure 9.1 shows that the ERPs for hit/hits start to diverge from approximately 270ms at anterior electrodes from CRs, and somewhat later at posterior electrodes, from approximately 320ms. The ERP waveforms elicited by the hit/hit response categories are more positive going than those elicited by CRs. The differences are broadly distributed along the anterior-posterior dimension in the 500-700ms time window, and become more left lateralized at posterior electrodes, as well as at right anterior electrodes toward the end of the recording epoch.

Figure 9.1 shows that the ERPs for hit/miss differ minimally from CRs in the first 500ms. The differences become more prominent in the 500-700ms time window where the magnitude of the differences decreases along the superior-inferior dimension. From approximately 850ms onwards, the differences become largest at prefrontal and right anterior electrodes.

Global contrasts: All participants

Following the analysis strategy in Experiment 4, the initial analyses for all 24 participants for each of the 3 categories revealed an interaction between category, hemisphere and site in the first three epochs (see Tables 9.6. The interaction between category, location and hemisphere is also obtained across the 500-900ms epoch. In the last epoch, category, location, and hemisphere, as well as category, location and site interactions were obtained. These outcomes license the subsequent paired contrasts that are described below. Table 9.6 displays the outcomes of the analyses for the initial and subsequent paired comparisons between the ERPs associated with the hit/hit, hit/miss, and correct rejection response categories.

Critical paired contrasts

Hit/hit vs. CR

The analyses revealed reliable old/new differences in all epochs. A reliable main effect of category and interactions between this factor and location, as well as site, were obtained in the 300-500ms epoch. These two interactions reflect the fact that the greater positivity for the hit/hit response category is larger over anterior scalp, as well as at sites closest to the midline (see Figure 9.3). In the last two epochs, reliable interactions between category, location and hemisphere were obtained, and the same interaction term approached significance in the 500-700ms epoch. These interactions reflect the fact that the old/new effect is largest at right anterior electrodes. Interactions between category, location and site occurred in the last three epochs, indicating that the old/new effect is largest over anterior (prefrontal) regions in these time windows. The analyses also revealed a significant interaction between category, hemisphere and site in the 700-900ms epoch, because the old/new effect is largest at left inferior sites.

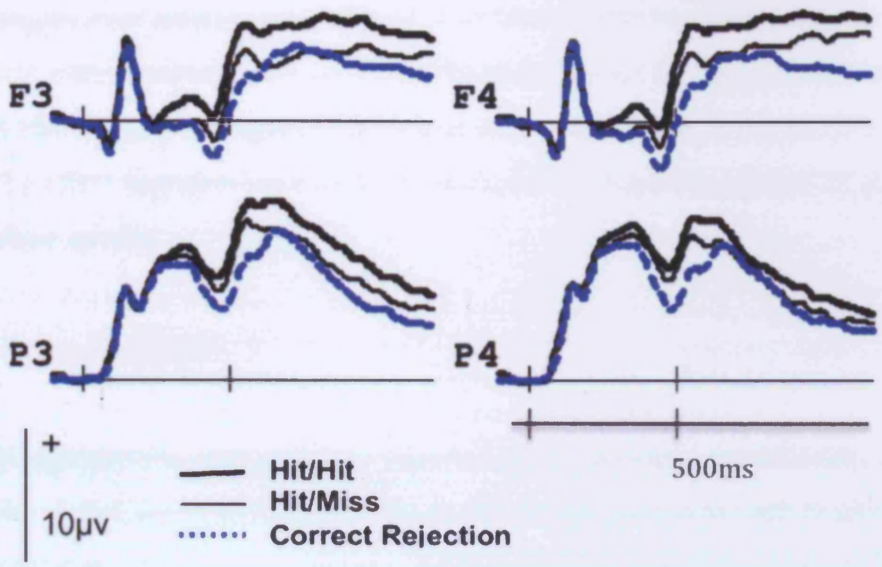


Figure 9.3 Grand averaged event-related potentials elicited by hit/hit, hit/miss and correct rejection. Data are shown for 4 superior electrodes (F3, F4, P3, P4). (n=24)

Hit/miss vs. CR

The analyses gave rise to a reliable interaction between category and site in the 300-500ms epoch, indicating that the positive old/new effect is largest at sites closest to the midline. The analyses revealed interactions between category, location and hemisphere in the last three epochs. These interactions indicate that the old/new effects are largest at right anterior sites. A reliable interaction between category, location and site occurred in the 900-1100ms epoch, and the same interaction was marginally significant in the 500-700 and 700-900ms epochs. These interactions reflect the fact that the positive-going old/new effect is largest at prefrontal electrodes. The interaction between category, hemisphere and site approached significance in the two earliest epochs, because the positive old/new effects are largest at right inferior sites.

Hit/hit vs. hit/miss

A significant interaction between category and location was obtained in the 300-500ms epoch, reflecting the greater positivity for the hit/hit response category that is largest over anterior scalp. Three-way interactions between category, hemisphere and site were obtained in all epochs, reflecting the fact that the greater positivity for the hit/hit response category is largest at left superior sites in the 300-500ms epoch, while the effect increases in magnitude along the left superior-inferior dimension in the last three epochs.

Focused analyses: 1

Keeping to the same analysis approach in the previous experiments, the outcomes of the global analysis for the hit/hit vs. CR comparison was used to guide the focused analyses. The initial analysis contained all three response categories and was followed up by all paired contrasts as necessary. The electrode selections for each epoch are described below. In the first epoch, the focused analysis was conducted at four superior sites (F3, F4, P3, P4) with factors of location (2 levels), and site (2). In the 500-700ms and the 900-1100ms epochs, the focal analysis was conducted at right anterior electrodes. This includes four right anterior electrodes (FP2, F8, F6, F4). In the 700-900ms epoch, the focused analysis was conducted over anterior scalp, including 8 frontal electrodes (FP1, F7, F5, F3, FP2, F8, F6, F4) with factors of hemisphere (2), and site (4). The initial focused analyses revealed reliable main effects, as well as interactions with other factors, in all epochs, which permits the subsequent analyses described below. The outcomes of the initial and the paired focused analyses are shown in Table 9.7.

In the first epoch, reliable main effects of category were obtained for all paired contrasts, indicating reliable old/new effects for the hit/hit and for the hit/miss response categories[1]. The old/new effect for hit/hit is also larger than the effect for the hit/miss category. For the two contrasts involving hit/hit, reliable interactions between

[1] The same focused analysis at the four superior electrodes was conduced on the data from the preceding experiment. The magnitude of the superiorly distributed old/new effects in Experiment 4 did not differ between the hit/hit and hit/miss response categories ($p>0.10$).

category and location reflect the fact that the greater positivity for the hit/hit response category relative to CR, as well as to hit/miss, is largest at anterior electrodes.

Reliable main effects were obtained for all contrasts for the 500-700 and 900-1100ms epochs. The main effects indicate that the waveforms associated with the two classes of old responses in each case are more positive-going than those associated with CRs. There is also a greater positivity for the hit/hit relative to the hit/miss response categories. In addition, reliable interactions between category and site were obtained for the 500-700ms epoch for the analyses involving the hit/hit category, indicating the greater positivity for the hit/hit response relative to CR and the hit/miss response category, which is largest at F4.

In the 700-900ms epoch, the analysis revealed a category by site interaction for the hit/hit vs. CR comparison, because the positive-going old/new effect increases in magnitude along the inferior-superior dimension. For the contrasts involving the hit/miss category, reliable three-way interactions were obtained between category, hemisphere and site but for different reasons. The hit/miss vs. CR term indicates a positive old/new effect that is largest at right superior sites. The hit/hit vs. hit/miss contrast reflects a more positive-going waveform for the hit/hit response relative to the hit/miss category that is largest over the left hemisphere. This differences increases in magnitude along the superior-inferior dimension.

Focused analyses: 2

These analyses outcomes are shown in Table 9.8. The initial focused analyses over the three mid-frontal electrodes (F3, Fz, F4) for the three response categories in the 300-500 and 500-700ms epochs revealed main effects of category. For the paired contrasts, reliable main effects were obtained for all comparisons in the two epochs, indicating positive old/new effects for the hit/hit and hit/miss categories. The waveform for the hit/hit response category is also reliably more positive going than that for the hit/miss response category.

The initial focused analyses at three parietal electrodes (P7, P5, P3) across the 500-700ms and 700-900ms epochs revealed reliable main effects as well as interactions with site. In the subsequent paired analyses, reliable main effects and the same interaction with site were obtained for all contrasts (except in the 700-900ms epoch, in which no reliable effects were obtained in the hit/miss vs. CR comparison). The reliable effects indicate positive-going old/new effects for the hit/hit and hit/miss response category, and a greater positivity for the hit/hit relative to the hit/miss category. The interaction term indicates that these differences are largest at P3 in all cases.

Topographic analyses

The scalp topographies of the ERP old/new effects for the hit/hit and hit/miss response categories are shown in Figure 9.2. The differences between the scalp distributions of the hit/hit and hit/miss old/new effects were compared for all epochs, because both response categories differed reliably in the foregoing analysis in each epoch. The analyses revealed three-way interactions between category, hemisphere and site in all epochs (300-500ms: ($F(2.0,46.7)=4.40$, $p=0.02$); 500-700ms: ($F(2.0,45.1)=5.30$, $p<0.01$); 700-900ms: $F(2.2,50.5)=5.51$, $p<0.01$; 900-1100ms: $F(2.2,51.4)=3.94$, $p=0.02$). These interactions reflect a general pattern where the old/new effects for hit/hit are more left lateralized, whereas the effects extend towards the opposite lateralisation.

The second part of the analysis investigated the distribution of the old/new effects for the hit/hit as well as for the hit/miss response category over time. These analyses included the factor epoch (2 levels: 300-500 vs 500-700; 500-700 vs 700-900, and 700-900 vs 900-1100ms) as well as the location factors described above.

For the old/new effects associated with the hit/hit response category, there were four-way interactions between epoch, location, hemisphere, and site in the first and the last latency pairs [300-500 vs. 500-700ms: $F(2.1,47.7)=3.49$, $p<0.04$; 700-900 vs.900-1100ms: $F(2.3,52.9)=3.03$, $p=0.05$)]. These interactions were followed up by analyses separated for anterior and posterior sites for the two time ranges. In the first latency range, an interaction between epoch and site ($F(2.0,45.8)=9.50$, $p<0.05$) was obtained at posterior sites only, indicating the old/new effect has a more diffuse distribution over superior sites in the later epoch. In the last latency range, an epoch by hemisphere interaction was obtained at anterior sites ($F(1,23)=8.94$, $p<0.01$), indicating the effect becomes more right-lateralised over time. This is also true for posterior scalp, where the left-lateralized effect is largest at the mid-lateral electrodes in the 700-900ms epoch, and the effect diminishes over time, as indicated by the interaction between epoch, hemisphere, and site ($F(2.4,55.4)=5.78$, $p<0.01$). Finally, in the second latency range (500-700 vs. 700-900ms), an interaction between epoch, hemisphere and site ($F(1.9,44.0)=3.38$, $p<0.05$) indicates the old/new effect in the 700-900ms has a broader distribution over the left hemisphere relative to that in the 500-700ms epoch.

For the old/new effects associated with the hit/miss response category, an interaction between epoch, location, hemisphere, and site was obtained in the first latency pair ($F(2.0, 44.9)=4.65$, $p<0.5$). Follow up analyses revealed an interaction involving epoch and site at posterior sites only ($F(2.0,46.4)=4.05$, $p<0.03$). This interaction indicates that the old/new effects extend to a greater degree to posterior sites in the earlier epoch.

Global and focused contrasts: Misses (16 Participants)

To explore whether there were reliable differences for the ERPs elicited by Misses and CRs, global analyses as described above and the two sets of focused analyses also described were conducted for these response categories only. Figures 9.4 and 9.5 shows that the ERP waveforms for the Misses and CRs differ minimally from each other. The only reliable effect was obtained from the global analysis in the 700-900ms epoch, where an interaction between category, hemisphere and site ($F(2.4,35.5)=3.38$, $p<0.05$) reflects a greater positivity for CRs that is largest at left inferior, mid-lateral electrodes. The behavioural data for these 16 participants can be found in Tables 9.4 and 9.5.

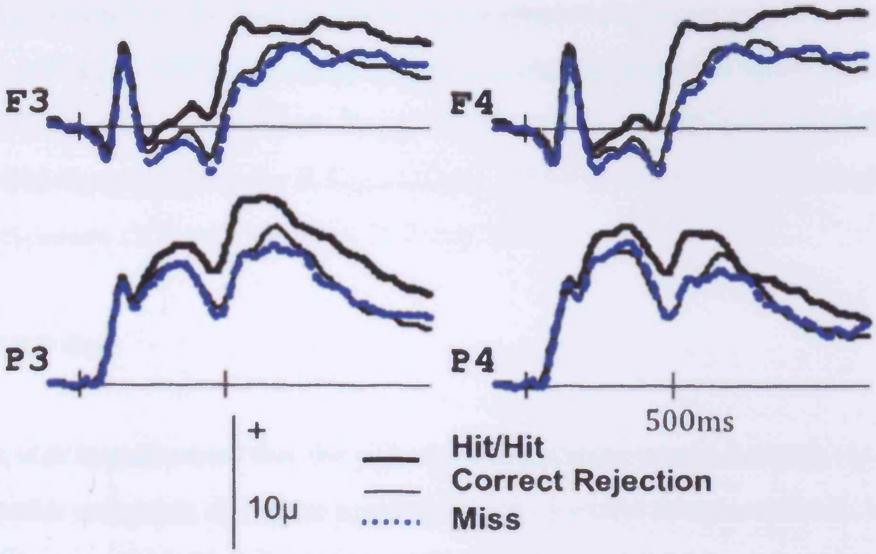


Figure 9.4. Grand averaged event-related potentials elicited by hit/hit, correct rejection and miss. (n=16)

Discussion

Behavioural data

Memory performance is comparable to that reported in Experiment 4. The overall memory performance for all 24 participants and the sub-group of 16 participants was broadly similar. Participants were able to discriminate old from new items. The conditional probability of a correct source judgment was reliably above chance. Although the source memory task was made more difficult in comparison to Experiment 4 by increasing the number of source options available, source accuracy did not differ markedly across the two experiments, possibly because of the shorter study-test blocks employed in Experiment 5. Hence, because of the use of three rather than two source response options, the present experiment is likely to have reduced the proportion of correct source judgments that were based on "lucky guesses".

Consistent with findings in the previous experiments is the finding that participants were quickest for making correct new responses. The RT data also converges with previous studies in that correct source judgments were associated with faster RTs than incorrect source judgments (see Experiment 4 and Wilding & Rugg, 1996). Because the reported RT data reflects the initial old/new judgments for the source memory test, the slower RTs for the incorrect source relative to correct source judgments is likely to reflect an additional decision process when recollection failed (see also Dewhurst & Conway, 1994; Henson, Rugg, Shallice, & Dolan, 2000). Comparable results have been reported using the R/K paradigm, where R responses are typically faster than K responses (Vilberg, Moosavi & Rugg, 2006).

ERP data

It was hypothesised that the present manipulation would increase the proportion of hit/hit responses that were associated with genuine source retrieval, because the chances of guessing the source option correctly should be reduced in comparison to Experiment 4. Consequently, the ERPs elicited by the hit/hit response category should provide a more reliable index of the processes that support correct source memory, hence a better reflection of the processes that differentiate correct and incorrect source judgments. The analysis outcomes for all 24 participants and the subset of 16 participants in which analyses focused on misses are discussed separately.

All 24 participants:

300-500ms

For both hit/hit and hit/miss responses, the global analyses revealed reliable old/new effects that are largest at superior electrodes, as well as over anterior sites. There was also a greater positivity for the hit/hit relative to the hit/miss response category particularly at anterior and left hemisphere sites. The topographic analysis showed that the distributions of the hit/hit and hit/miss old/new effects are different. These distribution differences indicate that the neural generators supporting the retrieval of specific source information are not entirely the same as those supporting the retrieval of non-specific information. The more left-lateralized effect associated with the hit/hit category might be the early onset of the left-parietal old/new effect that is commonly linked with recollection, because it is selectively associated with responses for which the critical source information was retrieved. Broadly consistent with the finding in Experiment 4, the greater anterior activity for the hit/hit category might index the on-line recollection of source information.

The major inconsistency in the findings between Experiment 4 and the present study is the outcomes from the focused analyses at the mid-frontal and the superior sites. Critically, these old/new effects were sensitive to source accuracy in this experiment. The graded pattern of old/new effects in this epoch challenges the view that old/new effects at superior sites or restricted to mid-frontal sites is a neural index of familiarity (see Experiment 4; Curran &Hancock, 2007). This modulation, in contrast, differentiates between the hit/hit and hit/miss responses in a paradigm where the study and test manipulation is likely to have increased the proportion of trials accompanied by veridical source retrieval that fall into the hit/hit response category. This effect thus tracks the accuracy of source memory judgments and is therefore tied to recollection. Hence, in contrast to the data in Experiment 4, the findings in this time window provide no direct evidence that any modulation is associated with familiarity.

500-700ms

Consistent with the behaviour of indices of recollection, the effects reported in this epoch are sensitive to source accuracy and were broadly similar to those in the previous epoch. The fact that reliable effects were obtained for the two classes of old responses suggests that recollection was engaged for all correct old responses regardless of the accuracy of source judgments, but these recollection processes were engaged to a greater extent when the task relevant source information was recovered. As in previous experiments, these findings are consistent with the view that recollection is a graded process, and the magnitude of the parietal effect is indicative of the quality of the retrieved information (Wilding, 2000; Yonelinas 2002; Vilberg & Rugg, 2007; 2009).

The fact that the old/new effects have an anterior maximum along with a reliable left-parietal modulation in this epoch is consistent with findings in previous experiments in this thesis. The findings are in line with the view that the left-parietal old/new is related to generic recollection, whereas the anterior modulation could be related to the on-line recollection of information that is specific to faces (Experiments 1 and 4). With the present data it is difficult to determine whether there are two distinct processes with separable frontal and parietal components or whether one single process that is broadly distributed across anterior and posterior scalp.

The topographic analysis outcomes between 300-700ms epochs provide some evidence for the former possibility. Common to both the hit/hit and hit/miss response categories is that the distribution of the old/new effects over the anterior scalp did not change over time, but the parietal effects become more focused over superior electrodes in the 500-700ms epoch. One possibility is that the frontal old/new effect (with an early onset from around 300ms post-stimulus) differentiates between the hit/hit and hit/miss responses on the basis of the amount of face-related information that is recovered, whereas the parietal old/new effect onsetting from around 500ms is related to generic recollection processes. Other alternatives will be discussed in the subsequent chapter (General discussion).

700-900ms and 900-1100ms

The old/new effects for the hit/hit and hit/miss responses in these epochs are largest over anterior scalp and maximal at right-frontal scalp. Contrasting with Experiment 4, these right-frontal old/new effects did not differ between hit/hit and hit/miss responses, suggesting functional roles associated with retrieval monitoring or post-retrieval evaluation processes that are independent of source accuracy.

Like in the early epochs, the hit/hit old/new effect in comparison to the hit/miss old/new effect had a different distribution. The topographically distinct left lateralized effect associated with the hit/hit category is likely to reflect a left-parietal old/new effect that extends over time (see Figure 9.2). In keeping with the data from other source memory studies, as well as the data for the 500-900ms time window, the transition of the hit/hit old/new effect from a left to a right hemisphere maximum over time is broadly consistent with the view that the early left-parietal effect indexes recollection, and the late right frontal effect indexes processes contingent upon recollection (Wilding & Rugg, 1996; Henson, Rugg, Shallice, & Dolan, 2000; Senkfor & Van Petten, 1998; Herron, 2007).

Misses

An analysis on data from 16 participants contrasted the ERPs elicited by misses with those associated with CRs. The rationale for this contrast is that any old/new effects that are common to the Miss vs. CR effects are likely to be correlates of implicit memory. Thus it is important to analyse misses to ensure that effects one wishes to associate with explicit memory operations are not evident or are attenuated for misses. Critically, the analyses involving misses revealed no reliable old/new effects in time intervals and scalp locations where effects that might be linked to recollection or familiarity were identified.

Conclusions

Experiment 5 used a source memory paradigm similar to Experiment 4 in which the source options at retrieval were increased to reduce the proportion of hit/hit responses that are not associated with source retrieval. This was done to provide a clearer separation between responses associated with source recollection and other retrieval processes.

While a superior old/new effect in the 300-500ms epoch in Experiment 4 was insensitive to source accuracy, this modulation had a greater positivity for old responses attracting correct relative to incorrect source responses in Experiment 5. This finding challenges the view that this modulation indexes familiarity. The same pattern of data was obtained in the 500-700ms epoch. The anterior old/new effects for the hit/hit and the hit/miss responses did not change across the 300-700ms epoch, whereas the effects become more focused over posterior superior sites from 500-700ms, supporting the possibility that there are distinct components engaged across the two time windows. Finally, the data for misses suggests that the majority of the ERP old/new effects reported in this thesis index explicit memory processes.

Table 9.4. Mean probabilities and standard deviations (SD) of correct initial judgment to old and new faces and the conditional probabilities of correct and incorrect source judgments for the sub-group of 16 participants who had sufficient miss trials for analyses (collapsed across the two incorrect source judgments).

P(Hit)	0.75 (0.07)
P(CR)	0.88 (0.12)
Conditional P(Hit/hit)	0.63 (0.13)
Conditional P(Hit/miss)	0.27 (0.13)

Table 9.5. Mean reaction times and standard deviations (SD) of initial old/new judgments for the subset of 16 participants who had sufficient miss trials for analyses. Hits are separated according to the source accuracy.

Hits	1122 (366)
CR:	1082 (250)
Miss:	1163 (291)
FA:	1462 (645)
Hit/hit:	1182 (350)
Hit/miss:	1161 (394)

Table 9.6. F-values and significance values for the Hit/Hit-Correct Rejection (CR), Hit/Miss-CR, Hit/Hit-Hit/Miss comparisons over the 300-500, 500-700,700-900, and 900-1100ms epochs. All terminology and other information as for Table 5.3.

Global Analyses:

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (2,46)	**20.79, p<0.01 (0.97)**	**38.29, p<0.01 (0.91)**	**14.64, p<0.01 (0.96)**	**17.56, p<0.01 (0.89)**
RC x AP (2,46)	**4.26, p<0.05 (0.89)**	n.s.	n.s.	**5.00, p<0.01 (0.95)**
RC x HM (2,46)	n.s.	n.s.	**4.25, p<0.05 (0.99)**	n.s.
RC x ST (6,138)	**10.14, p<0.05 (0.56)**	**16.49, p<0.01 (0.61)**	**7.62, p<0.01 (0.60)**	**6.58, p<0.01 (0.60)**
RC x AP x HM (2,46)	n.s.	**4.01, p<0.05 (0.90)**	**7.36, p<0.01 (0.74)**	**11.78, p<0.01 (0.86)**
RC x AP x ST (6,138)	n.s.	2.10, p=0.09 (0.64)	2.47, p=0.06 (0.64)	**3.22, p<0.01 (0.73)**
RC x HM x ST (6,138)	**3.30, p<0.05 (0.61)**	**3.33, p<0.05 (0.63)**	**4.15, p<0.01 (0.70)**	2.29, p=0.06 (0.73)

All paired contrasts:

Hit/Hit vs. CR

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 23)	**37.02, p<0.01**	**83.80, p<0.01**	**22.12, p<0.01**	**32.79, p<0.01**
RC x AP (1, 23)	**9.62, p<0.01**	ns.	**4.68, p<0.05**	**8.58, p<0.01**
RC x HM (1, 23)	ns.	ns.	**7.47, p<0.01**	ns.
RC x ST (3, 69)	**19.33, p<0.01 (0.66)**	**30.46, p<0.01 (0.75)**	**14.08, p<0.01 (0.73)**	**10.87, p<0.01 (0.70)**
RC x AP x HM (1, 23)	ns.	3.10, p=0.09	**8.53, p<0.01**	**14.94, p<0.01**
RC x AP x ST (3, 69)	ns.	**3.13, p<0.05 (0.80)**	**5.34, p<0.01 (0.79)**	**6.33, p<0.01 (0.77)**
RC x HM x ST (3, 69)	ns.	ns.	**3.39, p<0.05 (0.69)**	ns.

Hit/Miss vs. CR

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 23)	**10.70, p<0.01**	**22.11, p<0.01**	ns.	**8.78, p<0.01**
RC x AP (1, 23)	ns.	ns.	ns.	**4.95, p<0.05**
RC x HM (1, 23)	ns.	ns.	ns.	ns.
RC x ST (3, 69)	**5.18, p=0.01 (0.56)**	2.72, p=0.09 (0.53)	ns.	ns.
RC x AP x HM (1, 23)	ns.	**6.92, p<0.05**	**8.51, p<0.01**	**14.45, p<0.01**
RC x AP x ST (3, 69)	ns.	3.08, p=0.06 (0.66)	2.87, p=0.06 (0.71)	**3.76, p<0.05 (0.76)**
RC x HM x ST (3, 69)	2.74, p=0.07 (0.73)	3.06, p=0.06 (0.67)	ns.	ns.

Hit/Hit vs. Hit/Miss

	300-500ms	500-700ms	700-900ms	900-1100ms
RC (1, 23)	**11.54, $p<0.01$**	**16.12, $p<0.01$**	**16.83, $p<0.01$**	**9.93, $p<0.01$**
RC x AP (1, 23)	**4.83, $p<0.05$**	ns.	ns.	ns.
RC x HM (1, 23)	ns.	ns.	**4.85, $p<0.05$**	ns.
RC x ST (3, 69)	ns.	**14.88, $p<0.01$ (0.70)**	**9.78, $p<0.01$ (0.74)**	**9.02, $p<0.01$ (0.85)**
RC x AP x HM (1, 23)	3.76, $p=0.7$	ns.	ns.	ns.
RC x HM x ST (3, 69)	**5.08, $p<0.01$ (0.63)**	**5.63, $p<0.01$ (0.75)**	**7.47, $p<0.01$ (0.71)**	**4.26, $p<0.05$ (0.74)**

Table 9.7. F-values and significance values for focused analyses 1 at four superior electrodes (F3, F4, P3, P4) for the 300-500ms epoch; at four right frontal electrodes (FP2, F8, F6, F4) for the 500-700 and 900-1100ms epochs; and at eight frontal electrodes (FP1, F7, F5, F3, FP2, F8, F6, F4) for the 700-900ms epoch. Global analyses and all paired comparisons were conducted between the mean amplitudes associated with Hit/hit (HH), Hit/miss (HM) and correct rejection (CR) for all epochs. All terminology and other information as for Table 5.3.

Focused Analyses 1: Global Analyses

300-500ms

RC (2,46)	**23.35, p<0.01 (0.97)**
RC x AP (2,46)	3.17, p=0.06 (0.93)

500-700ms

RC (2,46)	**22.51, p<0.01 (0.95)**
RC x ST (6,138)	**7.80, p<0.01 (0.66)**

700-900ms

RC (2,46)	**16.11, p<0.01 (0.99)**
RC x ST (6,138)	**3.27, p<0.05 (0.49)**
RC x HM x ST (6,138)	**3.09, p<0.05 (0.71)**

900-1100ms

RC (2,46)	**26.30, p<0.01 (0.94)**

Focused Analyses 1: All Paired Analyses

300-500ms

	HH vs. CR	HM vs. CR	HH vs. HM
RC (1,23)	**39.47, p<0.01**	**10.99, p<0.01**	**14.92, p<0.01**
RC x AP (1,23)	**4.884, p<0.05 (0.93)**	n.s.	**4.74, p<0.05**

500-700ms

	HH vs. CR	HM vs. CR	HH vs. HM
RC (1,23)	**45.33, p<0.01**	**16.24, p<0.01**	**7.86, p<0.01**
RC x ST (3,69)	**11.30, p<0.01 (0.67)**	n.s.	**9.65, p<0.01 (0.75)**

700-900ms

	HH vs. CR	HM vs. CR	HH vs. HM
RC (1,23)	**28.02, p<0.01**	n.s.	**15.86, p<0.01**
RC x ST (3,69)	**3.40, p<0.05 (0.79)**	n.s.	**4.57, p<0.05 (0.55)**
RC x HM x ST (3,69)	n.s.	n.s.	**3.81, p<0.05 (0.77)**

900-1100ms

	HH vs. CR	HM vs. CR	HH vs. HM
RC (1,23)	**47.75, p<0.01**	**20.36, p<0.01**	**6.12, p<0.05**
RC x ST (3,69)	2.71, p=0.07 (0.75)	n.s.	n.s.

Table 9.8. F-values and significance values for focused analyses 2 at F3, Fz, F4 for the 300-500 and 500-700ms epochs, and at P3, P5, P7 for the 500-700 and 700-900ms epochs. Global analyses and all paired comparisons were conducted between the mean amplitudes associated with Hit/hit (HH), Hit/miss (HM) and correct rejection (CR). All terminology and other information as for Table 5.3.

Focused Analyses 2: Global Analyses

Anterior Sites

	300-500ms	500-700ms
RC (2,46)	**22.69, p<0.01 (0.94)**	**32.01, p<0.01 (0.85)**

Parietal Sites

	500-700ms	700-900ms
RC (2,46)	**18.90, p<0.01 (0.96)**	**8.97, p<0.01 (0.90)**
RC x ST (4,92)	**6.91, p<0.01 (0.77)**	**2.88, p<0.05 (0.77)**

Focused Analyses 2: All Paired Analyses

Anterior Sites

		300-500ms	500-700ms
HH vs. CR	RC (1, 15)	**38.23, p<0.01**	**55.62, p<0.01**
	RC x ST (1, 15)	n.s.	n.s.
HM vs. CR	RC (1, 15)	n.s.	**3.51, p=0.05 (0.78)**
	RC x ST (1, 15)	n.s	n.s
HH vs. HM	RC (1, 15)	**22.82, p<0.01**	**21.30, p<0.01**
	RC x ST (1, 15)	n.s	n.s

Parietal Sites

		500-700ms	700-900ms
HH vs. CR	RC (1, 15)	**31.72, p<0.01**	**13.99, p<0.01**
	RC x ST (1, 15)	**12.92, p<0.01 (0.80)**	**6.77, p<0.01 (0.84)**
HM vs. CR	RC (1, 15)	**10.47, p<0.01**	n.s.
	RC x ST (1, 15)	**3.66, p<0.05 (0.84)**	n.s.
HH vs. HM	RC (1, 15)	**10.44, p<0.01**	**10.93, p<0.01**
	RC x ST (1, 15)	**3.85, p<0.05 (0.91)**	3.02, p=0.08 (0.86)

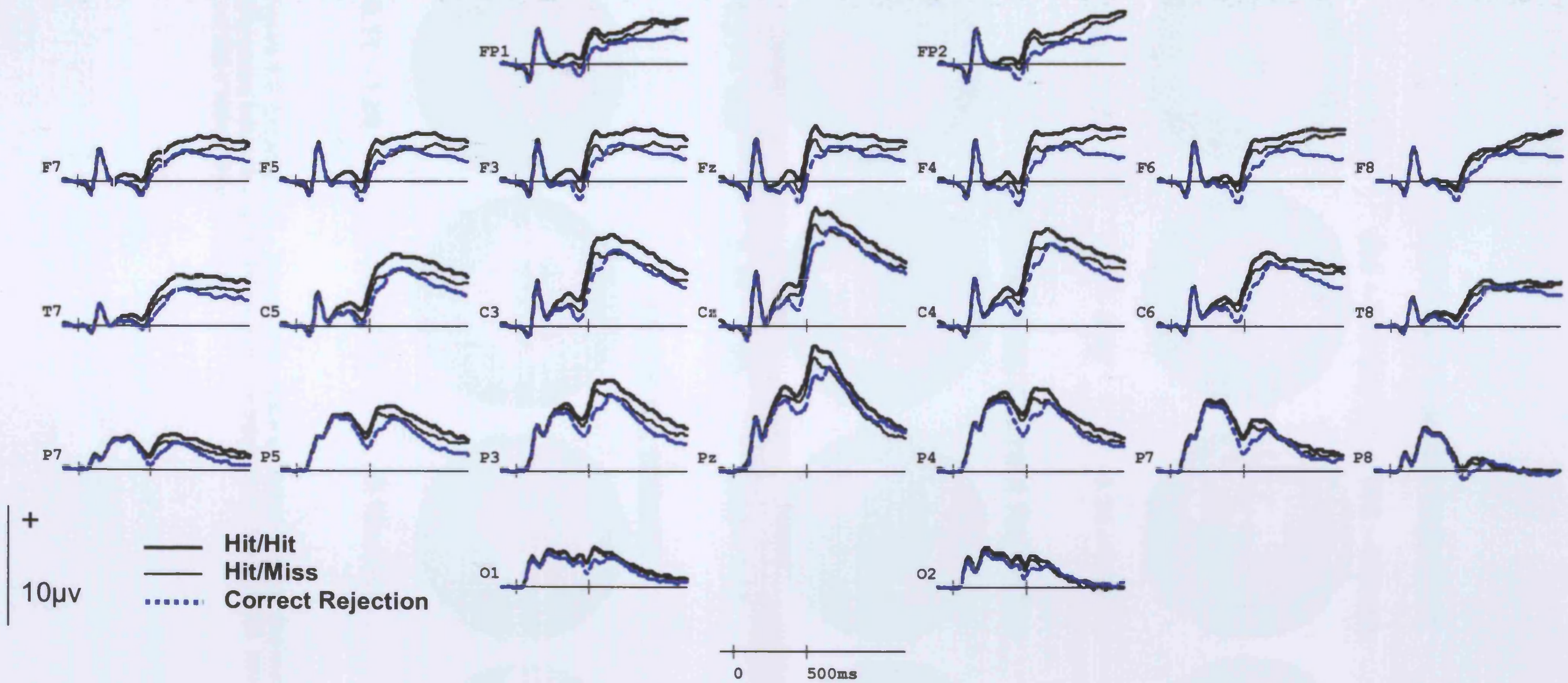


Figure 9.1. Experiment 5 – Grand averaged event-related potentials elicited by hit/hit, hit/miss and correct rejection. Data are shown for 25 electrodes covering prefrontal (FP1, FP2), frontal (F7, F5, F3, Fz, F4, F6, F8), central (C7, C5, C3, Cz, C4, C6, C8), posterior (P7, P5, P3, Pz, P4, P6, P8) and occipital sites (O1, O2). (n = 24)

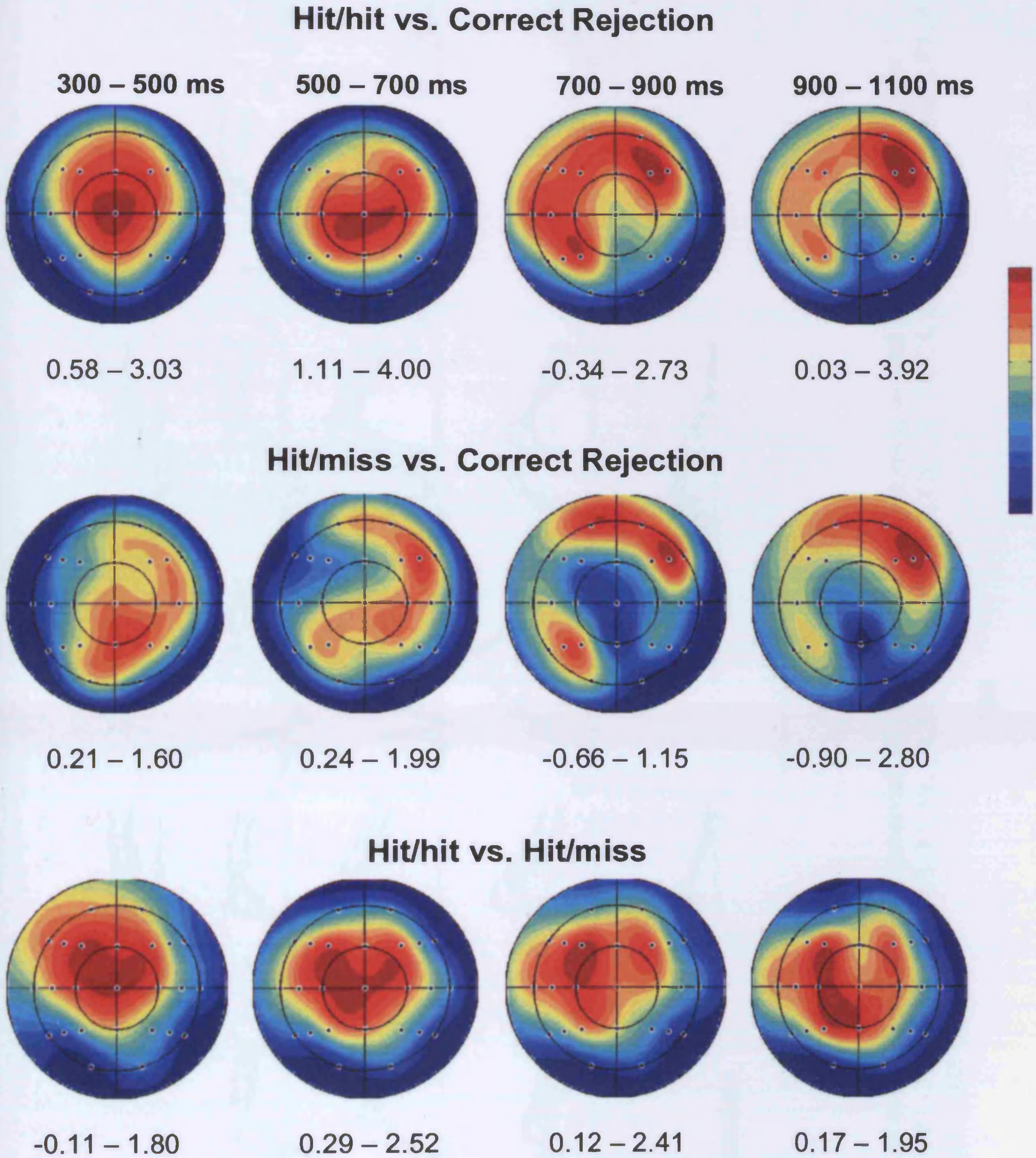


Figure 9.2. Experiment 5 - Topographic maps showing the scalp distributions of the differences between 3 different contrasts of interests for the 300-500, 500-700, 700-900 and 900-1100ms time windows.

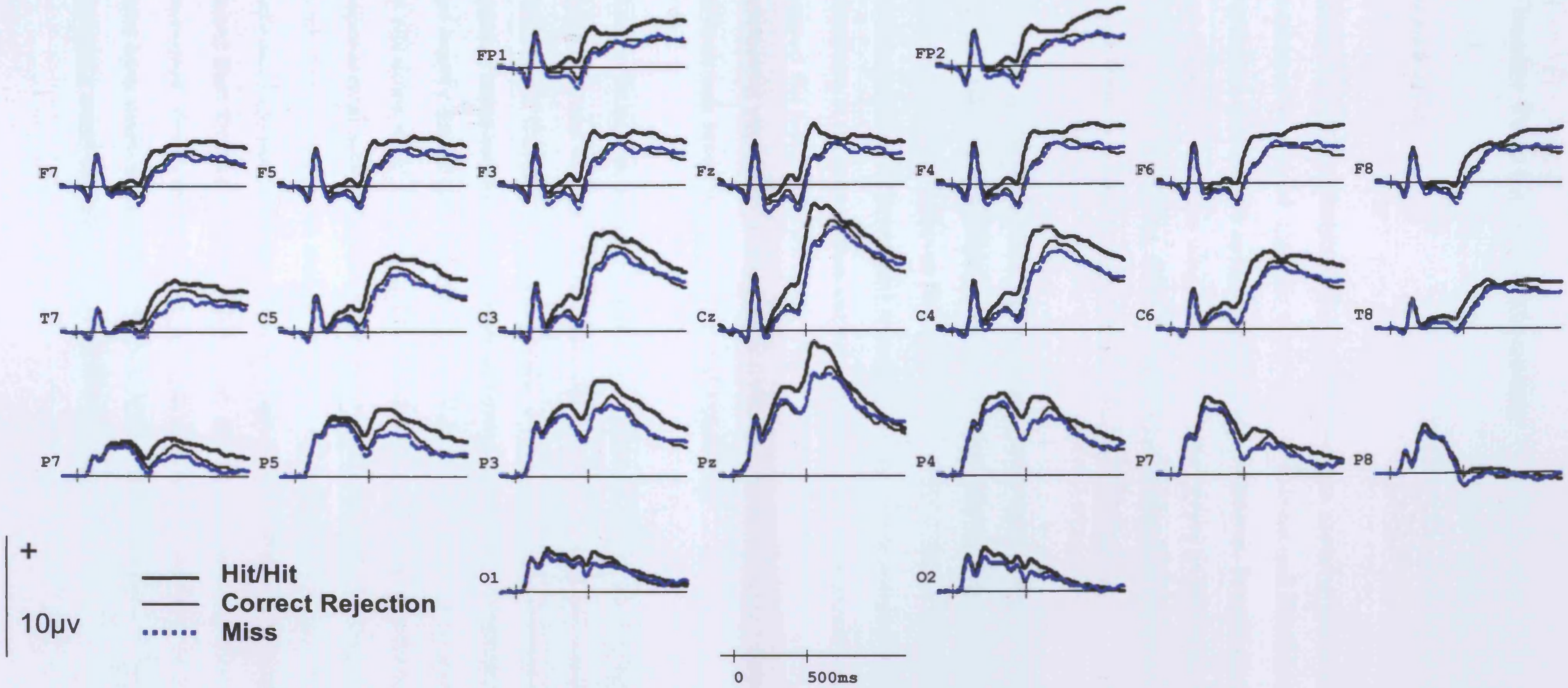


Figure 9.5. Experiment 5: Grand averaged event-related potentials elicited by hit/hit, correct rejection and miss. Data are shown for 25 electrodes covering prefrontal (FP1, FP2), frontal (F7, F5, F3, Fz, F4, F6, F8), central (C7, C5, C3, Cz, C4, C6, C8), posterior (P7, P5, P3, Pz, P4, P6, P8) and occipital sites (O1, O2). (n = 16)

Chapter Ten: General Discussion

Introduction

The principal operational distinction between two memory processes widely considered to support episodic retrieval - recollection and familiarity - is whether contextual information accompanies memory retrieval. Recollection is often viewed as a categorical process when contextual information is reinstated at retrieval (e.g. Jacoby, 1991; Yonelinas, 2002), whereas familiarity is regarded as an acontextual signal of prior occurrences that occurs to different degrees.

The most common characterisation of a sense of familiarity has been the "Butcher on the bus" phenomenon which was first described by Mandler (1980). It refers to the situation when one believes that a person is familiar but no other information (often autobiographical information) about the person can be remembered. In these situations, it is assumed that only familiarity rather than recollection is engaged to support the memory experience. This characterisation of familiarity is central to a substantial amount of research that seeks to identify the neural correlates that differentiate between recollection and familiarity.

Such a distinction, however, could be difficult to implement for recognition memory judgments and variants for complex stimuli such as faces and scenes. Memory retrieval for this type of material could consist of multiple features and might well provide some contextual information forming the basis for memory judgments that is not readily describable (e.g. for faces: distances between the internal facial features). In situations when the contextual information might be of this form, in some experimental approaches to investigating the brain basis of recognition memory, this kind of retrieval may be assigned incorrectly to familiarity. Thus, a clear separation between familiarity and recollection might be more difficult for complex stimuli (i.e. faces) than for materials for which there are fewer forms of content that may be recovered. Words might be one example of this kind, and they are the materials that have been employed in the majority of brain imaging studies of memory retrieval, including event-related potential (ERP) studies.

The main motivation for the series of five experiments presented in this thesis was to contribute to an understanding of (i) the retrieval processes that support face recognition memory, (ii) the utility of ERPs for indexing these processes, and (iii) the recognition memory system in humans more generally. The main experimental focus for achieving this was on investigations of the sensitivity of ERPs to recollection and familiarity.

The general memory paradigms employed in this thesis have been used extensively to study the memory processes associated with verbal materials, and here these paradigms were modified and applied to the study of faces. The experiments identified several ERP modulations and provided ways of inferring their likely associated cognitive functions. These have contributed to our understanding of the retrieval processes that are fundamental to face recognition memory, and provided insights into the reasons for the apparently inconsistent findings in the published literature where ERP signatures of familiarity and recollection have been reported. The findings also extend knowledge on generic and material specific memory retrieval processes that are indexed by ERP old/new effects (those that are common to faces and words, as well as old/new effects that are specific to faces, or at least to some kinds of non-verbal stimuli). The findings also have some implications for the broad functional significance of the mid-frontal ERP old/new effect that has commonly been reported for verbal materials. Finally, this series of experiments is important for bridging the gaps between the findings from different imaging modalities in which the focus is on the mapping between the neural bases and cognitive mechanism that are involved in recognition memory for faces.

Paradigms Employed in this Thesis

Experiment 1 provided a baseline comparison study that identified the ERP neural correlates that are common or specific to face and/or word recognition memory. The motivation for this study was the fact that there were very few direct demonstrations of either the content- or material-specificity of ERP old/new effects (Allan & Rugg, 1998; Johnson, Minton, & Rugg, 2008). To accomplish this intention, old/new recognition memory judgments were made to faces and words. This paradigm was employed to enable a high power contrast across material type, but the ERP separations it permits provide only limited insight into the processes ERP effects might index. The paradigms employed in the subsequent experiments were designed to delineate the neural correlates of face recognition memory that are linked to familiarity and recollection, respectively.

Experiments 2 and 3 employed a recognition memory paradigm in which participants were asked to indicate recognition memory confidence on a 4-point scale. Experiment 3 employed a somewhat deeper encoding task than in Experiment 2. This was the only difference between the experiment designs. The logic of the task is that high confidence and low confidence judgments depend differentially on the cognitive processes supporting memory (Yonelinas, 2001, 2002; Wixted & Stretch, 2004, Dunn, 2004). It was assumed that familiarity correlates with recognition confidence in a linear fashion; therefore any neural signatures of familiarity should vary according to the confidence ratings acquired along the old-new dimension. Recollection is often regarded as a high threshold process that is likely to attract mainly if not entirely high confidence old responses; consequently, the neural signatures for recollection should be ERP old/new effects associated primarily with high confidence judgments (Yonelinas, Dobbins, Szymanski et al., 1996; Yonelinas, 2001; 2002). According to some accounts, however, recollection can also be graded (e.g. Rotello et al., 2005; Wixted 2007). Rotello and colleagues (2005) demonstrated that "Remember" responses in the Remember/Know paradigm are made according to the task instruction given and it does not necessarily have an all-or-none character. This issue is still a matter of debate, and because of this, comparisons of high and low confidence 'new' judgments are important in distinguishing processes linked to familiarity or recollection. Familiarity is assumed to be used to differentiate between the memory strength associated with high and low confidence responses for both old and new items; however, recollection does not operate for new items because they are associated with minimal episodic memory.

In Experiments 4 and 5, source memory paradigms were used. The two experiments differed mainly in the number of different source features at encoding. Participants learned face-source associations at study. They were then asked to retrieve source information for faces given old responses on the subsequent memory test. It was assumed that the basis for old responses attracting correct source judgments was recollection, therefore any ERP indices of recollection should be old/new effects that are associated with correct source judgments; these indices should also be larger for correct relative to incorrect source judgments. On the other hand, familiarity is diagnostic for the old/new status of the test items and it should be insensitive to the accuracy of the source judgments; therefore any neural signatures of familiarity would be old/new effects that are equivalent in magnitude for old judgments associated with correct and incorrect source judgments.

The following discussion is separated into three sections. The first section focuses on findings that relate to the neural indices of familiarity or recollection. The first part of this section begins with a brief summary of the principal findings from each experiment, followed by discussions of how these data points relate to the principle memory components of interest. The second part of this section focused on findings that differentiate implicit (priming) and explicit memory effect. The second section provided a discussion of broader issues concerning the theoretical implications for human recognition memory from this line of research as well as other relevant neural imaging studies. The final section provides a summary and conclusions, along with some suggestions for future work.

Neural Indices of Familiarity and Recollection

In Experiment 1, the ERP old/new effects for faces and words shared similar time courses; a common superiorly distributed effect was obtained for faces and words in the 300-500ms time window. The novel finding was an ERP modulation that is specific to faces; a frontal ERP old/new effect was temporarily coincident with left-parietal ERP old/new effects for faces and for words in the 500-800ms time window. The functional significance of the observed effects was under-determined, however, because of the use of only old/new recognition memory judgments in the test phases. The findings from Experiment 1 showed that the memory retrieval processes for faces and words, as indexed by ERP old/new effects, are not entirely the same.

In the remaining experiments in this thesis, global and focused analyses were conducted with regard to the assumptions underlying the paradigms employed for Experiments 2 to 5. The focused analyses were conducted at electrodes where the old/new effects were largest in the critical conditions for all epochs, as well as at three mid-frontal electrodes (F3, Fz, F4) in the 300-500ms epoch, and at three parietal electrodes (P3, P5, P7) across the 500-900ms time windows. The pre-defined focused analyses were based on previous claims that the ERP old/new effects at mid-frontal electrodes are likely to index familiarity (at least for verbal materials; for evidence for faces, see Curran & Hancock, 2007 as well as discussion by Donaldson & Curran, 2007), and the effects at the left-parietal electrodes are likely to index a generic recollection process (Rugg, Mark, & Walla et al., 1998; Curran, 2000; 2004).

Recognition Confidence

In Experiments 2 and 3, the assumption for an index of familiarity is that a familiarity modulation will vary with recognition confidence systematically. A similar pattern of findings was obtained for the two experiments. For all analyses, reliable old/new effects were evident for high confident judgments only across the 300-700ms time windows. In Experiment 3, the focused analysis over superior electrodes in the 300-500ms time windows varied between high and low confidence for both hits and correct rejections, respectively (see Figure 10.1). This differentiation between high and low confidence new items is partially supportive of the view that this element of the electrical record is a candidate for a familiarity effect, however, the absence of reliable low confidence old/new effects across the two experiments is inconsistent with a familiarity interpretation. Nonetheless, the superior old/new effect in Experiment 3 provides some indication that there is an ERP correlate of familiarity when participants are asked to rate their level of confidence at the time of retrieval.

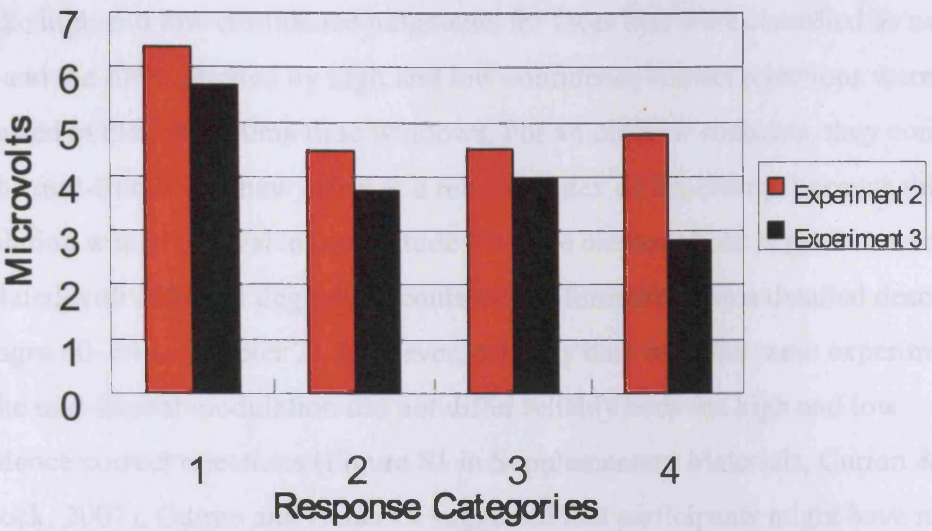


Figure 10.1 Mean amplitudes of superior modulations (amplitudes averaged across F3, F4, P3, P4) from high confidence hits to high confidence correct rejections judgments (1 to 4) in the 300-500ms time window for Experiments 2 and 3. These electrodes carried the largest old/new effects across experiments.

Several ERP studies have been conducted in which kinds of recognition memory confidence judgments have been required (Rugg & Doyle, 1992, Rugg, Cox, Doyle, & Wells, 1995; Curran, 2004; Woodruff, Hayama, & Rugg, 2006; Curran & Hancock, 2007). Woodruff and colleagues (2006) demonstrated that a left-lateralised frontal modulation in the 300-500ms was sensitive to recognition confidence using words. They excluded trials made on the basis of recollection, and the early left-frontal modulation reduced in amplitude along the confidence dimension from high confidence old to high confidence new judgments. This experiment provides some of the strongest evidence that the frontal ERP old/new effect indexes familiarity, and adds to the existing literature where it has been claimed that it does so in a graded fashion (Azimian-Faridani & Wilding, 2006; see also Curran, 2004; Curran, DeBuse, & Leynes, 2007). When faces were employed as the testing stimulus in Experiments 2 & 3, however, the ERPs at mid-frontal electrodes did not behave consistently as an index of familiarity, therefore challenging the view that ERPs provide a material-independent index of familiarity.

Using a source memory paradigm, Curran and Hancock (2007) required participants to make high and low confidence judgments for faces that were classified as new only, and the ERPs elicited by high and low confidence correct rejections were contrasted in the 300-700ms time windows. For all old/new contrasts, they concluded that the mid-frontal old/new effect is a reliable index of familiarity, because this modulation was of equivalent magnitude for three classes of old items that were associated with different degrees of contextual information (for a detailed description, see pages 60–64 in Chapter 2). However, contrary data from the same experiment is that the mid-frontal modulation did not differ reliably between high and low confidence correct rejections (Figure S1 in Supplementary Materials, Curran & Hancock, 2007). Curran and Hancock suggested that participants might have made their new judgments based on the distinctive characteristic of faces (i.e. glasses, moustaches, etc.), therefore using a recall-to-reject strategy rather than basing recognition judgments on the level of familiarity.

The facial stimuli used in the present experiments contained minimal distinctive features, unlike those employed in Curran and Hancock (2007). Hence participants should have relatively less opportunity to reject new items on the basis of distinctive features and be more likely to base their memory judgments on relative memory strength. This might partly explain the presence of a reliable difference between the ERPs for high and low confidence correct rejections in Experiment 3 and not in Experiment 2, because the overall familiarity estimate was lower in Experiment 2. The outcomes of Experiment 3 suggest that a strength based signal is sensitive to the perceived oldness of new items, but this needs to be set in the context of the absence of differences in Experiment 2, as well as the absence of reliable differences between low confidence hits and correct rejections in Experiment 3.

Similar to Experiments 2 and 3, Curran (2004; Experiment 2) acquired confidence ratings for both old and new test words on a four-point scale; in addition, Curran also manipulated attention (full/divided)at encoding. Although the ERP waveforms are more positive-going for low confidence new than for high confidence new responses, Curran reported no reliable differences between the ERPs for the two new responses when the full/divided attention was averaged across ($p = 0.06$). In addition, the analyses for low confidence old judgments separated for full and divided attention against low confident new responses revealed no reliable differences. This pattern of data resembles those reported in Experiments 2 and 3 in which reliable old/new differences were carried by contrasts involving high confidence old judgments only. Because Curran (2004) used words as the test stimuli, this data implies that the use of facial stimuli cannot account fully for the absence of evidence for a neural index of familiarity using recognition memory confidence paradigms. Importantly, this outcome from Curran (2004) suggests that there are some conditions where, regardless of the types of stimulus employed, is difficult to obtain graded ERP effects. This is possibly due to individual differences in the placement of the response criteria for making high and low recognition confidence judgments for old and new test items. Curran (2004) argued that the statistical power available for measuring the familiarity ERP signals was weak in his experiment, and that the likelihood of extracting the familiarity signal using ERPs was less than for his behavioural measure. This leads to the suggestion that there might generally be sensitivity issues concerning when ERPs are useful in detecting the correlates of familiarity. Consistent with this view, the ROC data in Figure 7.5 shows that there is some distance between the four response options and they were markedly similar in both Experiments 2 and 3. This means that the response criterions were relatively evenly distributed, but they did not give rise to consistently statistically distinguishable ERP waveforms. Therefore the ERPs outcomes from Experiments 2 and 3 are unlikely to be due to the fact that responses were clustered relatively close together on the memory strength dimension,

The above evidence is consistent with the view that the null results for familiarity are likely caused by the insensitivity of ERPs for detecting differences in relative memory strength that are accomplished using recognition memory confidence measures. On the other hand, the pattern of data across the two experiments can readily be interpreted as a neural index of recollection, based on the fact that reliable old/new differences are carried by high confidence responses only in the two early time windows, and these effects had a prefrontal maximal in Experiment 2 and a superior maximum in Experiment 3 (the distribution differences across the two experiments will be discussed below).

Source Recognition Memory

Experiments 4 and 5 used a source recognition memory paradigm to provide an objective measure of the content of the retrieved information and the likelihood of recollection occurring. The directed analyses in Experiment 4 showed that old responses associated with correct and incorrect source judgments were both more positive-going than correct rejections, and these old/new effects were equivalent in amplitudes at superior sites in the 300-500ms time window. This effect provided the strongest evidence in this thesis that a common cognitive process was engaged in these two conditions, which is likely to be either familiarity or non-criterial recollection processes. However, this pattern of effects was not replicated in Experiment 5 when the contribution of recollection and familiarity based memory was separated more effectively (see Figure 10.2). The superior effect in the 300-500ms and the 500-700ms epochs in Experiment 5 differentiated not only the old/new status of the test items but also whether source information was recovered correctly, thereby making it a likely neural index of a recollection process. The possible reasons for, and the implications of these contradictory findings across the two source-retrieval experiments are discussed below.

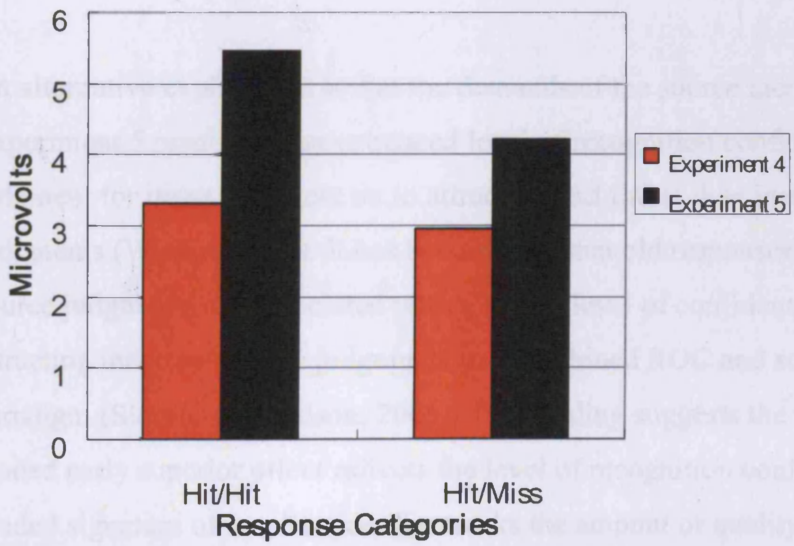


Figure 10.2. Mean amplitudes of superior ERP old/new effects (amplitudes averaged across F3, F4, P3 and P4) for correct and incorrect source judgments in the 300-500ms time window for Experiments 4 and 5. These electrodes carried the largest old/new effects across experiments.

The most straightforward interpretation for the disparate results across the two experiments is that they stem from differences between the proportions of trials associated with genuine source recollection that contributed to the correct source judgment response categories. As mentioned previously, averaging ERP signals means that the magnitude for the recollection related old/new effects in response categories associated with correct source judgments will be reduced in experiments with forced choice source tasks because the task requirements are effectively adding some proportion of "correct guesses". This is the case in Experiments 4 and 5. By increasing the response options to 3 source features in Experiment 5, a clearer separation of recollection effects from familiarity effects should have been accomplished in comparison to Experiment 4. The equivalent amplitude of the early superior modulation in Experiment 4 could therefore be explained by the insensitivity of the task in respect of separating that were or were not associated with recollection. By the same argument, the larger effect for correct source than for incorrect source judgments in Experiment 5 reflects the superior sensitivity in this case because increasing the number of response options reduces the proportion of guesses that contribute to the averaged ERPs for correct source judgments. These data together therefore suggest that this early observed signal is likely to be an index of recollection rather than familiarity.

An alternative explanation is that the demands of the source memory task in Experiment 5 resulted in an enhanced level of recognition confidence in the initial old judgment for items that went on to attract correct rather than incorrect source judgments (Wixted, 2007). It has been shown that old responses attracting correct source judgments are associated with a higher level of confidence than those attracting incorrect source judgments in a combined ROC and source memory paradigm (Slotnick & Dodson, 2005). This finding suggests the possibility that the graded early superior effect reflects the level of recognition confidence rather than a graded signature of recollection that tracks the amount or quality of recovered contextual details. Why this is more likely to be true for Experiment 5 than Experiment 4 is not clear, however. In addition, in Experiments 2 and 3, when the levels of recognition confidence and the magnitudes of their neural correlates were examined directly, there was no compelling evidence that any ERP modulation tracks the level of face recognition confidence systematically. This implies that the observed effect in Experiment 5 is unlikely to reflect the graded nature of recognition confidence, but the graded nature of recollection.

Furthermore, it is important to consider the view that the accuracy for the item memory judgment and the associated source memory judgment are not necessarily dependent on each other. Although it is likely the case that accurate source judgments are associated with strong item memory, incorrect source judgments could also be associated with an equivalent level of item memory because of recovery of other non-task relevant contextual information (non-criterial recollection, see Yonelinas & Jacoby, 1996). In both Experiments 4 and 5, the presence of reliable old/new effects provides some basis for arguing that incorrect source judgments were associated with non-criterial recollection. If non-criterial recollection functions like familiarity (e.g. Yonelinas & Jacoby, 1996; for an alternative evidence see Parks, 2007) then the early superior effect might index this kind of recollection.

Although it has generally been thought that correct source judgments are based solely on recollection (Wilding & Rugg, 1996; Allan, Wilding, Rugg; 1998), several recent studies have considered the possibility that accurate source memory judgments could be based on familiarity under some circumstances (Mayes, Montaldi & Migo, 2007; Diana, Yonelinas, & Ranganath, 2008). Recent research has investigated the possibility that familiarity could contribute to source retrieval for item-context combinations that are unitized (Ranganath, Johnson, & D'Esposito, 2003; Diana et al., 2008). Unitisation refers to when target (item) and source information are bound together to form a single entity, and as a result the retrieval of source information can be supported by familiarity. This view implies that old items attracting correct source judgments could in principle be associated with a higher level of familiarity strength than those attracting incorrect source judgments if familiarity contributes to source retrieval. Hence unitisation as a basis for successful source judgments could result in a graded effect that indexes continuous familiarity strength. This implies that the greater positivity for the hit/hit responses relative to the hit/miss responses is a reflection of a greater level of familiarity in the former category.

Although the view that familiarity supports source retrieval is possible, it is unlikely that unitisation is an adequate explanation for source retrieval in these kinds of experiments. This is because the present source experiments had an explicit instruction to recall the source information, which enhance the use of recollection for the source judgments. Consistent with this view is the evidence that the generic index of recollection: the left-parietal old/new effect is consistently evident in both Experiments 4 and 5.

It is also important to consider the disparate results between the confidence and the source memory experiments: the absence of reliable old/new effects for low confidence judgments across Experiments 2 and 3 and the presence of reliable old/new effect for the hit/miss judgments across Experiments 4 and 5. It is broadly accepted that low confidence hits and hit/miss responses can be supported by familiarity. Consequently it is unlikely to be the case in these experiments that the early ERP effect indexes familiarity given that the ERP outcomes have little resemblance for the two types of responses across Experiments 2-5. The minimal conclusion these findings support is that ERPs have little sensitivity to familiarity. A much stronger claim is that familiarity is not a useful process for making memory judgments for faces under some circumstances (see Donaldson & Curran, 2007), possibly because faces are associated with a relatively high level of baseline familiarity for both old and new items (see below for a detailed discussion).

Scalp distributions of ERP "Recollection" Effects

Despite the consistency of the functional claims that can be made across experiments, the ERP old/new effects that can be accommodated most readily with a recollection account appear to have different scalp distributions across experiments, and across epochs within experiments. These distributions are summarised in Figure 10.3 for experiments 2-5. The high confidence hit (experiments 2-3) and the hit/hit response categories (experiments 4-5) have diffusely distributed effects in the 300-500ms epoch. The principal departure across experiments is the markedly more anterior distribution of the effects in Experiment 2. This may be related to the fact that response accuracy was lowest in this experiment, and if this is correct, there are at least three possibilities to consider. The first is that the more anterior distribution reflects the fact that activity at central and posterior sites in this epoch is particularly sensitive to memory strength ('weak recollection'), so the apparent anterior distribution is a consequence of the differential engagement of the same set of generators across experiments. The second is that the anterior distribution indexes the operation of processes reflected in activity over prefrontal scalp that are engaged differentially according to task difficulty. This possibility cannot be ruled out for ERPs elicited by faces in these kinds of tasks, and it is notable that, for other materials used in tasks requiring more than old/new judgments there is little in the published literature charting how old/new effects change when only difficulty is manipulated.

The third possibility follows from the logic employed in Experiment 1. In Experiment 4, the fact that the early prefrontally distributed modulation is evident for the hit/hit response category and not for the hit/miss response category suggests that this effect reflects directly the retrieval of the source (possibly face) information that is specific to this memory task. If this account was correct, it would comprise stronger evidence than that reported in Experiment 1, where the time course of material-specific activation overlapped with that of the left-parietal ERP old/new effect (see Chapter 2 and the discussion directly below). This account is challenged, however, by the absence of comparable effects in the later experiments, where recovery of material-specific information is at least equally likely.

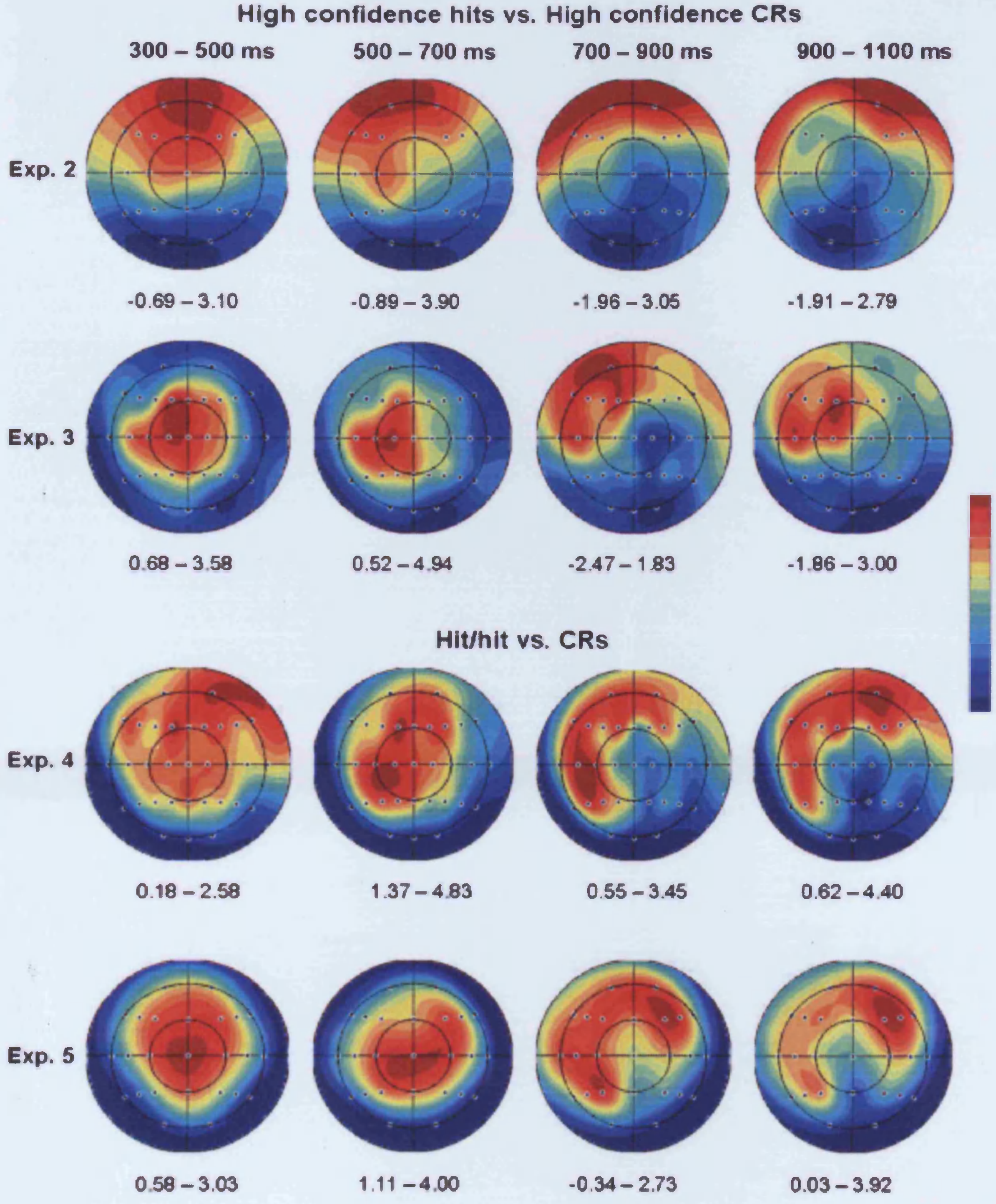


Figure 10.3. Topographic maps showing the scalp distributions of the differences between activities evoked by response categories associated with recollection (Experiments 2 & 3: *High confidence hits*; Experiments 4 & 5: *Hit/Hit*) and correctly identified new items for 300-500, 500-700, 700-900, and 900-1100ms time windows.

In all four experiments (see also Figure 5.3 for Experiment 1 in Chapter 5) there is evidence for a posteriorly distributed left-lateralised old/new effect over the 500-900ms time period. The consistency with which this effect is present is in line with previous claims that the left-parietal ERP old/new effect is a generic index of recollection (Allan & Rugg, 2000; Tsivilis, Otten, & Rugg, 2001; Groh-Bordon, Zimmer, & Ecker, 2006; Yick & Wilding, 2008; Johnson et al., 2008). These effects appear larger, or at least are temporally extended, in the later (4-5) compared to the earlier experiments. It is difficult to make strong inferences on the basis of the magnitudes of effects in tasks with different participants as well as different response requirements, but one possibility is that this general pattern reflects the fact that high confidence responses in experiments 2-3 can be made on the basis of familiarity, so the proportion of trials not associated with recollection is higher in the old/new effects for the earlier experiments (2-3) described in this thesis.

Another observation relevant to the effects in this epoch is that, in Experiment 1, it was demonstrated that the old/new effect for faces in this epoch extended to anterior sites to a greater degree than the effect for words, but the findings in Experiments 2-5 add little to this issue, because the task requirements are ones likely to engage processes that result in activity over frontal scalp more so than in Experiment 1, and in addition there is no comparison task (e.g. verbal retrieval) for these later experiments.

For experiments 2 & 3 a late posterior negativity (LPN: Wilding & Rugg, 1997; Herron, 2007; for a comprehensive review see Johannsen & Mecklinger, 2003) is also evident, but there is little evidence of this modulation in Experiments 4 & 5. This may reflect opposing contributions of temporally and spatially overlapping effects: the temporally extended parietal old/new effects in 4-5 (compared to the earlier experiments), as well as the larger late frontal effects. The right-frontal old/new effect has been shown to be functionally dissociable from the LPN (Wilding, 1999) but that does not preclude the possibility that the two effects can influence each other at the level of propagation of activity over the scalp. The same is true for the LPN and the left-parietal ERP old/new effect.

While little has been mentioned about the LPN in the previous chapters because it is not the principal focus in this thesis, the likely functional significance of this component on the basis of the findings from the two confidence experiments (3 & 4) will be discussed briefly. These were the only experiments in which marked LPNs were obtained. The LPN was evident for high confidence responses in both Experiments 2 and 3, it is also evident for low confidence responses in Experiment 3 where the effects for the high and low confidence responses were statistically equivalent (the waveform for high confidence hits was marginally more negative-going than the waveform for low confidence hits; p=0.07). According to one functional account of the LPN, it reflects the binding of associated contextual information to items (Johansson & Mecklinger, 2003). The data in Experiments 2 and 3 is consistent with this account if high confidence responses are those most likely to be associated with recollection, and if recollection involves binding processes. The marginally bigger LPNs for low confidence responses, however, are inconsistent with this account which suggested that the LPN could index attempts to bind as the LPNs are not restricted to high confidence responses only.

On the other hand, it has also been suggested that the LPN could reflect the response conflict and the action monitoring demands experienced at the time of retrieval (Wilding & Rugg, 1997; Curran, 2000; Johansson & Mecklinger, 2003). This view explains the pattern of data as low confidence responses should require more response conflict than for high confidence responses because of the lower level of memory strength. It is possible that the statistically equivalent LPNs reflect a combination of the "binding process" which is more prominent for high confidence responses; and the "response conflict process" which is stronger for low confidence responses.

Finally, for the source memory paradigm, only in Experiment 5 was there statistical support for the claim that the ERP old/new effects that have been linked to recollection change over time. The presence of the reliable effects here but not in Experiment 4 is probably due mainly to the larger sample size (n=24 vs. n=16). There is also evidence in Experiment 2 that the high confidence old/new effect change over time, suggesting the sample size could not be the only explanation for the null results in Experiments 3 and 4.

What claims do the findings in Experiments 2 and 5 licence? To recap the data in Experiments 2 and 5, there were reliable differences between scalp distributions for the high confidence and the hit/hit old/new effects over the 300-500 and 500-700ms epochs respectively. For Experiment 2, this difference reflects a shift from a frontal focus to posterior sites over time. For experiment 5, the difference reflects the shift from a central maximum effect to effects that are left-lateralised at posterior sites and right-lateralized anteriorly. For verbal stimuli, broadly comparable scalp distributions have been reported over these time windows, but in those cases, the findings have been interpreted as evidence for the engagement of two functionally distinct processes – recollection and familiarity. The data for faces, however, are best explained here, by arguing that the differences between scalp distributions reflect electrophysiologically (hence neurally) distinct processes that are tied to recollection, but they may be functionally unitary.

There were also reliable changes in scalp distributions between 500 and 700ms and the later time periods (Experiment 2: 700-900ms and Experiment 5: 700-1100ms). These changes, as Figure 10.3 shows, reflect the diminution of the left-parietal ERP old/new effect in both cases, and the onset and maintenance of a sustained right-frontal positivity in Experiment 5. The finding that the right-frontal old/new effect predicts the accuracy of the face occlusion judgments fits with previous work in which the effect has been larger for hit/hit than hit/miss responses (Wilding & Rugg, 1996; Wilding, 1999), but this pattern of differences has not always been reported (e.g. Senkfor & Van Petten 1998; Rugg et al., 2000) and the reasons for these disparities remain unclear. It has been shown, however, that right-frontal old/new effects are functionally distinct from earlier left-parietal effects (e.g. Wilding & Rugg, 1997; Johansson, Stenberg, Lindgren, & Rosén, 2002), suggesting that they index different processes. The data presented here do not themselves licence this claim, because for both effects hit/hit was greater than hit/miss, nevertheless the correspondence between the data shown here and that reported previously suggests that, with appropriate experiment manipulations, this functional dissociation is likely to be observed.

Separating Neural Indices of Priming and Episodic Memory

As discussed previously, ERP old/new effects could in principle reflect combinations of contributions from priming and episodic memory processes (Rugg & Curran, 2007; Paller, Voss, & Boehm, 2007). The on-going debate that the mid-frontal ERP old/new effect might index conceptual priming rather than familiarity is based on this consideration. This topic has been discussed previously (see pages 57-58 in Chapter 2). Briefly, among the supporting evidence for a priming account is the fact that stimuli containing little or no conceptual information (unfamiliar faces) did not elicit reliable mid-frontal old/new effects (Yovel & Paller, 2004, Mackenzie & Donaldson, 2007). Contradictory data is that unfamiliar faces and novel line drawings (squiggles) (Johansson, Mecklinger, & Treese, 2004; Nessler, Mecklinger, & Penney, 2005) have elicited reliable mid-frontal old/new effects (Curran & Hancock 2007; Curran, Tanaka, & Weiskopf, 2002; Groh-Bordin, Zimmer, & Ecker, 2006). In addition, purely perceptual manipulations of stimuli (for example, changes in modality, size or colour have also induced changes in the magnitude of mid-frontal effects: Curran, Schacter, Johnson, & Spinks, 2001; Ranganath & Paller, 2000; Groh-Bordin et al., 2006).

One possible way to discriminate between the contributions of priming and recollection or familiarity is to analyse the ERP for "misses" (incorrectly rejected old items). If priming does not contribute to explicit memory judgments, then the neural correlates for priming would be modulations that differentiate the old/new status of test items irrespective of explicit recognition memory. Experiment 5 provided the only leverage to address this question because the miss data in this experiment was available for analysis. According to the signal-detection model (see Figure 1.3 in Chapter 1), misses are responses falling below the old and above the new decision criterion, therefore reflecting an intermediate level of familiarity between hits and correct rejections. In some experiments the finding in the literature for both words and faces is that ERPs for misses do not differentiate from correct rejections (Wilding, Doyle & Rugg, 1995; Wilding & Rugg, 1996, 1997; Curran & Hancock, 2007). In another experiment, ERPs differed from correct rejections and not hits at posterior sites from 300-500ms. At mid-frontal sites in the same epoch, however, ERPs were indistinguishable for misses and correct rejections and both were more negative-going than hits (Rugg, Mark, Walla et al., 1998).

For faces, only one study has analysed ERPs elicited by misses and the data was interpreted as support for a familiarity account of the mid-frontal ERP old/new effect. Curran and Hancock (2007) reported the absence of the mid-frontal modulation for misses and therefore proposed that this effect was unrelated to conceptual priming, because it should have been equivalent for hits and misses if a conceptual priming account was correct. The miss data remains a little problematic for this account, however, as strong support for a familiarity account would have been demonstrated by an effect for misses that fell between the effect for hits and for correct rejections.

In Experiment 5, no reliable effects were obtained for the contrasts between misses and correct rejections in the two early epochs, indicating misses share similar memory strength as new items. This data argues strongly against a conceptual priming account of the data and the absence of an effect that is reliable but smaller than the hit/miss effect in the 300-500 ms epoch also supports the view that the effects in Experiment 5 are related more closely to recollection than they are to familiarity.

Theoretical Implications

The main ERP finding in this thesis is strong evidence for neural signatures of recollection. These correlates have an early onset (approximately 300ms) and last to at least 700ms post-stimulus. These ERP signals in Experiments 2 and 3 showed an all-or-none pattern that is non-diagnostic to the perceived oldness of test items because they were not graded according to recognition confidence. These signals differed in amplitudes according to the quality of the recovered information in Experiment 5. These results therefore converge with the ERP findings using faces (Yovel & Paller, 2004; Mackenzie & Donaldson, 2007) which have been used to claim that the face old/new effects are indices of processes supporting recollection-based memory.

The extent to which familiarity is necessary or useful in support of recognition memory for faces can be questioned on the basis of the findings in this thesis, as there is no convincing ERP evidence for the engagement of this process. As mentioned before, Curran and Hancock (2007) have proposed that the absence of a neural index of familiarity in some experiments could arise from the relatively similar level of familiarity between old and new items when the stimulus set is homogeneous.

It could be the case that when the presence of distinctive features in a face stimulus set is controlled, these faces are associated with a similar level of baseline familiarity regardless of old/new status because of the basic configural structures that they share. According to Bruce and Young's (1985) face recognition model, the recognition of a face involves the transformation of a particular perceived face into a viewpoint-invariant structure. In other words, new faces are readily associated with a certain level of baseline familiarity, hence the relative level of familiarity between old and new items might be highly similar, thereby making it insufficient to support familiarity-based recognition. An additional process, presumably a recollection-based process, would then be necessary when familiarity fails. In more general terms, the extent to which recollection and/or familiarity are available to support recognition memory judgments might be expected to differ according to types of material (e.g. faces vs. words) as well as the variability within the particular stimulus set that is being tested.

This is the argument used by Curran and Hancock (2007), who observed what they described as a mid-frontal old/new effect for faces. Adding variability to the stimuli by including faces with different external features and different ethnic backgrounds as in Curran and Hancock (2007) might mean that familiarity becomes a useful basis for separating faces. Thus the current findings, or at least the null result for reliable indices of familiarity, can be regarded as a function of the stimulus set.

There is a problem here, however, which is that, in both Experiments 2 & 3 participants made a reasonable number of low confidence responses. If these are in fact based on familiarity, then the face data in these experiments is most readily interpreted as an insensitivity of ERPs to familiarity signals for face stimuli. Alternatively, the confidence data in Experiments 2 & 3 reflects the fact that people have only a graded recollection signal for these stimulus sets. This interpretation is in turn difficult to explain when considering the correct rejection data: if these items are associated with little or no recollection then why should people be inclined to assign different confidence ratings to them? Thus the behavioural data might be seen to support the view that familiarity is used for judgments for faces, but ERPs are not particularly sensitive to this. It should also be noted, however, that there was some evidence for changes in neural activity linked to familiarity for correct rejections in Experiment 3.

The Implications of Material-Specific Cognitive Processes in Support of Face Recognition Memory

ERP old/new effects for faces and for words are not identical, as shown in Experiment 1 (see also McKenzie & Donaldson, 2009). The disparate ERP results for verbal and facial stimuli in the literature are likely to stem from the nature of the stimuli and how these two forms of information are processed neurally. All information enters consciousness via bottom-up processes driven by sensory input initially, while memory encoding and retrieval of different material types differ in the cognitive processes that are required subsequently. One way to understand the disparate results between the ERP old/new effects for verbal and facial material is to conjecture that they rely on different retrieval processes, and these retrieval processes engage different neural networks that are not entirely overlapping. Because of the differences between the complexity of the stimuli, it may be that memory judgments for complex stimuli (faces or scenes) require additional attention or other cognitive capacities to actively maintain internal representations of the stimulus (perhaps in a working memory buffer) while the relevant details are accessed in service for the retrieval goal (for example, the recovery of source information). In contrast, the cognitive processes for other materials (i.e. words) may be more likely to trigger top-down processes that are readily associated with relevant conceptual/semantic details without the need to maintain information in a temporary work space while certain aspects of the memory are accessed.

These additional cognitive demands required during memory judgments for faces at retrieval can explain the presence of the material-specific ERP component which had a greater projection to the frontal scalp compared to verbal materials in Experiment 1 (Yick & Wilding, 2008; see also recent data reported by Mackenzie & Donaldson, 2009). Experiments 2, 3 and 5 indicate that the recollection process is likely to onset as early as 300ms post-stimulus and the evidence that the anteriorly/superiorly distributed effect is sensitive to the quality of memory retrieval is consistent with the interpretation that it indexes the online maintenance of retrieved facial information. Yick and Wilding (2008) acknowledged, however, that this effect may not be specific to faces, and may instead be associated with operations on kinds of information that differentiate faces from words, but are also shared by other stimulus types. Obvious examples here are configural information, and, as observed above in another context, a starting point to address this question is to conduct ERP studies using other stimulus types such as scenes.

It is also notable that the 'face-specific' effect extends to at least 700ms post-stimulus, a claim based on the finding that there is little evidence for qualitative changes between the scalp distributions of the critical old/new effects during the 300-700ms time period. This time course is broadly compatible with the notion of maintenance of task relevant information, and if this account is correct it may be that the time course of the effect can be manipulated. One way to do this would be to impose a delay between the presentation of a face and the time at which a memory judgment is required.

Implications for the organization of face recognition memory from other brain imaging research

The most straightforward interpretation for the main ERP findings in this thesis is that face recognition memory is associated with a strength-based signal that tracks the quality of recovered information rather that the level of familiarity strength. This is consistent with fMRI findings that monotonic strength-based signals in the medial temporal lobe (MTL) co-vary with objective ratings of oldness using the Remember/Know paradigm for faces (Gonsalves, Kahn, & Curran et al., 2005). This fMRI study did not report any regions within the MTL that showed a specific sensitivity to correct Remember responses that did not overlap with those associated with correct Know responses. Notably, this is not the case for verbal stimuli (Aggleton & Brown, 1996; Ranganath, Yonelinas, & Cohen et al., 2004; Yonelinas, Otten, Shaw et al., 2005). A magnetoencephalographic (MEG) version of the same task was also reported in the same paper with the aim of identifying the time course of the strength-based signal. The MEG data showed that a strength-based effect onset from as early as 150ms and lasted to at least 450ms post-stimulus. The results of source localisation provided the basis for the claim that the signal was generated in perirhinal cortex. Whether this is the correct solution is debatable, but irrespective of the localisation claim, these findings are broadly consistent with the present data where a graded ERP effect was observed from as early as 300ms post-stimulus. As in the experiments here, moreover, the outcomes from these fMRI and MEG experiments provided no evidence for functionally and neurally distinct retrieval processes that could map onto recollection or familiarity separately (Gonsalves et al., 2005). Instead, they suggest strength-based signals that could reflect a single process: the graded level of familiarity, a graded recollection signal (Normal & O'Reilly, 2003; Squire, Wixted & Clark, 2007), or a combination of the two processes that converge into a single strength dimension strength (Wixted & Stretch, 2004). The data presented here favour the second of these accounts, although the third cannot be ruled out.

Additional relevant data comes from the amnesic patient study of Jon who has bilateral hippocampal damage. He produced face memory ROC and zROCs that were comparable with those of age and IQ matched healthy controls, and these data could be fitted equally well by dual-process and unequal variance signal detection models (unlike data obtained for scene memory: Bird, Vargha-Khadem, & Burgess, 2008). This result not only indicates that there is a material-specific deficit because of Jon's pathology; it also is consistent with the possibility that the neural signatures of recollection and familiarity converge to give a monotonic signal that is sensitive to overall memory strength when faces are tested. Alternatively, faces are recognised only on the basis of a single process – graded recollection for which the variance in the old item distribution is greater than that in the new item distribution (for arguments about why this is a reasonable account, see Wixted, 2007).

Implications for face recognition memory (Bruce and Young, 1986)

One influential model of face recognition (Bruce and Young, 1986) states that the first stage of recognition of a familiar face involves matching between the products of structural encoding and stored structural codes that are held in recognition units.

Identity-specific semantic information can then be accessed from person identity nodes, and other semantic information about the person can be retrieved from semantic information units. Face recognition units and person identity nodes could be considered to map onto the processes of recollection and familiarity in the following way. Activation at the level of face recognition units may be related to the process of familiarity; both of these processing operations are regarded as being relatively fast acting. The recovery of person identity information, however, is presumably an operation that is linked more tightly to recollection.

The ERP data in this thesis cannot really speak to this kind of possibility, however, given that all of the ERP old/new effects associated with faces were linked to recollection rather than familiarity. The recollection effects obtained over epochs between 300 and 700ms in this thesis argue for the presence of at least two functionally distinct recollection processes, but how these might relate to specific processing stages in models of face processing remains to be determined.

Future Directions

The findings in this thesis have established that there is at least one ERP signature that consistently behaves as an index of recollection across experiments with different assumptions and in which faces were the stimuli. Two important directions for further work are: (i) separating confidence from accuracy, and (ii) investigating the face selectivity of the effects reported. These are discussed in turn.

It has been proposed that a clean separation between familiarity and recollection can be accomplished by requiring confidence judgments for an initial old/new judgment as well as for a subsequent source judgment. The idea is that this design permits key contrasts while holding possible confounds constant. For example, with appropriate parameters it should be possible to analyse neural activity associated with recollection and minimal differences in response confidence by comparing ERPs associated with hit/hit and hit/miss responses where participants were, in both cases, highly confident for the initial old judgment. In addition, it should be possible to contrast ERPs associated with incorrect source judgments that vary according to confidence in the initial old/new decision. This might produce a 'clean' familiarity contrast. With careful piloting, an amended design to Experiment 5 in this thesis might enable these contrasts, the outcomes of which might permit stronger claims than those made here.

The logic for the second future direction has already been touched upon on pages 219-220 above. While it has been shown that ERP old/new effects for faces and words are neurally dissociable, the specificity of this distinction to word/face contrasts has not been established. It makes sense to establish the specificity (or generality) of these effects by analysing old/new effects elicited by other stimulus types. Scenes and objects are perhaps obvious examples, but the motivation for using these kinds of stimuli is bolstered by the emerging literature in which claims about content- and material-specific processing in the MTL have been made. While these data have been interpreted in terms of their implications for fractionating the roles played by the MTL in memory for different materials, ERP evidence for material specificity is unlikely to relate directly to MTL function, but may provide insights at the network level into the kinds of processing requirements that engage distinct neural networks during memory retrieval.

Generic Conclusions

While previous memory research (and particularly ERP research) has focused mainly on the use of verbal materials, there is now an increasing emphasis, across different neuroimaging modalities, on the cognitive and the neural processes that support memory retrieval for different material types. This has arisen partly because the explanations generated from experiments employing verbal materials do not generalize in all cases when other materials have been employed. This broad statement is true for the ERP literature when faces are the test stimuli.

This thesis comprises a report of a systematic investigation of the processes that might support recognition memory for faces using ERPs. One key finding in this thesis is the absence of convincing evidence for a neural index of familiarity when faces are used as the test stimuli. Notably, across all experiments ERP old/new effects elicited between the 300 and 700ms time windows can most readily be interpreted as neural indices of recollection. The extent to which familiarity is necessary (and/or available) to support face recognition memory has been considered in detail.

The findings in this thesis have shown that the neural networks supporting memory judgments differ for faces and words, and have provided some insights into the processes that are necessary for making face memory judgments. The focus here has been on processing of unfamiliar faces, and a sensible extension will be to employ familiar faces subsequently (see Nessler, Meckliner & Penney, 2005), as well as to employ other kinds of stimuli that have configural properties. The work here provides building blocks for developing more complete accounts of how memory for different materials and contents is implemented than are available currently.

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Appendix A. Examples of the facial stimuli used in this thesis: complete and incomplete faces with the four possible occlusions.

Complete Faces | Incomplete Faces

Left Eye

Right Eye

Nose

Mouth