Event-Related Potential Correlates of Recollection and Familiarity

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Abstract

Five experiments employed event-related potentials (ERPs) to investigate dual-process models of recognition memory. Each experiment consisted of a three phase design in which two lists of words were presented in two temporally segregated study tasks. During the third, 'test', phase, subjects were required to respond on one key to old items from a specified study phase, and to respond on another key both to old items from the alternate study phase and to new items. As recognised items require differential responding depending on their source, it is argued that recollection-based recognition of a studied item allows subjects to respond accurately whereas familiarity-based recognition does not. Four principal patterns of neural activity were observed throughout the course of the five experiments. Items recognised on the basis of familiarity elicited greater positivity than new items at frontal sites between 300-600 msec. Recollected items were associated with a second phase of positivity between 500-800 msec, maximal at parietal sites. The finding that these two patterns of neural activity were qualitatively distinct supports dual-process models of recognition memory which state that recollection and familiarity are independent. Recognised items also elicited greater positivity than new items over right frontal and frontopolar sites from 800 msec until the end of the recording epoch (approximately 1400 msec). It is argued that this ERP effect reflects processes that evaluate and monitor the products of retrieval. Finally, a fourth pattern of neural activity is reported in which ERPs associated with studied items are more negative going than those associated with new items, maximal at mid and right parietal sites between 800-1400 msec. It is suggested that this ERP effect may reflect the response conflict experienced when recognition does not determine the response. The implications of these findings for models of recognition memory are discussed.
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Chapter 1. Models of recognition memory: A cognitive neuroscience perspective.

Cognitive neuroscience is a discipline that has recently emerged as a consequence of the developing and increasingly overlapping disciplines of cognitive psychology and neuroscience, the marriage of which has provided both the theoretical frameworks and powerful new methodologies necessary to investigate the physical basis of the mind. Cognitive neuroscience is defined as the study of the neural mechanisms and cognitive operations by which the brain processes information. The development of this field of study has been informed by significant advances in molecular, cellular and systems neuroscience. Advances in clinical neuroscience have also contributed, in that the study of patients with focal lesions and more complex brain disorders provides additional information about the role of particular brain regions and neural systems in cognition. Both cognitive and clinical neuroscience have benefited greatly from the advent of high resolution neuroimaging techniques, such as functional magnetic resonance imaging (fMRI), positron emission tomography (PET) and event-related potentials (ERPs).

Cognitive neuroscience has been applied extensively in the last ten years to the study of human memory. Building upon the vast literature generated by experimental psychology, cognitive neuroscience continues to study the putative processes and systems which are thought to underlie human memory, as well as attempting to identify their neural correlates. This review turns its attention to the study of recognition memory, and is principally concerned with the debate between dual-process and single-process accounts of recognition memory. In order to address this area from a cognitive neuroscience perspective, it is necessary initially to give behavioural findings from experimental psychology due consideration. It is essential to have a good understanding of the theoretical framework and issues involved in the study of dual-process accounts in order to be able to comprehend and interpret evidence from cognitive neuroscience techniques in a meaningful way. Therefore, a taxonomy of memory will initially be detailed (see figure 1.1), followed by a consideration of dual-process and single-process accounts of recognition memory. Behavioural evidence pertaining to the debate surrounding models of recognition memory will then be discussed. Finally, consideration is given to how evidence from neuroimaging and neuropsychological studies can inform models of recognition memory.
**A Brief Taxonomy of Memory**

![Image of a taxonomy diagram]

Figure 1.1. A taxonomy of long-term memory systems. Derived from Squire and Zola-Morgan (1996).

**Short term vs long term memory**

Throughout the last 50 years, dissociations observed between different measures of memory have been interpreted as evidence that memory is not a unitary system, but that it is rather comprised of separable and functionally distinct components. This view has been supported by neuropsychological findings which indicate that different kinds of lesions and disorders damage memory for some kinds of information while leaving memory for other kinds of information intact. In an attempt to account for these data, memory researchers have concentrated on determining the ways in which the memory system is fractionated. This process began in earnest in the early 1960’s, when it was demonstrated that subjects showed no memory for a small number of words read only a few seconds previously if they were briefly distracted prior to testing (Peterson & Peterson, 1959). For the next few years, memory research concentrated on this apparent dichotomy between short-term and long-term memory, culminating in a memory framework formulated by Atkinson and Shiffrin in 1968. This framework specified short-term memory as an attention-dependent process of short duration (maximum of approximately 30 seconds) and of limited capacity (approximately 7 items) which served as a temporary store for information (Atkinson & Shiffrin, 1968). Long-term memory was specified as a system of limitless capacity and long duration (maximum of a lifetime), which allowed information to be passively stored until retrieval of this information was required. This framework also stated that sufficient rehearsal allows
information to pass from short term memory into long term memory (Atkinson & Shiffrin, 1968).

Explicit/declarative vs implicit/non-declarative memory

Findings from experimental psychology and from amnesia suggested that long term memory was comprised of two further components (see figure 1.1), one of which is a conscious form of memory for facts and events while the other is a nonconscious form of memory which manifests itself by influencing behaviour (e.g. skills, habits, conditioning etc.). This dichotomy has been expressed in two different ways; the explicit vs implicit distinction (Graf & Schacter, 1985; Schacter, 1987) and the declarative vs non-declarative distinction (Squire & Zola-Morgan, 1991). Episodic or declarative memory is conceptualised as a conscious form of memory retrieval, as one can introspect on and report the contents of the memory. Implicit or non-declarative memory is characterised as memory which influences behaviour in the absence of awareness. Different theories exist to account for dissociations between explicit and implicit memory. Processing theories argue that implicit and explicit memory performance differ because they reflect different types of processing, with implicit memory reflecting data-driven processing and explicit memory reflecting concept-driven processing (e.g. Blaxton, 1989). Systems theories assert that this distinction arises because explicit and implicit memories tap the operations of different memory systems (Squire & Zola-Morgan, 1991). Activation theories state that implicit memory reflects the temporary activation by an item of its internal representation, whereas explicit memory reflects active, elaborative or controlled processing (e.g. Mandler, 1980).

Episodic vs semantic retrieval

Explicit memory itself has also been fractionated into two different components; episodic memory and semantic memory (Tulving, 1972; Tulving, 1983). Semantic memory describes memory for facts and general knowledge. This form of memory is accompanied by ‘noetic’ awareness (Tulving, 1985a) in which one is aware that retrieval has occurred, but in which one is oriented in the present. Episodic memory is an autobiographical form of memory and is characterised by the retrieval of personally experienced events. Episodic retrieval is accompanied by ‘autonoetic’ awareness or ‘mental time travel’ (Tulving, 1985a), in which one is aware that retrieval has occurred, and in which one is oriented towards the past.
Autonoetic and noetic awareness are considered to be phenomenologically distinct. Episodic retrieval is generally measured by means of one of two tasks; recall or recognition (see figure 1.1). Recall tasks come in a number of different forms (e.g. cued, serial, free) and require subjects to search memory for an item that has previously been studied. Recognition memory tests require subjects to match a retrieval cue to a memory trace in order to judge whether the cue has been previously experienced or not, and can either take the form of yes-no recognition (in which a subject responds 'yes' or 'no' to each of a sequence of items) or forced-choice recognition (in which a subject must identify which of a pair or more of items has been previously studied). The remainder of this thesis is concerned with the study of yes-no recognition memory.

Models of Recognition Memory

**Dual-process Models of Recognition Memory**

Over the last thirty years, dual process conceptualisations of recognition memory have been developed by cognitive psychologists. The dual process approach, although expressed in a number of different ways, fundamentally asserts that recognition memory is comprised of two separate mnemonic processes. The first process is known as familiarity, and has been conceptualised as an acontextual, fast-acting and automatic expression of fluency, in which fluency is defined as the relative ease and increased speed with which familiar items are processed. The second process is known as recollection, and is generally considered to be a largely intentional retrieval mechanism subject to conscious control, although exceptions to this characterisation are evident and shall be discussed. A defining characteristic of recollection is the ability to retrieve contextual information from the encoding episode (known as 'source information'). The dual-process approach has been described both within a framework which utilises first-person phenomenological (or 'experiential') information to supplement behavioural evidence, and within an entirely objective third-person framework that does not make use of self-report.

Third-person accounts

**Evolution of third-person accounts**

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

Much of this early work was consolidated by Mandler (1980), who discussed a theoretical framework in which the detection of familiarity and recollection were conceptualised as additive and separate processes which were thought to occur conjointly in normal recognition. Importantly, Mandler assumed that familiarity and recollection were independent, in that they are separate but overlapping. Familiarity was assigned to intra-event organisational processes, whereas recollection was related to inter-event elaborative processes. Several functional properties of familiarity and recollection were proposed (Mandler, 1980); specifically, the familiarity value of an item was assumed to decay more rapidly than does its retrievability, and recollection was conceptualised as an iterative process which involves the recovery of contextual aspects of the event. These contextual details were thought to be located within the relational network of long-term memory, and it was argued that items obtaining access to this retrieval process were almost perfectly recognised, whereas
items that did not were recognised only on the basis of their familiarity information. Items that were judged on the basis of familiarity could be recognised as having been previously encountered, but no contextual information would be retrieved. Contextual information would only be available when the retrieval process was activated.

In the development of the dual-process approach, Jacoby (1991) drew parallels with the attention literature (Hasher & Zacks, 1979) in which consciousness was identified with a controlled processing system reflecting intention. Conscious operations were assumed to be subject to processing capacity limitations, whereas automatic processing was characterised as being a passive consequence of stimulation which does not require intention and is not constrained by processing capacity. Thus controlled (i.e. recollection) and automatic (i.e. familiarity) influences of memory were defined in terms of their reliance on processing capacity and intention; recollection was proposed as being subject to limited processing capacity, conscious control and intention, whereas familiarity was not thought to share any of these functional characteristics (Jacoby, 1991). The difference between recollection and familiarity has also been conceptualised as being similar to the contrast between analytic and nonanalytic bases for categorisation (Jacoby & Brooks, 1984), in that recollection serves as an analytic basis for judging, whereas familiarity is a nonanalytic judgement of prior presentation. More recently, Yonelinas et al. (1996) delineated a dual-process model of recognition memory in which recollection is characterised as a discrete all-or-none memory state whereas familiarity assessment is continuously distributed. Increasing numbers of items may therefore be endorsed as being familiar as the response criterion becomes more lax, whereas the number of items recollected remains invariant across this variable (Yonelinas, Dobbins, Szymanski, & King, 1996).

**The Process Dissociation Procedure (PDP)**

The majority of dual-process experiments conducted within the third-person approach employ paradigms derived from the process dissociation procedure (Jacoby, 1991). Jacoby (1991) was concerned with the issue of 'process purity'. This relates to the practice of equating experimental tasks with the cognitive processes that they are thought to elicit, a practice which rests on the problematic assumption that performance on a particular task provides a pure index of the target process. Jacoby (1991) asserted that performance always represents a blend of conscious and automatic processing, and that memory performance on
'indirect' tests (i.e. tests that do not require explicit retrieval, and which therefore putatively reflect only implicit memory) would be at least partially contaminated by explicit memory. Likewise, memory performance on 'direct' memory tasks (i.e. memory tasks requiring explicit retrieval) would be similarly contaminated by automatic influences. The process dissociation procedure (PDP) was introduced as a means of separating the contributions of conscious and automatic influences towards performance on a particular task. The PDP was further developed to tackle the issue of dual process accounts of recognition memory, and to estimate the contributions of familiarity and recollection to recognition performance (Jacoby, 1991).

The PDP uses facilitation and interference paradigms in opposition in an attempt to separate estimates of recollection and familiarity. Jacoby (1991) argued that items in a recognition memory test requiring a simple judgement of prior presentation may be recognised either on the basis of recollection (which could be brought under intentional control) or on the automatic processes associated with familiarity (which could not). Such a paradigm is therefore facilitatory, as both recollection and familiarity contribute towards a common goal. A facilitatory paradigm is employed as the inclusion test condition which forms one part of the PDP. Jacoby (1991) evolved an interference paradigm which would place automatic and intentional uses of memory in opposition. In the interference paradigm, study items are presented in one of two different lists. At test, subjects are required to respond 'old' only if the item was presented in the specified list. New items, and items previously presented in the non-specified list are to be rejected (or 'excluded'). The interference paradigm is referred to as the exclusion test condition which forms the other part of the PDP.

Differential responding to different classes of studied item can only be achieved by an intentional and controllable retrieval process; automatic influences of memory would not allow selective responding of this nature. Recollection, therefore, can be quantified as the difference between the probability of endorsing an item of a specified class when directed to select for items belonging to that class (facilitation/inclusion) and the probability of endorsing these same items when directed to select against items of that class (interference/exclusion). A series of simultaneous equations based on a probabilistic model are then solved to yield estimates of the contributions of familiarity (F) and recollection (R) to recognition performance. Under exclusion conditions, a to-be-excluded studied item will only intrude as an exclusion error when recollection fails:
Exclusion = F (1 - R)

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

Inclusion = R + F (1 - R)

The probability of recollection equals the probability of responding with a to-be-excluded studied item under exclusion conditions subtracted from the probability of responding with the same item under inclusion conditions:

R = Inclusion - Exclusion

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

F = Exclusion / (1 - R)

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

The PDP has been criticised on a number of counts, and has generated a significant amount of debate. While this review does not consider this debate in full, it is necessary to delineate a few key criticisms relevant to studies of recognition memory employing this paradigm. One of the principal criticisms is that the PDP conflates retrieval volition with states of awareness. Therefore the approach fails to account for phenomena such as involuntary conscious memory (Schacter, 1987; Richardson-Klavehn, Gardiner, & Java, 1994) in which recollection is experienced without intention. The PDP also requires specific task-relevant contextual features to be retrieved in order for an item to be designated as recollected. If the specified contextual information is not retrieved the response is designated familiar, regardless of what other contextual aspects may have been recollected (recollection of contextual details other than those specified is termed ‘noncriterial recollection’). In response to this criticism, the PDP was employed to directly address this phenomenon (Yonelinas & Jacoby, 1996). It was demonstrated that noncriterial recollection exhibited functional characteristics similar to those associated with familiarity (Yonelinas & Jacoby, 1996), and that the effects of noncriterial recollection were independent from those associated with criterial recollection. Yonelinas and Jacoby (1996) subsequently argued that recollection is situation specific, in that it is defined by task demands. This stance illustrates a key philosophical difference between the PDP and phenomenological accounts; whereas the former operationalises recollection as the retrieval of contextual information that can be employed in the conscious control of behaviour, phenomenological accounts operationalise recollection as the retrieval of any contextual aspect whether it be voluntary or involuntary, criterial or noncriterial.

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

The assumption that recollection and familiarity share a relationship of independence has also come under criticism (Joordens & Merikle, 1993; Cowan & Stadler, 1996). Joordens and Merikle (1993) argued that a relationship of redundancy (Jones, 1987) provided an equally plausible model, based on the assumption that any conscious influence is always accompanied by correlated unconscious influence (Joordens & Merikle, 1993). This criticism was primarily levelled at the PDP as applied to explicit/implicit memory, but could also conceivably be directed at the recognition memory application of the PDP as it can been argued that all recollected responses are also familiar. It has also been argued by phenomenological theorists that recollection and familiarity share a relationship of exclusivity rather than a relationship of independence, as one cannot experience familiarity and recollection simultaneously (Gardiner & Parkin, 1990). However, this argument applies to states of awareness and consequent responses as delineated by the phenomenological approach, and does not address the processes underlying familiarity and recollection themselves.

Phenomenological accounts

Evolution of the phenomenological approach

The phenomenological approach to recognition memory relies on subjective reports of states of awareness to supplement behavioural measures of recognition performance. This approach was developed out of Tulving’s distinction between noetic and autonoetic
consciousness (Tulving, 1983; Tulving, 1985b). Tulving argued that episodic remembering (or 'mental time travel') is specifically oriented towards the past and is accompanied by 'autonoetic' awareness, whereas the retrieval of declarative information is phenomenally distinct and is accompanied instead by 'noetic' awareness (Tulving, 1993; Tulving & Markowitsch, 1998). The Remember/Know distinction was introduced by Tulving (1985) who identified Remembering with the episodic autonoetic memory system and Knowing with the semantic noetic system, as Knowing is operationalised as retrieval without any specific recollective experience. Gardiner and his colleagues developed this paradigm in order to apply it to the study of the contributions of familiarity and recollection to recognition memory performance (Gardiner, 1988; Gardiner & Java, 1990; Gardiner & Java, 1993a; Gardiner & Parkin, 1990). Experiments adopting this approach require subjects to respond 'Remember' if they can consciously recollect any contextual aspect of prior presentation, and to respond 'Know' if they recognise the item on some other basis. The Remember/Know distinction is generally assumed to overlap with the recollection/ familiarity distinction described by Mandler (1980), and it was proposed that phenomenological accounts can be used to supplement objective accounts of recognition memory (Gardiner & Java, 1993a).

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

**Criticisms of the Remember/Know Procedure**

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

\[
F = \frac{K}{1 - R}
\]

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

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

Theoretical relationships between recollection and familiarity

The three types of relationship proposed between recollection and familiarity are independence, exclusivity and redundancy (Jones, 1987).

A relationship of independence means that the non-occurrence of one of these processes does not preclude the occurrence of the other, in that the two processes are separate but overlapping (see figure 1.2.1). A relationship of exclusivity states that recollection and familiarity can never co-occur (see figure 1.2.2). Phenomenological accounts (Gardiner & Parkin, 1990) propose that recollection (as operationalised as ‘Remember’ responses) and familiarity (as operationalised as ‘Know’ responses) share a relationship of exclusivity, in the sense that one response necessarily precludes the other. A relationship of redundancy assumed between the two processes would reflect the view that recollected items form a subset of items recognised on the basis of their familiarity, in that familiarity can occur.
without recollection, but the occurrence of recollection necessarily implies the occurrence of familiarity (see figure 1.2.3).

Single Process Models of Recognition Memory

Global matching models

Evolution of global matching models

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

Global matching models were developed from this complementarity between search models and direct-access models in terms of processing speed and accounting for the influence of other items on recognition. Gillund and Shiffrin (1984) conducted a series of experiments examining the question of whether recognition is comprised of both a direct-access component and a search component or whether it is comprised of a single process. It was
argued that fast responses should reduce the contribution of a search component while leaving direct-access unaffected, whereas the relative contribution of search processes should increase for slow responses (Gillund & Shiffrin, 1984). Variables thought to differentially engage search processes (e.g. list length, orienting task) should therefore show interactions with experimental manipulations that selectively reduce or eliminate the search component (Gillund & Shiffrin, 1984). However, although speeded performance decreased $d'$, no such dissociations were observed. Therefore, the search of associative memory model (SAM) was developed as a single-process model of recognition memory (Gillund & Shiffrin, 1984). SAM, together with other global matching models, account both for the sensitivity of recognition performance to other items in memory and for the production of relatively fast responses.

**Common principles of global matching models**

There are a variety of single-process global matching models of recognition, including SAM (Gillund & Shiffrin, 1984), MINERVA 2 (Hintzman, 1988), the theory of distributed associative memory TODAM (Murdock, 1982), the matrix model (Pike, 1984), and the composite holographic associative recall model CHARM (Metcalfe, 1982). Although these models differ in detail, they share a number of common features. First and foremost, recognition is modelled as a single signal detection process based on global familiarity, which represents the total activation in memory in response to a test cue. They also share two other underlying assumptions; a test cue is combined with its context into a single probe of memory (the interactive cue assumption), and the cue is simultaneously matched against all events in memory activating multiple events in parallel (the global matching assumption) rather than being used to retrieve a specific item (Clark & Gronlund, 1996). Global matching results in a scalar value which can be conceptualised as item familiarity, the match of item to memory, or the activation of memory produced by item (Clark & Gronlund, 1996). This value is generally perceived as an index of global familiarity (Ratcliff, Van Zandt, & McKoon, 1995). A scalar value above a certain criterion leads to a positive response whereas a value below criterion leads to a negative response.

The different global matching models account for both item and associative recognition with a single retrieval process, although the nature of this retrieval differs between the models. In both MINERVA 2 and the matrix model, associative information is stored in a single memory
trace and item-specific information is stored as a subsidiary component of that trace. As item-specific and associative information are part of the same memory trace, they make non-independent contributions at retrieval. SAM stores item-specific and associative information separately, with item-specific information corresponding with a self-strength parameter (i.e. the strength of the relationship between a test cue and its representation in memory), and associative information modelled as an interitem strength parameter (i.e. the strength of the relationship between the test cue and other items in memory). Although they are stored separately, item and associative information do not make independent contributions to retrieval as the test-cue is matched against both the self-strength and the interitem parameters in order to yield a global value of familiarity. TODAM stores item-specific and associative information independently, and the two types of information make independent contributions to retrieval; single item recognition is largely based on item-specific information and makes little use of associative information, whereas associative recognition makes use of associative information and single-item information is largely irrelevant. Thus, although all global matching models specify a single retrieval process, the assumptions underlying retrieval vary substantially. In paradigms such as the PDP (i.e. when two study lists are encoded), the test probe is comprised of the test item and both study contexts, with the contributions to familiarity of the item and of each context varying across experimental manipulations. Therefore another key difference between dual-process models and global matching models is that the latter state that familiarity can be different in PDP inclusion and exclusion conditions, as list contexts are weighted more heavily if items from that list require a positive response. According to global matching models, familiarity can be used either to include or to exclude items, whereas this is not possible for familiarity as conceptualised by the PDP.

Two-criteria signal-detection models

A number of single-process models of recognition memory employing signal detection theory (Green & Swets, 1966) were developed from classical signal detection models of yes/no recognition memory (Banks, 1970; Glanzer, Adams, Iverson, & Kim, 1993) to examine Remember/Know dissociations in the literature (Donaldson, 1996; Inoue & Bellezza, 1998; Hirshman & Master, 1997). Similar to global matching models, two-criteria signal detection models of recognition memory specify a single continuously distributed familiarity process, and normal distributions represent the overlapping familiarity distributions of old and new words (see figure 1.3). The mean of the old item familiarity distribution is higher than the mean of the new item familiarity distribution. The distance between the two means is
denoted as $d'$, which provides an index of discrimination of old from new items free from response bias, and assumes that the standard deviations of the old item and new item distributions are equal (Swets, 1986). An alternative measure of discrimination, $A'$, does not make this assumption.

![Signal Detection Model](image)

**Figure 1.3.** An equal-variance signal detection model illustrating familiarity distributions associated with studied and unstudied items. Adapted from Yonelinas (2001).

In the two-criteria signal detection models described to explain dissociations reported in Remember/Know studies, a decision criterion is placed somewhere along the familiarity continuum running through these overlapping distributions. Responses associated with familiarity above this criterion will be recognised as old whereas items below this criterion will be judged to be new. Subjects then place a second response criterion above the old/new criterion which is used to make Remember/Know judgements (see figure 1.4); items whose familiarity lies above this second criterion will attract a Remember response, whereas those that fall between this criterion and the lower yes/no criterion will attract a Know response (Donaldson, 1996; Hirshman & Master, 1997; Inoue & Bellezza, 1998). Increasing the yes/no criterion (i.e. in a more lenient direction) should increase the rate of Know responses but leave Remember responses unaffected. Therefore, the placement of the yes/no criterion and the proportion of Know responses should be positively correlated (Donaldson, 1996).

Levels of a variable that result in easy recognition (e.g. short retention interval) are represented by a higher familiarity distribution than levels of a variable resulting in more difficult recognition (e.g. long retention interval). If strict response criteria are adopted, a greater number of both Know and Remember responses will be seen for the ‘easy’ level than for the ‘difficult’ level. If the criteria are more lenient, a greater number of Remember
responses will be seen for the ‘easy’ level while equivalent numbers of Know responses will be observed for both levels, and if the criteria become even more lenient the ‘difficult’ level will appear to have the effect of increasing Know responses while decreasing Remember responses. In this way, the two-criteria signal-detection model of Remember/Know responses can account for a wide range of dissociations.

Donaldson (1996) argued that a central tenet of these models is that bias-free estimates of memory (i.e. d’ or A’) should be equal for overall recognition and for Remember responses, as Remember responses are argued to be nothing more than conservative yes responses. A meta-analysis of published data from 28 studies yielded a mean A’ of .83 for Remember responses and a mean A’ of .86 for overall recognition responses, and it was therefore argued that measures of A’ for the two types of response were close enough to support the detection model (Donaldson, 1996). These models have been used to demonstrate that a number of Remember/Know dissociations cited to support the dual-process approach can also be explained within a single-process model. Findings pertaining to specific Remember/Know dissociations are discussed at the relevant points in this chapter. Some researchers adopting the two-criteria single-process model do not claim that all dual-process dissociations can be accounted for within a single-process model, but rather argue that Know responses are an unreliable estimate of familiarity as this measurement relies strongly on the placement of the second decision criterion (Donaldson, 1996).
Criticisms of single-process models of recognition

Most criticisms of single-process models of recognition memory derive from studies showing experimental dissociations between two measures of recognition memory (whether they be Remember and Know responses, or PDP measures of recollection and familiarity) by a single independent variable. Evidence pertaining to this issue comes from a variety of sources, including behavioural, neuropsychological and neuroimaging studies. This evidence, together with its implications for models of recognition memory, is discussed throughout the remainder of this chapter. Particularly problematic for global matching models is the 'mirror effect' (Glanzer & Adams, 1990), a term that refers to the finding that certain experimental manipulations simultaneously increase hits (i.e. correct recognitions) and decrease false alarms (i.e. incorrect recognitions) for one class of items (e.g. Remember responses), while decreasing hits and increasing false alarms for another class of items (e.g. Know responses). This finding is particularly difficult to explain with a single retrieval process as posited by global matching models, although the originators of the two-criteria signal detection process models described above have asserted that they can account for this effect (Donaldson, 1996; Hirshman & Master, 1997; Inoue & Bellezza, 1998). These findings are also discussed in greater detail later in this chapter.

Models of recognition memory: Behavioural evidence

Researchers in experimental psychology have investigated models of recognition memory by attempting to demonstrate dissociative effects of a single independent variable on the two hypothetical components of recognition memory. There are three principal ways in which the two putative bases of recognition memory can be dissociated; the first type of dissociation identifies variables that influence the recollective component of recognition memory but leave familiarity unaffected, the second identifies variables that affect familiarity but leave recollection unaffected, and the third identifies variables that influence recollection and familiarity in opposite directions. Such dissociations have been reported both by studies employing phenomenological Remember/Know paradigms and by studies adopting the third person approach and the PDP. As noted previously, the relationship assumed between familiarity and recollection is important when interpreting these dissociations, as it has been argued that some of the Remember/Know studies described below produce different findings.
when the data are reanalysed under the independence assumption as opposed to the exclusivity assumption (Yonelinas & Jacoby, 1995).

**Single dissociations in which recollection is selectively affected**

A dissociation of this nature was originally reported by Gardiner (1988) who reported that the classical levels-of-processing effect associated with recognition memory (in which recognition accuracy increases with depth of processing) was entirely accounted for by Remember responses, with Know responses remaining equivalent across this manipulation. The levels-of-processing manipulation employed in this experiment required subjects at study either to think about the phonemic properties of words or to make semantic judgements about words (Gardiner, 1988). The finding that levels-of-processing selectively increases Remember responses was later replicated (Rajaram, 1993), although this study reported the opposite effect on Know responses. The argument that levels-of-processing selectively influences recollection also appeared to be consistent with an earlier study which had reported that depth of processing at study influenced hit rates during a recognition test, but did not affect performance in a perceptual identification task (Jacoby & Dallas, 1981).

Perceptual identification tasks assess the speed or ease with which items previously presented are identified relative to new items under perceptually difficult conditions, and as performance on tasks of perceptual identification was presumed to be a strong correlate of familiarity-based recognition (based on the assumption that familiarity shares common cognitive processes with those underlying perceptual learning), it was argued that this dissociation reflected a selective manipulation of the recollective component of recognition memory (Jacoby & Dallas, 1981).

However, the assumption that performance on the perceptual identification task reflected familiarity was later called into question when it was demonstrated that familiarity (as measured by the PDP) did increase with conceptual processing (i.e. picture naming versus word reading) whereas word-identification priming did not (Wagner, Gabrieli, & Verfaellie, 1997). The finding that depth of processing does in fact influence familiarity was consistent with other studies employing the PDP which also demonstrated levels-of-processing effects for familiarity (Toth, 1996; Jacoby & Kelley, 1991). The discrepancy between these findings and those reported by Gardiner (1988) and Rajaram (1993) was partially accounted for when it was reported that reanalysis of these Remember/Know data under the independence
assumption showed a depth of processing effect in the same direction for both recollection and familiarity (Wagner, Gabrieli, & Verfaellie, 1997; Yonelinas & Jacoby, 1995), although it has recently been reported that familiarity may consist of one component which is sensitive to levels-or-processing and another which is not (Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998).

The finding that a full versus divided attention manipulation at study selectively affected Remember responses (Gardiner & Parkin, 1990), together with early demonstrations of a selective influence of levels-of-process on recollection (Gardiner, 1988), contributed to the formulation of a framework in which Remember responses were viewed as a form of explicit memory and Know responses resembled implicit memory. Although it was later argued that Know responses express too high a level of awareness to be a manifestation of implicit memory (Richardson-Klavehn, Gardiner, & Java, 1996), the finding that dividing attention selectively decreases recollection was replicated in an experiment employing the PDP (Jacoby, 1991). Convergent evidence for the finding that attentional capacity selectively influences recollection was provided by an experiment employing the PDP and a list length manipulation (Yonelinas & Jacoby, 1994). This experiment reported that increasing list length at study (which, it was argued, increases demand on attentional capacity) impaired subsequent recollection-based recognition but did not affect estimates of familiarity (Yonelinas & Jacoby, 1994), although it was later argued that the SAM single-process global matching model (Gillund & Shiffrin, 1984) could also account for these data (Ratcliff, Van Zandt, & McKoon, 1995). An additional dissociation between recollection and familiarity was demonstrated by the finding that estimates of recollection were lower when subjects were required to respond at a fast deadline than at a slow deadline, whereas estimates of familiarity were not influenced by this response deadline manipulation (Yonelinas & Jacoby, 1994). This finding was replicated in a study which required subjects to study two different lists, and then to either to make an old/new judgement or a source judgement (depending on instructions) at different response signals ranging from 100 to 2000 msec (Hintzman, Caulton, & Levitin, 1998). It was reported that old/new judgements could be made accurately approximately 100 msec prior to source judgements, and it was argued that this finding dissociated an early familiarity process from a later recall process (Hintzman, Caulton, & Levitin, 1998). These dissociations were consistent with the hypothesis expressed 23 years earlier that familiarity has a faster time course than recollection (Juola, Fischler, Wood, & Atkinson, 1971).
The word frequency recognition effect (i.e. the finding that low frequency items are better recognised than high frequency items (e.g. Gregg, 1976) has posed a significant problem for single-process models of recognition memory for some time, as these models inevitably conclude that low frequency words are both more familiar (due to an enhanced hit rate) and less familiar (due to a decreased false alarm rate) than high frequency words. This pattern of responses is an example of the 'mirror effect' described previously (Glanzer & Adams, 1990). The word frequency effect was explained within a dual-process framework by a study which combined the PDP with the Remember/Know paradigm to provide convergent evidence indicating that this effect is primarily a recollection based phenomenon, although familiarity was also influenced by word frequency to a lesser extent (Guttentag & Carroll, 1997). This finding replicated an earlier Remember/Know study that had reported a word frequency effect for Remember responses and not for Know responses (Gardiner & Java, 1990), a finding that had been somewhat surprising in the light of earlier arguments that the word frequency effect is caused by greater relative increments in familiarity for rare stimuli as opposed to frequent stimuli (Mandler, 1980).

Another variable reported to selectively influence recollection is that of cognitive effort at study (Dewhurst & Hitch, 1999; Dewhurst & Conway, 1994). Dewhurst and Hitch (1999) reported that the proportion of Remember responses increased with categorisation difficulty at study whereas familiarity was not affected by this manipulation, and that Remember responses were also selectively enhanced when subjects solved anagrams as opposed to reading words at study. Drawing from the source monitoring framework (which states that memories rich in contextual detail are more likely to be recollected and acknowledged as being 'real'; Johnson, Hashtroudi, & Lindsay, 1993), it was argued that recollection is selectively influenced by the distinctiveness of the encoding operations (Dewhurst & Hitch, 1999). The fact that manipulations such as presenting items as pictures rather than words (Dewhurst & Conway, 1994), rating the degree to which trait adjective describe oneself (Conway & Dewhurst, 1994a), and performing actions upon objects as opposed to imagining performing these actions (Conway & Dewhurst, 1994b) also selectively increased Remember responses were cited to support this hypothesis, which, it was argued, was consistent with the view that richer episodic traces result from more effortful encoding operations (Johnson, Raye, Foley, & Foley, 1981). However, some of these findings should be treated with caution, as it has been reported that the picture superiority effect reported for Remember
responses (Dewhurst & Conway, 1994) is also observed for Know responses if Remember/Know data are analysed under the independence assumption (Wagner, Gabrieli, & Verfaellie, 1997). In addition, the advantage seen for Remember responses in the rating of trait adjectives (Conway & Dewhurst, 1994a) can be explained within a single-process model (Hirshman & Master, 1997).

**Single dissociations in which familiarity is selectively affected**

Only a small number of independent variables have produced this kind of dissociation. Early theories stating that Remember and Know responses are selectively influenced by conceptual and perceptual processing respectively (e.g. Gardiner & Java, 1990) resulted in the proposal that Know responses should be selectively influenced by variables that increase the perceptual fluency with which items are processed (Rajaram, 1993). A number of studies reported dissociations that appeared to support this view (Rajaram, 1993; Gregg & Gardiner, 1994; Mantyla & Raudsepp, 1996). One such study employed a masked repetition paradigm in which studied and unstudied words were preceded at test by a masked repetition either of themselves or of an unrelated word, and found that this manipulation did indeed increase Know responses while leaving Remember responses unaffected (Rajaram, 1993). Gregg and Gardiner (1994) also manipulated perceptual fluency by using an orienting task at study that emphasised the perceptual attributes of the item. They found that matching modality between study and test produced a higher proportion of Know responses than when modality shifted between study and test, whereas Remember responses remained invariant across this manipulation (Gregg & Gardiner, 1994). A third study (Mantyla & Raudsepp, 1996) manipulated attention to stimuli by implementing a separate task between study and test in which both studied and unstudied words were flanked with two numbers. Subjects were required to process these numbers as opposed to the words (i.e. a foveal suppression task). During the subsequent test phase, it was reported that the proportion of Know responses to both studied and unstudied items was higher for items that had been included in the foveal suppression task than for those which had not, whereas Remember responses remained unaffected by this manipulation (Mantyla & Raudsepp, 1996). It was argued that the foveal suppression task enhanced the perceptual fluency of items in the absence of awareness, and that the finding that this manipulation selectively increased Know responses supported the view that Know responses are sensitive to perceptual fluency whereas Remember responses are not (Mantyla & Raudsepp, 1996).
Complex dissociations

Dissociations of this nature strongly support dual-process models of recognition memory, as it is particularly difficult for single-process models to demonstrate how a single variable can affect recollection and familiarity in opposite directions. Complex dissociations can either take the form of a double dissociation or a crossed dissociation. The former occurs when the experimental manipulation is comprised of two discrete levels (e.g. pictures versus words), one of which selectively affects recollection, and the other selectively affects familiarity. A crossed dissociation is considered to occur if the experimental manipulation can be conceptualised as a single variable along a continuum (e.g. retention interval) which influences recollection and familiarity in opposite directions. Such a distinction is often difficult to determine in practice, as levels of variable can be considered as either discrete or continuous, depending on one’s conceptualisation of the task. For example, a word versus non-word manipulation can either be conceptualised as two discrete stimulus types, or as points along a continuum of lexical familiarity. The specific nature of many of the following dissociations are, therefore, open to debate.

Most experiments adopting the phenomenological approach have reported double dissociations as opposed to crossed dissociations. Rajaram (1993) reported that conceptual processing (i.e. deep encoding) at study produced more Remember than Know responses at test whereas producing rhyme associations (i.e. shallow encoding) resulted in the opposite pattern of responses. However, this finding contradicted Gardiner (1988), and it was later reported that the double dissociation disappeared when data were reanalysed under the independence assumption (Yonelinas & Jacoby, 1995). A second experiment (Rajaram, 1993) investigated the picture superiority effect previously observed in recognition memory, in which memory is better for items studied as pictures than as words (Madigan, 1983). Items were presented either as pictures or as words at study, and all items were presented as words at test. Remember responses showed an advantage for items studied as pictures whereas Know responses showed an advantage for items studied as words (Rajaram, 1993). Rajaram’s (1993) conclusion that symbolic form dissociated recollection and familiarity was weakened when it was reported that a picture superiority effect was observed for both Know and Remember responses when the data were reanalysed under the independence assumption (Wagner, Gabrieli, & Verfaellie, 1997). A third experiment reporting that the level of Know
responses was not greater when study-test modalities were the same than when they were
different (Rajaram, 1993) was inconsistent with Gregg and Gardiner's (1994) finding that
study-test modality matching did increase the level of Know responses. Again, it is possible
that these contradictory findings are accounted for by differences in the number of Remember
responses between the two experiments, as the number of Remember responses necessarily
constrains the observed number of Know responses when data are analysed under the
exclusivity assumption (Yonelinas & Jacoby, 1995).

Gardiner and Java (1990) reported a double dissociation in which nonwords elicited higher
levels of Know responses than words whereas words elicited a higher proportion of
Remember responses than nonwords, and argued that the advantage shown by Remember
responses for words compared with nonwords resulted from a greater degree of semantic
processing (Gardiner & Java, 1990). Following arguments that perceptual fluency
contributes more towards nonword recognition than towards word recognition (Johnston,
Dark, & Jacoby, 1985), Gardiner and Java (1990) claimed that the advantage observed for
Know responses for nonwords suggested greater sensitivity of Know responses to perceptual
fluency. An alternative explanation was suggested by the finding that a maintenance versus
elaborative rehearsal manipulation also produced a double dissociation between Remember
and Know responses (Gardiner, Gawlik, & Richardson-Klavehn, 1994). It was argued that
maintenance facilitates intra-item organisation (or familiarity) by integrating an item with its
perceptual features whereas elaborative rehearsal affects extra-item organisation (or
recollection) by associating an item with other studied items, and it was reported that
elaborative rehearsal did indeed increase Remember responses while maintenance rehearsal
increased Know responses (Gardiner, Gawlik, & Richardson-Klavehn, 1994). On the basis of
this finding, it was proposed that the double dissociation elicited by the word/nonword
manipulation (Gardiner & Java, 1990) may have occurred because nonwords promote
maintenance rehearsal rather than elaborative rehearsal, whereas words elicit greater
elaborative rehearsal (Gardiner, Gawlik, & Richardson-Klavehn, 1994). However, it should
be noted that Ratcliffe et al. (1995) demonstrated that a single-process global matching model
(SAM) could also account for dissociations between maintenance and elaborative rehearsal.

A double dissociation was also reported by Jacoby and Dallas (1981) as part of their series of
experiments exploring performance on recognition and perceptual identification tasks. One
of these studies employed a read/solve-anagram manipulation, and found that items presented
as to-be-solved anagrams at study were subsequently more likely to be recognised than words, whereas words were more likely to be subsequently identified in a test of perceptual identification than anagrams (Jacoby & Dallas, 1981). Although the authors argued that this finding dissociated familiarity and recollection, the logic of equating performance on tasks of perceptual identification with familiarity now appears to be highly questionable (as previously discussed). Later studies employing the PDP also undermined this dissociation by demonstrating gains for both familiarity and recollection following anagram solving as opposed to reading (Jacoby, 1991; Verfaellie & Treadwell, 1993).

Evidence for a crossed dissociation came from a study which used both the PDP and the Remember/Know procedure to examine the 'revelation effect', a term describing the finding that subjects are more likely to respond 'old' to items that have been initially disguised and then revealed at test than to items that have not (LeCompte, 1995). This effect is considered to be a response bias effect, as subjects are more likely to respond 'old' both to studied items and to unstudied items. LeCompte (1995) explored which component of recognition memory was responsible for the revelation effect. Subjects were instructed to study and memorise words presented both visually and auditorily. In the PDP version of the task, subjects in the exclusion condition were directed only to report words that had been presented auditorily at study, and it was found that revelation significantly enhanced familiarity without affecting recollection (LeCompte, 1995). However, the Remember/Know version of this task demonstrated that Know responses increased as a function of revelation while Remember responses decreased (LeCompte, 1995). A difference in relational assumptions was not to blame for these discrepant results, as the same pattern of Remember/Know responses was observed whether data were scored under the independence or the exclusivity assumption, and no explanation was given for this apparent contradiction. LeCompte (1995) suggested that the observed increase in familiarity appeared to support the view that the revelation effect occurs as an increase in perceived fluency is misattributed to the study episode (Luo, 1993). Such an interpretation would be consistent with attributional accounts of recognition memory which state that items associated with high levels of perceived fluency are attributed to the study episode, whether the item has been studied or not (Jacoby, Kelley, & Dywan, 1989). However, it was noted that this interpretation could not explain the decrease in recollection observed in the Remember/Know study (LeCompte, 1995). A second phenomenological study reported that a massed versus spaced repetition manipulation also produced a crossed dissociation between Remember and Know responses, with spaced
repetition increasing Remember responses and massed repetition increasing Know responses (Parkin & Russo, 1993).

A third phenomenological study examined the effect of size congruency on recognition memory (Rajaram & Coslett, 1992; described by Yonelinas & Jacoby, 1995). Line drawings were presented at study, and these items were either presented in the same (size congruent) or a different (size incongruent) size at test. It was predicted that Know responses would increase for size congruent items, as it was argued that these responses should be sensitive to perceptual similarity (Rajaram & Coslett, 1992). However, whereas Remember responses were greater for size congruent items, Know responses were greater for size incongruent items (Rajaram & Coslett, 1992). Yonelinas and Jacoby (1995) examined this surprising dissociation, and reported a replication employing the PDP in which size congruency increased both Remember and Know responses. These contradictory results were explained in terms of the relational assumptions adopted by the two experiments; Remember/Know data analysed under the exclusivity assumption replicated Rajaram and Coslett (1992) whereas the same data analysed under the independence assumption gave rise to the same pattern of results as that observed in the PDP study (Yonelinas & Jacoby, 1995). Similarly, another study reporting a crossed dissociation between Remember and Know responses across age has been called into question by Yonelinas and Jacoby (1995). This study reported that older adults showed poorer recollection (as indexed by Remember responses) than younger adults, but that the reverse was true for Know responses (Parkin & Walter, 1992). Reanalysis of this data under the independence assumption indicated that recollection decreased with age while familiarity remained invariant, suggesting that the increase in Know responses reported by Parkin and Walter (1992) was in fact an artefactual consequence of the observed decrease in Remember responses, and that this increase in Know responses was only observed because data were analysed under the exclusivity assumption (Yonelinas & Jacoby, 1995).

Jacoby, Jones & Dolan (1998) employed an exclusion recognition test and a deadline manipulation to examine the effect of repeated study presentations on subsequent recollection- and familiarity-based recognition performance. Participants were presented with repeating visually and auditorily presented words at study. At test they were required to identify which words had been presented auditorily at study and to exclude those that had been presented visually. Participants were split into a deadline group (who had to respond immediately) and a wait group (who had to wait before responding) in an attempt to separate
the contributions of fast-acting familiarity and slower recollection (Yonelinas & Jacoby, 1994). Increased exclusion error rates in the deadline group indicated that familiarity increased with repetition in this group, whereas decreased exclusion error rates in the wait group indicated that repetition increased recollection in this group. Jacoby et al. (1998) argued that the crossed dissociation observed between performance in the two deadline groups supported dual-process accounts of recognition memory as opposed to single-process models, as study repetition should not result in opposite patterns of data across differing response deadlines under the single-process model of recognition (Donaldson, 1996) (Hirshman & Master, 1997). However, this pattern of data can also be explained without recourse to dual-process models of recognition, but can rather be explained within the source monitoring framework (Johnson, Hashtroudi, & Lindsay, 1993); the authors of this framework state that the retrieval of contextual information gradually accrues over time, and that highly differentiated information (i.e. memory with highly specific attributes) takes a relatively long time to emerge. As source monitoring requires a greater degree of differentiation than yes-no recognition, memory tasks requiring source judgements suffer more from short response deadlines than do yes-no recognition tasks (Johnson, Hashtroudi, & Lindsay, 1993; Johnson, Kounios, & Reede, 1994). Similarly, time is also needed for heuristic processes to reflect upon the products of retrieval in order to respond accurately on the basis of source information (Johnson, Hashtroudi, & Lindsay, 1993).

Evidence from receiver operating characteristics (ROCs)

A receiver operating characteristic, or ROC, is the function that relates the proportion of correct recognitions (i.e. hits) to the proportion of incorrect recognitions (i.e. false alarms) in a binary discrimination task. ROCs are typically plotted as a function of response confidence (e.g. Yonelinas, 1994; Yonelinas, Dobbins, Szymanski, & King, 1996; Yonelinas, 1997). When plotted as z-scores, ROCs give two measures of performance; the intercept of the transformed ROC provides a measure of discriminability (d') or memory sensitivity (Yonelinas, 1997), whereas the slope provides a measure of the symmetry of the ROC. Familiarity (modelled as signal-detection process) is assumed to be normally distributed, and therefore yields a ROC slope of 1.0. (see figure 1.5.1).
A z-ROC slope of 1.0 implies total symmetry of the original ROC as plotted in probability space (see figure 1.5.2), indicating that performance can be characterised by a single normally-distributed process. Overall increases in familiarity will increase the intercept (or $d'$), but the shape of the distribution will remain the same and retain a slope of 1.0. Equal-variance signal detection theories of recognition memory (in which the variances of the distributions of old and new items are equal) predict symmetrical ROCs with a slope of 1.0, as recognition judgements are assumed to be based solely on an assessment of familiarity (see figure 1.5.1). ROCs can also be plotted in probability space, in which case the signal-detection model of familiarity predicts a symmetrical and curvilinear ROC, a threshold process (such as that argued to underlie recollection) predicts a linear ROC, and dual-process models postulating the contribution of both a signal-detection process and a threshold process to recognition predict a skewed curvilinear ROC (see figure 1.5.2).

However, ROCs with a slope of 1.0 are rarely observed in recognition memory studies (Yonelinas, 1994; Yonelinas & Jacoby, 1994), which tend to produce skewed ROCs with a slope of around 0.8 (e.g. Ratcliffe, Sheu, & Gronlund, 1992). Indeed, Glanzer and Adams (1990) reported manipulations that improved recognition performance (including word frequency and word concreteness) while decreasing the ROC slope. The finding that recognition ROCs usually have a slope of less than 1.0 has been interpreted by some researchers (e.g. Yonelinas, 1994) as evidence that a secondary process must contribute to recognition performance. As the dual-process account specifies a threshold process for recollection which results in highly confident responding (Jacoby, Toth, & Yonelinas, 1993),
it predicts a skewed ROC with a slope of less than 1.0. Therefore, if recollection contributes towards performance, the slopes of the resulting ROCs for the dual-process and single-process approaches should be significantly different. Although certain single-process models can account for asymmetrical ROCs (i.e. with a slope of less than 1.0) by assuming that old items are always associated with a greater amount of variance than new items, these models predict that the degree of asymmetry will co-vary with the degree of accuracy, and therefore cannot account for the fact that these two factors are functionally independent (Ratcliffe, Sheu, & Gronlund, 1992; Glanzer, Kim, Hilford, & Adams, 1999; Yonelinas, 2001a). Actual ROCs obtained from recognition memory studies can be compared with ROCs predicted by both accounts to determine which has more explanatory power.

Yonelinas (1994) employed the PDP to examine the putative contributions of familiarity and recollection to recognition performance, and also plotted the associated ROCs across three experiments. ROC evidence was presented to support the hypothesis that recognition memory judgements are based on an assessment of familiarity, but that a second recollective process also contributes to performance. A model was described in which familiarity was represented by an equal-variance signal detection mechanism while recollection was modelled as an all-or-none threshold process (Yonelinas, 1994). These two processes were assumed to contribute independently to recognition memory performance. This model was tested across three experiments which employed manipulations such as list length and study time (Yonelinas, 1994). Decreasing list length increased PDP estimates of recollection but left familiarity unaffected, and produced a skewed ROC by increasing the intercept but decreasing the slope. Increasing study time increased PDP estimates of both familiarity and recollection, and increased the intercept while leaving the slope unaffected. This finding replicated an earlier study that had reported an ROC slope of 0.8 which did not change across item strength (Ratcliffe, Sheu, & Gronlund, 1992). The observed ROCs were in accordance with the ROCs predicted by the dual-process model, as the slope was always less than 1.0 when recollection was shown to contribute to performance (Yonelinas, 1994). ROCs associated with Remember and Know responses have recently been analysed, and the results support Yonelinas et al.'s (1994) dual-process model; whereas ROCs (plotted in probability space) associated with Remember responses were linear (thus indicating a threshold process), ROCs associated with Know responses were curvilinear and symmetrical thus indicating a signal-detection process (Yonelinas, 2001b).
The finding that observed ROCs match those predicted by dual-process models more closely than those predicted by single-process models was replicated and extended from equal-variance signal-detection models to unequal-variance signal detection models (Yonelinas, Dobbins, Szymanski, & King, 1996). ROCs predicted by dual-process models are very similar to those predicted by unequal-variance signal-detection models. However, because dual-process models incorporate recollection as a threshold process, these models predict ROCs that become more u-shaped than those predicted by unequal-variance signal detection models as the contribution of recollection increases (Yonelinas, Dobbins, Szymanski, & King, 1996). Yonelinas et al. (1996) used a levels-of-process manipulation to maximise the contribution of recollection to recognition performance, and demonstrated that observed ROCs were linear for shallowly processed items but became more u-shaped for deeply processed items. Therefore, although both the dual-process and unequal-variance signal-detection models provided comparable accounts for shallowly studied words, only the dual-process model could account for the ROC observed for deeply processed items (Yonelinas, Dobbins, Szymanski, & King, 1996).

Observed ROCs were plotted as z-scores and compared with Remember/Know data in a second experiment which attempted to demonstrate that the shape of ROCs could be predicted from Remember/Know data (Yonelinas, Dobbins, Szymanski, & King, 1996). Subjects were presented with items at study in a male or female voice, and were instructed to try to remember in which voice the word had been spoken. Again, this manipulation was intended to maximise recollection. At test, subjects were required both to make a recognition judgement on a six-point confidence scale, and then to respond Remember, Know or New. The Remember/Know data (which was analysed under the independence assumption) was used to constrain estimates of the contributions of recollection and familiarity to performance, and these contributions were then used to predict ROCs. These predicted ROCs were then compared with the observed ROCs. The observed ROCs showed a slight u-shape, and predictions made from the Remember/Know data fitted the ROCs better than predictions made by either the equal-variance or unequal-variance signal-detection models (Yonelinas, Dobbins, Szymanski, & King, 1996). Estimates of familiarity and recollection derived from the ROC also matched subjective reports. Therefore, Yonelinas et al.’s (1994) dual-process models of recognition was supported, and generalised to phenomenological data (Yonelinas, Dobbins, Szymanski, & King, 1996).
Yonelinas (1997) also employed ROCs to dissociate item and associative recognition. The term ‘associative recognition’ refers to paradigms in which each critical stimulus is comprised of two or more items. Yonelinas (1997) reported that whereas ROCs for item recognition were curvilinear, ROCs for associative recognition were u-shaped. It was argued that these findings indicated that item recognition relied on a combination of recollection and familiarity, whereas associative recognition decisions were based primarily on recollection (Yonelinas, 1997). Although the ROC observed for item recognition could also be accounted for by an equal-variance signal-detection model, Yonelinas (1997) argued that the dual-process explanation was preferable as this accounted for both ROCs, an assertion supported by previous finding that U-shaped ROCs could be obtained for item recognition under conditions which maximise recollection (Yonelinas, Dobbins, Szymanski, & King, 1996). The finding that item recognition could be explained within single-process models but that associative recognition could not was replicated by Hockley & Consoli (1999), who employed the Remember/Know paradigm and measures of d' and A'. Associative recognition judgements were accompanied by more Remember responses and fewer Know responses than item recognition judgements, and whereas A'/d' associated with item recognition showed no significant differences between overall recognition and Remember responses, A'/d' associated with associative recognition was significantly greater for Remember responses than for overall recognition in associative recognition (Hockley & Consoli, 1999). The finding that A'/d' was not equal for Remember responses and overall recognition in associative recognition indicated that performance on this task could not be characterised by a single familiarity process (Donaldson, 1996), and it was therefore concluded that recollection must have played a significant role in associative recognition (Hockley & Consoli, 1999).

ROC's were also employed to investigate recognition memory and source memory across four studies which varied in their probability of eliciting recollection (Yonelinas, 1999). The first of these experiments presented subjects with words on the left and right side of the screen at study, and then required half of the subjects to make a recognition judgement on a six-point scale, and the other half to make left-right source judgements on a six-point confidence scale. It was argued that familiarity could not be used to make the source discrimination, and whereas the observed recognition ROC was relatively linear, the source memory ROC was u-shaped in accordance with dual-process model predictions (Yonelinas, 1999). This finding undermined the single-process model, which predicted a linear ROC for source memory, and
was replicated in a second study which specified list membership as source rather than study location. A third study specifying list membership as source presented list 1 items (i.e. those first presented) twice and list 2 items (i.e. those most recently presented) once in an attempt to balance familiarity elicited by recency with familiarity elicited by frequency. This manipulation was designed to discourage subjects from using familiarity when making their source judgements. Again, whereas the recognition ROC was linear, the ROC observed for source memory was U-shaped. Interestingly, a fourth study which maximised the use of familiarity in source discrimination by presenting the two study lists five days apart reported a source memory ROC with a significant linear component. It was argued that the dual-process account provided the most accurate account of all observed ROCs, as the shape of the ROCs co-varied with predicted contributions of familiarity and recollection to performance (Yonelinas, 1999). A second ROC study of source memory confirmed the view that confidence is high for recollected items, as accurate source memory was observed only for those items attracting the highest confidence scores (Yonelinas, 2001b).

Proposed bases of dual-process dissociations

Many of the early dissociations discussed above were employed to construct a framework in which recollection is sensitive to semantic processing at study and familiarity is sensitive to perceptual factors (Gardiner, 1988; Gardiner & Java, 1990; Rajaram, 1993). Early reports that putative measures of familiarity were influenced by the degree of perceptual similarity between items presented at study and at test led to the initial conceptualisation of familiarity as a manifestation of perceptual fluency (Jacoby & Dallas, 1981; Mandler, 1980), and it was proposed that the mechanisms underlying familiarity were the same as those that underlie priming (Jacoby, 1983). As priming is often observed following shallow encoding tasks that emphasise an item's perceptual features (data-driven processing), familiarity was thought to reflect data-driven, rather than conceptually-driven processing (Jacoby, 1988; Roediger, 1990). Early findings that manipulations such as divided attention (Gardiner & Parkin, 1990) and levels-of-processing (Gardiner, 1988) did not influence familiarity supported this view, as these findings had parallels in the implicit memory literature. Jacoby and Dallas (1981) speculated that a subjective experience of perceptual fluency could be attributed to past experience in the absence of actual recollection, and it was subsequently proposed that familiarity resulted from a 'fluency heuristic' (Jacoby & Dallas, 1981; Jacoby & Whitehouse, 1989).
A framework was proposed (Gardiner & Java, 1993a) in which Remember responses were influenced by conceptual and attentional factors whereas perceptual or data-driven factors influenced Know responses arising from the presemantic perceptual-representation systems that have been proposed to account for priming (Tulving & Schacter, 1990). However, it was later argued that Know responses express too high a level of awareness to be dependent on these systems, and that they are in fact an expression of conscious memory (Richardson-Klavehn, Gardiner, & Java, 1996). Experimental findings inconsistent with the theory that familiarity is a form of perceptual fluency also became evident, such as the finding that presenting pictures facing the same way at both study and test as opposed to facing in opposite ways did not increase Know responses as had been expected of a perceptual manipulation (Rajaram, 1996). Reports that familiarity is in fact sensitive to levels-of-processing manipulations (Toth, 1996; Wagner, Gabrieli, & Verfaellie, 1997; Yonelinas & Jacoby, 1995) also suggested that this process does not merely reflect perceptual fluency. Similarly, instances of sensitivity to perceptual factors have also been reported for estimates of recollection (Rajaram, 1996; Rajaram & Roediger, 1997; Rajaram, 1998). It therefore appeared to be unlikely that dual-process dissociations result entirely from differences in perceptual and conceptual processing.

In order to resolve these findings, Wagner et al. (1997) investigated whether or not the familiarity process posited to contribute to both explicit recognition and to implicit perceptual memory was a common process. Wagner et al. (1997) explored this issue by examining the influence of conceptual processing (i.e. picture naming vs word reading) and perceptual similarity (i.e. same vs different formats of items presented at study and at test) on word recognition, word-identification priming, and on word-stem completion. It was found that while familiarity-based recognition memory (as measured by both inclusion-exclusion and Remember/ Know methodologies) increased with conceptual processing, estimates of familiarity contributing to word-identification priming and word-stem completion increased with study-test perceptual similarity (Wagner, Gabrieli, & Verfaellie, 1997). A further study employing the independent Remember/Know procedure and a direct test of recognition memory again reported that familiarity-based recognition increased with conceptual processing (Wagner, Gabrieli, & Verfaellie, 1997). These dissociations indicated that whereas familiarity-based recognition is sensitive to conceptual processing, the familiarity process hypothesised to underlie priming tasks is instead sensitive to perceptual factors, and
that the familiarity process mediating explicit recognition memory is therefore functionally
distinct from the familiarity process mediating implicit perceptual memory (Wagner,
Gabrieli, & Verfaellie, 1997). Wagner et al. (1997) suggested that familiarity-based
recognition may instead rest on the same process or processes as those underlying conceptual
repetition priming tasks such as category exemplar generation.

It was argued that the critical distinction underlying dual-process dissociations may in fact be
between fluency and distinctiveness, rather than between perceptual and conceptual
processing (Rajaram & Roediger, 1997). Items that are more salient than others as a result of
distinctive perceptual or conceptual features may be better recollected, whereas those that are
processed more fluently may be better recognised on the basis of familiarity. Rajaram (1998)
discussed a fluency/distinctiveness framework in which recollection is sensitive to variations
in the distinctiveness or salience of encoding whereas familiarity is sensitive to variations in
processing fluency, and argued that this distinction is orthogonal to that between conceptual
and perceptual encoding. Within this framework, familiarity can be enhanced either by
increasing perceptual or conceptual fluency, whereas recollection can be increased by
increasing conceptual or perceptual distinctiveness (Rajaram, 1998). The finding that low-
frequency words (which are more unusual and therefore arguably more distinctive) lead to
greater levels of Remember responses than high-frequency words (Gardiner & Java, 1991)
supported this hypothesis, as did the finding that priming a word with a semantic associate
increases levels of Know responses (Rajaram & Geraci, 2000).

A criticism levelled largely at phenomenological dual-process models is that dissociations
between Remember and Know responses are nothing more than responses made with high
and low confidence respectively. By replicating their word/nonword study using confidence
judgements, Gardiner & Java (1990) demonstrated that this possibility was unlikely, as
confident responses exceeded nonconfident responses for both words and for nonwords. It
was argued from this finding that Remember and Know responses cannot be equated with
confidence ratings, although they may be correlated (Gardiner & Java, 1990). Rajaram
(1993) came to the same conclusion by replicating the masked repetition paradigm using
confidence judgements, and finding that confidence judgements did not equate with
Remember/Know judgements on this task. Nonetheless, as noted previously, it is advisable
to adopt a two-stage Remember/Know paradigm rather than a one-stage paradigm, in order to
minimise the contribution of confidence to estimates of recollection and familiarity
(Knowlton, 1998; Hicks & Marsh, 1999). Similarly, it has been argued that Remember and Know responses are manifestations of strong and weak trace strength respectively (Donaldson, 1996). Donaldson (1996) replicated a number of Remember/Know dissociations within a single-process two-criteria signal detection model, and argued that this provided evidence that these responses can indeed be modelled as different points on a trace strength continuum. However, although Donaldson (1996) argued that measures of A’ for recognition and Remember responses yielded by this meta-analysis were sufficiently close to support the single-process model, Gardiner and Gregg (1997) reported that A’ was significantly greater when derived from both Remember and Know responses than when derived from Remember responses alone, both in a meta-analysis and in individual subject data. It was additionally demonstrated that when a third Guess response was added, A’ for Remember responses, A’ for Remember and Know responses, and A’ for Remember, Know and Guess responses were all significantly different (Gardiner & Gregg, 1997), thus invalidating the two-criteria signal-detection model. The signal detection model of Remember/Know responses was also criticised for dissociating the two responses by means of a decision process, as it was argued that this distinction failed to take account of the often involuntary phenomenological characteristics of the two responses (Gardiner, Richardson-Klavehn, & Ramponi, 1998).

**Models of recognition memory: Neuropsychological evidence**

**Amnesia**

Evidence

The symptomatology of amnesic disorders associated with damage to bilateral medial temporal and diencephalic regions includes dense impairments in recall and some measures of recognition. A meta-analysis of recognition memory studies in amnesia concluded that amnesics with focal lesions in the hippocampus often display relative sparing of recognition performance (Aggleton & Shaw, 1996). It was suggested that this may be due to a preserved sense of familiarity for recently experienced stimuli (Verfaellie & Cermak, 1999). However, contradictory evidence indicating that bilateral damage to the hippocampus or hippocampal system can result in impaired recognition memory also exists (Reed, Hamann, Stefanacci, & Squire, 1997). The following studies have examined amnesic patients’ recognition performance in an attempt to dissociate familiarity-based recognition from that based on recollection.
Evidence that amnesics could show preserved recognition was presented when it was reported that extending study time for amnesic individuals resulted in forced-choice recognition performance that was relatively preserved compared to recall (Hirst et al., 1986). This finding was then extended with two further studies (Hirst, Johnson, Phelps, & Volpe, 1988). The first of these studies demonstrated that Hirst et al.’s (1986) finding was not paradigm-specific, as the same pattern of performance was repeated if retention interval was extended for normal participants rather than extending study time for amnesic participants. The finding was then generalised to yes-no recognition performance from forced-choice recognition by extending study time further for amnesics. These findings were some of the first to demonstrate that recall is disrupted to a greater extent than recognition in amnesia, and can be interpreted to support the view that familiarity-based recognition is relatively unimpaired in amnesia. The finding that extended study time improves recognition in controls and amnesics was replicated in a later study, although extending study time did not improve recognition performance of severely amnesic patient E.P (Reed, Hamann, Stefanacci, & Squire, 1997).

Contrary to Hirst et al. (1988), it was reported in a later study that recognition and recall were similarly impaired in amnesia (Haist, Shimamura, & Squire, 1992). Free recall and forced-choice recognition memory performance were examined across six study-test delays both in an amnesic group (consisting of hippocampal and diencephalic patients) and in a control group. Amnesics were presented with shorter study-test delays than controls in order to match the two groups’ performance curves across delays. Confidence ratings for each of the forced-choice recognition judgements were also collected from each group. It was reported that both recall and recognition were significantly impaired in the amnesic group, and that when performance curves associated with recognition memory were matched between amnesics and controls across several delays, recall was not disproportionately impaired in the amnesic group (Haist, Shimamura, & Squire, 1992). Confidence judgements were similarly correlated with recognition memory performance both in the control group and in the patient group. It was therefore argued that recognition, recall and confidence ratings are closely related functions of declarative memory that are similarly dependent on the brain systems damaged in amnesia (Haist, Shimamura, & Squire, 1992). As this study had differed from that conducted by Hirst et al. (1988) on several methodological points, Haist et al. (1992) replicated Hirst et al.’s (1988) experiment in order to clarify whether these experimental differences were responsible for the discrepant results described above. However, recall was
not found to be disproportionately impaired compared to recognition even in this replication (Haist, Shimamura, & Squire, 1992). It was suggested that the fact that Hirst et al. (1988) used a patient group of mixed aetiologies whereas Haist et al. (1992) could take advantage of neuroimaging in choosing a relatively homogeneous patient group may account for these discrepant results.

Experimental manipulations thought to specifically facilitate familiarity have been reported to elevate recognition performance in amnesia close to levels exhibited by normal controls. In one such study, two experiments were conducted to investigate the extent to which amnesic patients use perceptual fluency as a cue in recognition (Verfaellie & Cermak, 1999). Both experiments required subjects to gradually unmask each word before making a recognition judgement. In the first study, recognition judgements could only be based on familiarity as none of the words had actually been presented at study (although participants were told that they had been presented subliminally). It was reported that amnesics and controls were equally likely to use perceptual fluency as a cue for recognition (words judged old were identified at a higher masking level than those judged new), and it was asserted that fluently perceived items are felt to be familiar because their relative perceived fluency is attributed to the past (Verfaellie & Cermak, 1999). In the second study, test words had been previously presented at study so that subjects could make recognition judgements based either on recollection of the study episode or on perceptual fluency (Verfaellie & Cermak, 1999). It was found that amnesic patients were more likely than normal controls to use perceptual fluency as a cue for recognition judgements. Verfaellie et al. (1999) concluded that whereas normal individuals only use perceptual fluency as a basis for recognition in the absence of recollection, perceptual fluency is the only basis available for recognition in amnesic individuals. In the light of research indicating that fluency per se influences familiarity (e.g. Rajaram, 1998), it was argued that conceptual fluency may also serve as a cue for recognition in standard recognition tasks (Verfaellie & Cermak, 1999).

Interestingly, it has been noted that recognition accuracy in amnesia deteriorates under conditions in which familiarity cannot be used to aid recognition performance. Cermak et al. (1993) placed familiarity in opposition to conscious recollection during a fame judgement task (Dywan & Jacoby, 1990). Both patients and controls were informed that all names presented prior to the fame judgement task were non-famous. It was anticipated that both groups would be equally susceptible to gains in familiarity, but that controls would be able to
use recollection to oppose such feelings. Indeed, the performance of controls was significantly more accurate than that of the amnesic patients. In a second study, both groups were told that all names presented prior to the fame judgement task were famous, which allowed familiarity and recollection to operate in concert (Cermak, Verfaellie, Butler, & Jacoby, 1993). The false-fame effect (i.e. in which subjects classify non-famous studied faces as being famous) was slightly higher for controls than for patients, as the former were able to use both familiarity and recollection when making their decisions (Cermak, Verfaellie, Butler, & Jacoby, 1993). It was argued from these results that amnesic patients can only perform normally on recognition tasks when recollective control is not required (Cermak, Verfaellie, Butler, & Jacoby, 1993). Squire and McKee (1993) replicated Cermak et al.’s (1993) first study in which subjects were informed that all names presented prior to the fame judgement task were nonfamous, and observed the same pattern of results. However, rather than attributing false fame judgements to familiarity, it was concluded that the fame-judgement effect is driven by nondeclarative (implicit) memory as this is not supported by the limbic-diencephalic structures damaged in amnesia (Squire & McKee, 1993). Therefore, while the findings from the Cermak et al. (1993) and Squire and McKee (1993) studies concur, the interpretations differ.

The view that the false-fame effect in amnesia results from intact familiarity processes was supported by application of the PDP (which had been modified using multidimensional signal detection theory to correct for different false alarm rates between groups) to amnesics’ performance data during a false fame task (Mayes, Van Eijk, & Isaac, 1995). Mayes et al. (1995) reported that amnesics showed preserved PDP estimates of familiarity and impaired recollection. The PDP was also applied to recognition memory performance following a study manipulation in which words were either presented as to-be-solved anagrams, or as words presented in the same format as at test (Verfaellie & Treadwell, 1993). Whereas recognition for words presented as anagrams at study was impaired in amnesia, recognition of words presented in the same format at study and at test was comparable to that observed for controls. It was demonstrated that the preserved recognition performance observed for amnesics was largely due to an intact familiarity process, and it was argued that recognition performance under conditions which minimise the contribution of recollection can be relatively normal in amnesia (Verfaellie & Treadwell, 1993). However, it was argued that this result may have been an artefact of differing false alarm rates observed between controls and amnesics, and in reanalysing the data to account for these differences it was demonstrated
that familiarity did in fact show small but systematic decreases in amnesia (Roediger & McDermott, 1994).

The effect of amnesia on recognition memory has also been interpreted within a declarative memory framework, in which Remember and Know responses reflect the operation of episodic and semantic memory respectively (Tulving, 1989). Evidence that semantic retrieval is selectively spared in amnesia has been reported (Tulving, 1991; Vargha-Khadem et al., 1997), although it has also been argued that experimental studies comparing the abilities of amnesic patients both to acquire (Hamann & Squire, 1995) and to retrieve (Knowlton & Squire, 1995; Squire, Haist, & Shimamura, 1989; Reed & Squire, 1998) from episodic and semantic memory suggest that both kinds of memory are impaired similarly in amnesia (Squire & Zola-Morgan, 1998). Studies pertaining to this issue are not reviewed here. This is because it is argued here that application of the Remember/Know procedure to the episodic/semantic dichotomy does not speak to dual-process models of recognition memory; despite the fact that familiarity and semantic memory are both characterised by an acontextual conscious form of retrieval, familiarity is also characterised by a phenomenological feeling of prior personal experience whereas semantic retrieval is not. A number of studies employing the Remember/Know procedure with respect to dual-process models of recognition memory initially appeared to produce discrepant findings with regard to the effect of anterograde amnesia on Remember and Know responses. One such study (Knowlton & Squire, 1995) reported that amnesics tested 10 minutes after the study episode were impaired on both Remember and Know responses and performed like a control group tested after 1 week, whereas a second study (Schacter, Verfaellie, & Pradere, 1996) presented new words, studied words and semantically-related lures at test to demonstrate that anterograde amnesia decreases Remember responses but increases Know responses. A third study examining false recognition for semantically- and perceptually-related items reported that Remember responses decrease in amnesia whereas Know responses remain unaffected (Schacter, Verfaellie, & Anes, 1997). Therefore three studies employing the Remember/Know procedure produced conflicting results with regard to the influence of anterograde amnesia on Remember and Know responses.

However, as stated previously, it is important to consider the assumptions under which data from Remember/Know studies are scored, and this proved to be a key point in reconciling these findings. In all three experiments, large differences existed in the false alarm rates...
between amnesics and controls. Yonelinas et al. (1998) reanalysed each data set using a dual-process signal-detection model which incorporated response bias and allowed for independence between Know and Remember responses. Estimates of recollection and familiarity resulting from the application of this model were the same for each of the three studies; anterograde amnesia led both to a pronounced deficit in recollection and to a smaller decrement in familiarity (Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998). Application of this model to the PDP data discussed previously (Verfaellie & Treadwell, 1993) revealed that amnesia did in fact decrease estimates of familiarity in this study, albeit to a smaller degree than the reduction observed for recollection (Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998). The dual-process signal-detection model used to analyse this data was tested by examining ROCs produced by amnesic and normal individuals during a recognition memory test (Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998). Whereas the slope of controls’ ROCs was significantly lower than 1.0 (due to the contribution of recollection), the ROCs of amnesic individuals did not differ significantly from 1.0. The intercept of the amnesic ROC was also lower than the intercept of the control ROC. These results supported the claims of the model, in that amnesia was associated with deficits in both recollection and familiarity. However, familiarity was sufficiently preserved for amnesic individuals to rely on this information when making recognition judgements. Yonelinas et al. (1998) therefore suggested that although medial temporal regions play a role in both recollection and familiarity, familiarity may not be a unitary process and may instead reflect both perceptual and conceptual fluency as had previously been argued.

Neuroanatomical inferences
Several theories regarding amnesia have been proposed as a result of the findings discussed above. Yonelinas et al. (1998) hypothesised that recollection and familiarity may rely on the hippocampal and parahippocampal regions respectively, as it had been reported that lesions to area CA1 in the hippocampus causes deficits in tasks that require recollection (Zola-Morgan, Squire, & Amaral, 1986), whereas patients with parahippocampal lesions show deficits in familiarity (Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998). On the basis of the assertion that the Remember/Know distinction reflects a distinction within declarative memory and reflects episodic and semantic memory respectively, Knowlton and Squire (1995) argued that Know responses depend on the medial temporal lobe and diencephalic structures whereas Remember responses depend on these same structures but additionally require the engagement of the frontal lobes. It was claimed that such a system would parallel
that hypothesised between episodic and semantic memory (Shimamura & Squire, 1987). However, as previously argued, this framework may not speak to Remember and Know responses as applied to recollection and familiarity.

An alternative framework proposed by Aggleton & Brown (1999) combined information from both clinical studies and experimental animal studies to reformulate the anatomy underlying anterograde amnesia. This reformulation emphasised the importance of the efferents from the hippocampus to the diencephalon via the fornix, which was termed the ‘hippocampal-anterior thalamic axis’. This axis also contains projections back from the diencephalon to the temporal cortex and hippocampus, which, it is argued, support episodic memory but which are not needed for tests of item recognition that primarily involve familiarity judgements (Aggleton & Brown, 1999). Aggleton & Brown (1999) asserted that familiarity judgements reflect an independent process supported by a separate system consisting of the perirhinal cortex of the temporal lobe and the medial dorsal nucleus of the thalamus. In many amnesic cases, both hippocampal-anterior thalamic and perirhinal-medial dorsal thalamic systems are damaged, thus resulting in deficits in both episodic recall and familiarity-driven recognition. Therefore amnesics suffering damage to both systems may not demonstrate differentially impaired recollective- and familiarity-based recognition memory (Aggleton & Brown, 1999). Additional evidence supporting the view that recollection is dependent on the hippocampus whereas familiarity is associated with activity in the perirhinal cortex was presented in a recent review (Brown & Aggleton, 2001). Brown and Aggleton (2001) reviewed findings from animal lesion studies which showed that lesions to the perirhinal cortex impaired recognition memory for individual objects whereas this kind of single-item recognition memory was relatively intact following lesions to the hippocampus. Hippocampal lesions were instead reported to impair associative recognition in tasks requiring the retrieval of the spatial location of objects (Gaffan & Parker, 1996). In the light of the view that that single-item recognition can be supported by familiarity whereas associative recognition is thought to additionally require recollection, these findings suggest that recollection and familiarity are associated with activity in distinct brain regions. It was also reported that large decreases in neuronal responses to familiar objects (i.e. repeated stimuli) relative to novel objects were observed in the perirhinal cortex but were far less common in the hippocampus. Conversely, large neuronal responses associated with associative recognition (such as spatial information) were observed throughout the hippocampus, but were rarely observed in the perirhinal cortex (Brown & Aggleton, 2001).
This double dissociation cannot be easily accommodated by single-process models of recognition.

A similar account was proposed by Mishkin et al. (1998), who considered evidence from neuroanatomical and lesion studies and proposed a hierarchically organised system comprising the hippocampus and subhippocampal cortices. It was suggested that the greatest convergence of episodic information takes place in the hippocampus at the apex of this system, whereas context-free semantic memory can be supported by the subhippocampal cortices (including the entorhinal, perirhinal and para-hippocampal cortices), as this type of information requires fewer complex associations (Mishkin, Vargha-Khadem, & Gadian, 1998). This proposal is supported by the finding that recognition memory is severely impaired in monkeys following removal of subhippocampal cortices, whereas selective lesions of the hippocampus itself has little effect on these same indices (Mishkin, Vargha-Khadem, & Gadian, 1998). These findings accord with those of Vargha-Khadem et al. (1997) who demonstrated that patients with early hippocampal damage show largely intact recognition memory. A recent study of recall and recognition in YR, a patient who suffers from adult-onset selective hippocampal damage, also concluded that recognition is mediated by hippocampally-dependent recollection whereas familiarity is cortically-dependent (Holdstock et al., 2001). The authors reached this conclusion following the finding that whereas forced-choice object recognition was unimpaired in the face of this hippocampal damage, recall was clearly impaired. Holdstock et al. (2001) also presented YR with a second forced-choice recognition test in which an object studied in a particular location was again presented both in the same position and in three alternate positions at test, and asked her to judged in which position the object had been previously presented. Although this object-location recognition task was no more difficult than the forced-choice object recognition task (as reflected by controls’ performance), YR’s performance was impaired on this task. It was argued both on the basis of these findings, and of other findings suggesting that YR’s recognition of face-voice, word-meaning and picture-occupation associations is also impaired (Mayes, Van Eijk, Gooding, Isaac, & Holdstock, 1999; Holdstock, Mayes, Roberts, Gong, & Isaac, 2001), that YR suffers from a general associative memory deficit, and that the most complete convergence of various kinds of information represented within different cortical regions may therefore take place in the hippocampus (Holdstock et al., 2001).
However, it should be noted that other evidence has been presented indicating that patients with selective hippocampal damage are in fact impaired on a wide range of recognition memory tests (Reed & Squire, 1997; Manns & Squire, 2000), a finding that does not support the view that selective damage to the hippocampus leaves familiarity intact. Reed and Squire (1997) examined three amnesic patients whose lesions were restricted to the hippocampus or hippocampal formations across a large number of verbal and nonverbal recognition memory tasks, and on tests of immediate and delayed recall. Each patient showed a significant impairment on verbal and nonverbal, yes-no and forced choice recognition memory tests. It was also reported that these patients were impaired on forced-choice object recognition, and that recognition scores were highly correlated with recall scores (Reed & Squire, 1997).

Manns and Squire (2000) tested three patients, again with damage limited to the hippocampal region, on the Doors and People Test (Baddeley, Emslie, & Nimmo-Smith, 1994). The Doors and People Test contains standardised subtests of visual and verbal recognition and visual and verbal recall, and provides information regarding the relationship between recognition performance and recall. The amnesic patients performed significantly lower than controls on all four types of memory test, and showed no sparing of recognition relative to recall (Manns & Squire, 2000). Reports that patients with pathology specific to the hippocampus show impairments both on Know responses and on Remember responses (Knowlton & Squire, 1995; Squire & Zola-Morgan, 1998) are also inconsistent with the view that selective hippocampal damage disrupts recollection while leaving familiarity-based recognition relatively intact.

Evidence from amnesia is therefore inconclusive with regard to the influence of hippocampal damage on recollection and familiarity. It is unclear why different laboratories should report such contradictory findings, but a number of explanations could possibly reconcile these findings; perhaps the most obvious of these is the possibility that patients showing impaired familiarity-based recognition following selective damage to the hippocampus do in actuality suffer from damage to other 'occult' (i.e. undetected) brain regions. Conversely, it is also possible that those patients who do show relatively intact recognition compared to recall have greater residual hippocampal function than those who do not, and that their recognition performance is therefore supported by residual hippocampal function rather than a functionally and anatomically distinct familiarity process. It is hoped that the evolution of fMRI will result in higher resolution images that may in time clarify the actual extent of damage within these subject groups.
Other Neuropsychological Evidence

A number of other subject populations suffering from neuropathological disease or cognitive decrements as indexed by neuropsychological testing have been studied from the dual-process perspective. It has been suggested that many of these groups show some dissociation between familiarity- and recollection-based recognition performance, and it often appears to be the case that such dissociations result from decrements in recollection. For example, Huron et al. (1995) examined recognition memory for high and low frequency words in schizophrenic patients and in controls using the Remember/Know paradigm, and demonstrated that whereas the two groups exhibited comparable levels of Know responses, schizophrenic patients showed a significantly lower level of Remember responses. It was also noted that whereas normals exhibited a word frequency effect at test (i.e. more Remember responses for low frequency items than for high frequency items), this effect was absent in the schizophrenic group (Huron et al., 1995). A second study examined the relative contributions of familiarity and conscious recollection in a category production test among schizophrenic patients (Besche-Richards, Passerieux, Hardy-Bayle, Nicolas, & Laurent, 1999). Subjects were first required to perform a non-semantic encoding task followed by an inclusion test in which they asked to produce the first six words that came to mind for a semantic category. Subjects were then required to perform a semantic encoding task followed by an exclusion test in which they were again required to produce six category exemplars excluding the items that had been previously studied. Finally, a recognition test was administered. Controls’ and patients’ performance differed in the exclusion condition, in that the latter were unable to use recollection to exclude items. However, both groups showed similar levels of subsequent recognition performance, indicating a selective recollective deficit in schizophrenia. Drawing from Jacoby (1991), it was argued that preexposed items were mistakenly produced by patients in the exclusion condition on the basis of familiarity in the absence of recollection, and that it was this feeling of familiarity that facilitated their normal performance on the recognition task (Besche-Richards, Passerieux, Hardy-Bayle, Nicolas, & Laurent, 1999). However, it is also possible that the schizophrenic group suffered from a more general executive deficit and were less able to inhibit familiarity than were controls, as this kind of deficit could also result in the pattern of results reported above.
Blaxton and Theodore (1997) employed the Remember/Know paradigm when testing recognition memory for novel visuo-spatial materials in unilateral temporal lobe epilepsy (TLE) patients and normal controls, and found that both controls and left TLE patients produced more Know than Remember responses. In contrast, right TLE patients produced more Remember responses than Know responses. It was argued that this reversed pattern of responding in right TLE patients resulted from impaired perceptual fluency or familiarity (Blaxton & Theodore, 1997). To investigate this finding further, subjects were required to encode items either by counting the number of lines present in each item, or by assigning appropriate semantic labels. All participants at test showed the same pattern of responses as before for the 'line' condition. However, the increased semantic processing associated with labelling items only influenced the responses of controls; regardless of encoding task, left TLE patients gave more Know than Remember responses whereas right TLE patients gave more Remember than Know responses. These results were interpreted within a framework in which Remember responses are attributed to item distinctiveness, and Know responses reflect fluency (e.g. Rajaram, 1998), and it was suggested that structures in the left temporal lobe mediate distinctiveness whereas right temporal lobe structures subserve the processes underlying perceptual fluency (Blaxton & Theodore, 1997). Blaxton and Theodore (1997) argued that the double dissociation observed between Remember and Know responses is inconsistent with single-process models, as different levels of Remember and Know responses were given by the two groups even though overall recognition was equivalent across the groups. However, it is also possible that the two groups instead employed different criteria when responding Remember, rather than having differentially impaired familiarity and recollection.

Evidence suggests that source amnesia (in which recollection of contextual information is impaired while item memory remains intact) is greatest for those patients who show high levels of frontal dysfunction (Schacter, Harbluk, & McLachlan, 1984) (Craik, Morris, Morris, & Loewen, 1990). Similarly, it has been demonstrated that multiple-item recognition (in which groups of items are presented at study with one item alone designated as being a 'target', and in which subjects are required to identify the designated item at test) is impaired in normal ageing, and decreases yet further when the number of grouped items presented at study increases (Kausler, 1990). It was hypothesised that this pattern of performance resulted from young participants' greater ability to use recollection in order to discriminate 'correct'
items from group lures, whereas older subjects’ greater reliance on familiarity renders them unable to identify these words (Parkin & Walter, 1992).

**Models of recognition memory: Evidence from neuroimaging**

Functional neuroimaging techniques such as event-related potentials (ERPs), functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) have also recently been applied to the study of models of recognition memory. The application of such techniques allows one to identify the neural correlates of specified cognitive processes and to explore the dynamics of these correlates. Findings from neuroimaging studies have been interpreted on the basis of several core assumptions; foremost of these is the assumption that the mapping between a cognitive process and its neural substrate is invariant. Qualitatively distinct indices of brain activity are therefore interpreted as reflecting functionally distinct cognitive operations, whereas a pattern of brain activity that changes quantitatively between experimental manipulations suggests that the same cognitive operation is being engaged to varying degrees (Rugg, 2001). In this way, functional neuroimaging can inform the study of recognition memory. If manipulations designed to separate measures of familiarity and recollection engage qualitatively different patterns of brain activity, this provides strong support for dual-process accounts of recognition memory. However, it should be noted that the poor temporal resolution of event-related fMRI can render even qualitative dissociations ambiguous; whereas the high temporal resolution of ERPs allows researchers to discriminate between patterns of neural activity associated with retrieval processes and post-retrieval processes on the basis of their respective time-courses, event-related fMRI does not provide temporal information of a sufficient resolution to support these kinds of fine-grained inferences.

The one neuroimaging technique that has probably contributed the most evidence to the debate surrounding models of recognition memory is electrophysiology. Early studies reported event-related potentials (ERPs) associated with familiarity and recollection that differed quantitatively rather qualitatively (Smith, 1993; Wilding, Doyle, & Rugg, 1995; Wilding & Rugg, 1996; Donaldson & Rugg, 1998), whereas more recent studies have reported ERP correlates of the two processes that differ qualitatively (Curran, 2000; Curran, 1999; Rugg et al., 1998; Duzel et al., 1999; Tendolkar et al., 1999; Nessler, Mecklinger, & Penney, 2001). These findings are discussed fully in Chapter 3 as part of a wider discussion...
of the ERP literature and are therefore not reiterated here. Until recently, the study of recollection and familiarity had posed a problem for haemodynamic imaging methods. This is because fMRI and PET techniques traditionally employed blocked designs which do not allow for the analysis of event-related responses. Remember/Know and exclusion-based paradigms demand such analysis, and it is only with the advent of event-related fMRI that the study of models of recognition memory using haemodynamic techniques has become a real possibility. Therefore, investigation of this area of memory using haemodynamic imaging methods is in its infancy.

A recent event-related fMRI study using the Remember-Know procedure (Henson, Rugg, Shallice, Josephs, & Dolan. 1999) reported that Remember responses are associated with enhanced activity in anterior left prefrontal, left parietal and posterior cingulate regions (including the left hippocampus) relative to Know responses. Henson et al. (1999) speculated that left anterior prefrontal cortex may be involved in reflective processes associated with source retrieval and monitoring (Nolde, Johnson, & D'Esposito, 1998). Henson et al. (1999) also found that Know responses were associated with enhanced responses in right lateral and medial prefrontal cortex relative to both Remember and New responses, and that no hippocampal activation was detected for Know responses. These activations were attributed to post-retrieval processes rather than to familiarity per se (Henson, Rugg, Shallice, Josephs, & Dolan. 1999). A right dorsolateral prefrontal activation also observed for Know responses was specifically attributed to a greater degree of monitoring prior to responding when items were close to the Know/New criterion (Henson, Rugg, Shallice, Josephs, & Dolan. 1999). These interpretations were consistent with the finding that Know responses were associated with longer reaction times than Remember or New responses. Although Henson et al. 's (1999) findings indicated that neural activity as measured by fMRI does dissociate qualitatively according to whether memory retrieval is associated with a Remember response or a Know response, a dual-process model of recognition is not necessarily required to account for this data; if one assumes that activations observed for Know responses relative to Remember responses in right prefrontal cortex are associated with post-retrieval processes rather than with familiarity, all other data reported in this study indicate that brain regions showing activations for Know responses are a subset of those showing activations for Remember responses. This pattern of data can therefore be accommodated by single-process models of recognition memory if it is argued that activations in certain regions are only detected when information retrieved is of sufficient
complexity or strength. The fact that the Remember/Know paradigm employed in Henson et al.'s (1999) study was a one-step paradigm in which subjects made a single Remember/Know/New decision may have caused subjects to treat these responses as differing degrees of response confidence, rather than indicating phenomenological experiences of recollection and familiarity (Hicks & Marsh, 1999).

This criticism does not apply to a more recent event-related fMRI study which also employed the Remember/Know paradigm in demonstrating distinct patterns of activation associated with recollection and familiarity (Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000). Subjects were presented with a group of words for deliberate study, which was followed by a twenty minute study-test delay. A two-stage Remember/Know paradigm was employed, in which subjects first indicated if they recognised the word, and then made a Remember or Know response for recognised words only. Eldridge et al. (2000) reported that the hippocampus was selectively activated by Remember responses relative to both new items and Know responses. No activation was observed in the hippocampus for Know responses relative to new items. Relative to Know responses, Remember responses were also associated with activations in bilateral inferior parietal gyrus and in the left middle frontal gyrus. Regions showing greater activation for Know responses than for Remember responses included left anterior insula, right superior frontal sulcus and bilateral anterior cingulate. The finding that Know responses were associated with activations in brain regions distinct from those associated with Remember responses indicates that familiarity and recollection are associated with distinct patterns of neural activity and are therefore independent processes. However, it should again be noted that this study was unable to distinguish between activity dissociating familiarity and recollection per se, and activity associated with post-retrieval processes that may have been active to a greater extent for Know responses than for Remember responses.

A third fMRI experiment also reported qualitative differences between item recognition and recognition accompanied by the retrieval of contextual information by presenting subjects with line drawings at study and test, and either requiring them to retrieve source information (i.e. the colour of the picture at study) or requiring them to make a simple yes-no recognition judgement (Yonelinas, Hopfinger, Buonocore, Kroll, & Baynes, 2001). It was argued that recollection would be required in the source memory task, whereas familiarity should be sufficient to support responding in the recognition task. The source memory task elicited
activity in bilateral hippocampal and parahippocampal regions (including the hippocampus proper) relative to the item memory task. Activity in these regions was absent in the item recognition task, which instead elicited activity in left inferior temporo-occipital regions (Yonelinas, Hopfinger, Buonocore, Kroll, & Baynes, 2001). Both source memory and item recognition were also associated with an activation in the middle occipital gyrus. The fact that partially distinct temporal lobe regions were involved during item recognition and during source memory suggested that familiarity and recollection are associated with activity in qualitatively distinct brain regions. Yonelinas et al. (2001) proposed that the temporo-occipital regions recruited in item recognition may support the processing of individual aspects of an event, whereas the hippocampal regions recruited in source memory may support the reconstruction of associations.

The findings described above provide some evidence that recollection and familiarity elicit qualitatively distinct patterns of neural activity, and can therefore be interpreted as evidence consistent with the dual-process approach. It appears to be a relatively consistent finding that the hippocampus is engaged by various measures of recollection, although enhanced activity associated specifically with familiarity appears to be less replicable. The variability of activations associated with familiarity may arguably be interpreted as evidence that familiarity is functionally heterogeneous (Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998). The finding that recollection selectively increases activity in the hippocampus appears to support the theories of Aggleton and Brown (1999) and Mishkin (1998) which state that this structure is associated with the episodic retrieval of contextual details, a core functional characteristic of recollection. However, the finding that hippocampal activation is only detected for recollection does not necessarily imply that two independent familiarity and recollection processes are operating, as it is possible that the detection of hippocampal activation only occurs when mnemonic information retrieved by a single retrieval mechanism reaches sufficient complexity or strength. Therefore, studies which report activations associated with familiarity which are a subset of those associated with recollection can still be accommodated by single-process models of recognition memory. In order to provide compelling evidence for dual-process models, it is additionally necessary either to report activations associated with familiarity that are not observed for recollection (this finding could not be accommodated by a single-process theory based upon ‘trace-strength’), or to identify variables that have dissociating effects on activity in distinct brain regions. Even when identified, it is difficult to interpret activations selectively associated with either
familiarity or recollection, as a problem inherent in the interpretation of event-related fMRI
data is that its poor temporal resolution renders it extremely difficult to disentangle the
processes of interest (i.e. familiarity and recollection) from other factors such as post-retrieval
processing. It is therefore difficult to determine whether the qualitatively distinct patterns of
neural activity associated with recollection and familiarity observed in the fMRI studies
described above reflect a direct dissociation between familiarity and recollection themselves,
or differential involvement of post-retrieval processes.

Discussion
The strength of the cognitive neuroscience approach to the study of models of recognition
memory is its ability to provide convergent evidence, both behavioural and physiological.
Experimental, neuroimaging and neuropsychological studies employing both
phenomenological paradigms (i.e. Remember/Know) and third-person paradigms (e.g. the
PDP) have reported a persuasive variety of dissociations between familiarity and recollection
which support dual-process models of recognition. Findings from behavioural experiments
have indicated that a number of manipulations can either selectively affect recollection
(levels-of-processing, full/divided attention, cognitive effort, word frequency, retention
interval, list length, response deadline), selectively affect familiarity (masked repetition,
modality shifts, foveal suppression, revelation effects) or influence recollection and
familiarity in opposite directions (words/pictures, words/nonwords, maintenance/ elaborative
rehearsal, massed/spaced repetition, read/anagram). ROC data associated with recognition
memory have also indicated that recognition memory is comprised of two processes; the first
being a continuously distributed process as described by signal detection theory and the
second being a discrete threshold process (Yonelinas, 1994). A number of these dissociations
are either open to refutation, or have also been accounted for by single-process models of
recognition. Dissociations reported by studies employing the Remember/Know procedure
appear to be particularly fragile, as different estimates of familiarity can be obtained
depending on whether data are analysed under the exclusivity or under the independence
assumption. The majority of early Remember/Know studies reporting dissociations between
familiarity and recollection were analysed under the exclusivity assumption. However,
reanalysis of these Remember/Know data under the independence assumption has in some
cases produced the finding that the dissociating variable actually has parallel influences on
the two processes, and that the findings from these studies do not therefore necessarily
support the dual-process approach. Other dissociations have been simulated within single-process models, although the fact that these simulations define the Remember/Know distinction in terms of decision criteria has in itself been criticised (Gardiner, Richardson-Klavehn, & Ramponi, 1998). However, despite these controversies, a significant amount of evidence from a variety of different sources suggests that certain variables do genuinely dissociate recollection and familiarity. This is not to say that single-process models are not useful; single-process models are extremely useful in separating dissociations that can also be explained in terms of a single process from genuine dissociations that provide unequivocal support for the dual-process approach. In this way, simulations using single-process models can inform theories of recognition memory in terms of variables that genuinely dissociate familiarity and recollection, and can therefore help to delineate the functional characteristics of the two processes.

Very little haemodynamic neuroimaging data pertaining to models of recognition memory is currently available, as techniques that allow for an analysis of this issue have only recently been developed in the form of event-related fMRI. However, convergent evidence reported from a number of ERP and event-related fMRI studies suggests that familiarity and recollection are associated with the activity of at least partially non-overlapping neural populations, whether these processes are differentiated by Remember and Know responses or by source judgements (Henson, Rugg, Shallice, Josephs, & Dolan, 1999; Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000; Yonelinas, Hopfinger, Buonocore, Kroll, & Baynes, 2001). Further research is required, however, before the neural correlates of these two processes are understood. Data from functional neuroimaging studies may also help us to understand issues such as the relationship between familiarity and recollection, and the dynamics and functional characteristics of the two processes. A convergent approach employing both ERPs and event-related fMRI can provide detailed temporal and anatomical information respectively, as the two techniques are complementary. However, one problem inherent in the interpretation of neuroimaging data is the fact that no conclusions can be drawn from a null result, as not all brain activity can be detected by any neuroimaging method. Therefore, it is possible for qualitatively distinct neural populations to be engaged by the two types of processes but for this distinction not to be detected.

A number of studies employing manipulations designed to support the contribution of familiarity to recognition performance have reported that amnesics can perform at near-
normal levels in the absence of recollection (Hirst et al., 1986; Cermak, Verfaellie, Butler, & Jacoby, 1993; Verfaellie & Treadwell, 1993). These studies show that relatively intact familiarity-based recognition in the absence of recollection can either enhance or impair performance depending on whether facilitation or opposition paradigms are employed respectively. However, other studies have argued that both familiarity and recollection are impaired in amnesia (Haist, Shimamura, & Squire, 1992). Resolution of discrepant findings in neuropsychological studies can be particularly problematic as the exact loci of damage can be difficult to ascertain. One possibility is that studies identifying impaired familiarity in amnesia may include patients that have been lesioned outside the hippocampal system. As noted previously, Aggleton and Shaw (1996) specified in their meta-analysis that only those amnesic patients with focal lesions in the hippocampal system show preserved familiarity-based recognition, and that if other regions involved in the processing of familiarity are damaged then familiarity will suffer as a result. It has therefore been suggested that a dissociation is only observed between familiarity and recollection when the systems underlying these two processes are differentially damaged (e.g. Aggleton & Brown, 1999).

However, other authors have reported impaired familiarity and recollection even in patients with selective hippocampal damage (Reed & Squire, 1997; Manns & Squire, 2000). It is currently unclear how these findings can be reconciled, unless post-mortem examination or higher resolution fMRI scanning eventually reveal that these patients were in fact damaged outside the hippocampus. A second key to reconciling opposing findings is consideration of the measures and assumptions underlying the reported estimates of familiarity and recollection. As demonstrated by Yonelinas et al. (1998), apparently discrepant findings can accord if data are reanalysed under the same assumptions (i.e. independence). This issue is particularly relevant to studies employing Remember/Know paradigms. A meta-analysis of Remember/Know studies that initially reported discrepant findings (Knowlton & Squire, 1995; Schacter, Verfaellie, & Pradere, 1996; Schacter, Verfaellie, & Anes, 1997) indicated that the data from all of these studies, when analysed under the independence assumption, showed that amnesia actually results in a decrease in recollection and a less substantial decrease in familiarity (Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998). Yonelinas et al. (1998) argued that amnesics have to rely on their relatively intact familiarity processes during recognition despite the fact that these processes are also somewhat impaired.
While neuropsychological studies produce important convergent evidence and are invaluable in demonstrating causality in the living human brain, it is often difficult to determine the exact location of lesioned areas. Despite this, studies of a wide variety of neuropsychological populations have shown great consistency in demonstrating single dissociations between recollection and familiarity. Individuals suffering from amnesia, schizophrenia, left temporal lobe epilepsy, frontal dysfunction and normal ageing have all demonstrated relative sparing of familiarity in the face of damaged recollective processes (Huron et al., 1995; Besche-Richards, Passerieux, Hardy-Bayle, Nicolas, & Laurent, 1999; Blaxton & Theodore, 1997; Kausler, 1990; Schacter, Harbluk, & McLachlan, 1984; Craik, Morris, Morris, & Loewen, 1990). However, the fact that these data all show single dissociations in which recollection is selectively damaged (or damaged to a greater extent than familiarity) means that single-process models can also account for these findings, as it may be the case that these disorders simply result in a sparing of weak declarative memory (Reed, Hamann, Stefanacci, & Squire, 1997). The double dissociation observed between Remember and Know responses in left and right temporal lobe epilepsy patients (Blaxton & Theodore, 1997) provides stronger evidence for dual-process models, but this finding has not been replicated.

Despite a number of flaws in both the phenomenological and objective approaches, recollection has emerged as being a relatively well understood construct as a result of both lines of enquiry. Recollection is a process by which rich contextual aspects of the encoding episode can be retrieved. More controversial are the issues of volition and control; while some argue that recollection is characterised by the ability to manipulate and control retrieved information in order to fulfil task demands (Jacoby, 1991; Jacoby & Kelley, 1992), others have argued that this is not a necessary characteristic of recollection and that a simple phenomenological experience of ‘remembering’ some aspect of the encoding episode suffices (e.g. Gardiner & Java, 1993b). The phenomena of noncriterial recollection and involuntary conscious memory (Richardson-Klavehn, Gardiner, & Java, 1994) can been cited to argue that recollection requires neither control nor volition. The fact that recollection is maximal following conceptual elaborative processing led to the early theory that recollection is selectively influenced by conceptual processing (Gardiner, 1988; Gardiner & Java, 1990; Rajaram, 1993). However, this no longer appears to provide a full account of the construct. Instead, it appears that recollection may result from any type of processing which endows the target stimulus with salience, and that the degree of recollection is a function of the distinctiveness of the item or encoding episode (Rajaram, 1998). This processing may be of
either a perceptual or a conceptual nature, although conceptual processing tends to result in greater distinctiveness.

The basis for familiarity remains more elusive, and is likely to be multi-componential. Many investigations of recollection and familiarity were based on the assumption that the mechanisms underlying familiarity were identical to those that underlie priming, and that familiarity results from enhanced perceptual fluency (e.g. Jacoby & Dallas, 1981; Rajaram, 1993). Although it seems highly probable that perceptual fluency can contribute towards familiarity-based recognition under certain conditions, it now appears increasingly unlikely that such an explanation provides a complete account of all types of dissociations demonstrated between recollection and familiarity. Although it is possible that perceptual fluency has some role to play in familiarity-based recognition, other evidence suggests that the characterisation of familiarity extends beyond this factor. Richardson-Klavehn et al. (1996) argued that familiarity cannot be identified with priming, as priming is a manifestation of implicit memory while familiarity reflects some form of memory accompanied by awareness. It has also been demonstrated that the familiarity-processes hypothesised to contribute to both familiarity-based recognition and to priming are in fact dissociable processes (Wagner, Gabrieli, & Verfaellie, 1997). There is now considerable evidence to suggest that familiarity can also result from conceptual processing (Wagner, Gabrieli, & Verfaellie, 1997; Yonelinas & Jacoby, 1995; Toth, 1996; Rajaram & Geraci, 2000). Thus it seems that perceptual and conceptual processing are indeed orthogonal to recollection and familiarity, and that the crucial distinction may in fact be distinctiveness and fluency, with familiarity reflecting feelings of fluency. Perceptual processing may often result in item fluency, and conceptual processing may often result in item distinctiveness, but to interpret this correlational finding as a causal one is arguably incorrect.

Convergent evidence suggests that familiarity is associated with activity in parahippocampal regions, and that it acts as part of a continuously distributed familiarity-novelty detection process (Aggleton & Brown, 1999; Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998). This view is consistent with dual-process theories which describe familiarity as a continuously distributed signal-detection process based on trace strength (Yonelinas, 1994). Although further work is required to specify the characteristics of familiarity with greater clarity, it appears that they include a dependence on fluency and a greater processing capacity than that associated with recollection. Familiarity also appears to be faster, more automatic,
less intentional and less effortful than recollection, does not permit discriminative responding or retrieval of context, but instead provides occurrence information of prior presentation.

Chapter 2. ERPs

ERPs and cognitive psychology

The purpose of cognitive psychology is to identify the psychological processes that mediate between the environment and behaviour, and to elucidate the functional characteristics of these processes (Coles & Rugg, 1995). It is thought that all psychological function depends on basic biophysical processes, and that a large proportion of these processes consist of the transmembrane electrochemical activity of neurons (Churchland, 1986). Therefore, the recording and measurement of electrophysiological brain activity during specific psychological tasks can inform and constrain theories of psychological function.

The electroencephalogram (EEG) is the summation of the electrical activity of large populations of cells conducted through the brain and its coverings to the scalp (Allison, Wood, & McCarthy, 1986; Nunez, 1981; Nunez, 1990), and consists of a voltage by time function. The amplitude of the normal human EEG varies between approximately -100 and +100 microvolts, and the frequency ranges from DC up to 40Hz and beyond (Coles & Rugg, 1995). An event-related potential (ERP) is the scalp-recorded electrical activity time-locked to a specific physical or mental event (Picton, Lins, & Scherg, 1995). This event is typically the experimental stimulus. The ERP is extracted from the EEG by means of averaging the signal across multiple trials of the same stimulus type. These methodological aspects are discussed in greater detail shortly. ERPs provide a trial-based measure of neural activity, in that the activity recorded is time-locked to the presentation of each experimental stimulus. This allows averaged ERPs to be formed for each experimental condition post-hoc depending on performance. For example, ERPs elicited by the presentation of a studied item during a recognition memory test can be categorised according to whether the item was recognised or not. In this way, averaged ERPs can be formed both for correctly recognised studied items (i.e. 'hits') and for forgotten studied items (i.e. 'misses'). This event-related aspect of the electrophysiological technique differs from the blocked designs traditionally employed in recognition memory studies involving haemodynamic neuroimaging methods such as PET and fMRI, which would identify activations elicited across blocks of items which were designed to elicit different degrees of retrieval success, rather than identifying response-
related activity (e.g. Rugg, Fletcher, Frith, Frackowiak, & Dolan, R.J., 1996; Nyberg et al., 1995). For many years, ERPs could therefore provide a measure of neural activity that reflected the subtleties of performance in a way that measures provided by haemodynamic neuroimaging methods could not. This advantage has recently been weakened by the advent of event-related fMRI, which can also identify neural activity contingent on performance.

Despite this, electrophysiology still enjoys a number of advantages over event-related fMRI as a method of studying cognitive processes. Thirty years of research have shown ERPs to be sensitive to sensory, perceptual, motor and cognitive processes (Kutas & Dale, 1997). The technique's major strength is that of temporal resolution, which is in the order of milliseconds. ERPs can therefore track cognitive processes in real time, and provide information about the dynamics of neural activity such as its evolution over time, as well as interactions between the activity of multiple neural populations (Rugg, 2001). The fact that ERPs are sensitive indicators of changes in neural activity, regardless of whether these changes influence awareness or observable behaviour, means that they can be used to examine cognitive processes when direct behavioural measures cannot be obtained. For example, ERPs have been used to examine the processes underlying implicit memory (Paller, Kutas, & McIsaac, 1995; Rugg et al., 1998), and to study the neural correlates of attended versus unattended stimuli (Hillyard, Hink, Schwent, & Picton, 1973). The high temporal resolution of ERPs gives this technique a significant advantage over event-related fMRI when it comes to the study of recognition memory. A number of different processes are thought to contribute to recognition memory; in addition to the putative familiarity and recollection processes described in Chapter 1, it has also been proposed that post-retrieval processes that operate upon the products of retrieval also contribute towards recognition judgements (e.g. Juola, Fischler, Wood, & Atkinson, 1971; Squire, Knowlton, & Musen, 1993; Wilding & Rugg, 1997). Whereas the poor temporal resolution of event-related fMRI does not support the distinction between activations associated with familiarity and recollection per se and activations associated with post-retrieval processes, activity associated with these kinds of processes can be differentiated by electrophysiology on the basis of their respective time-courses.

ERPs do, however, suffer from poor spatial resolution. Because the brain acts as a volume conductor, there is no way of knowing the exact location of the neural generator/s that give rise to a particular pattern of activity detected at the scalp without using other constraining
sources of information. It is therefore incorrect to assume that the scalp location of an ERP deflection reflects its intracranial source. Far greater spatial resolution can be achieved through the use of functional magnetic resonance imaging (fMRI). This haemodynamic technique records changes in neural activity and indicates the loci of this activity by imaging the oxygenation level of the blood flowing through the brain, as blood leaving relatively active neural populations is more richly oxygenated than blood leaving relatively inactive neural populations (Ogawa, Lee, Kay, & Tank, 1990). However, this measure of neural activity is relatively indirect compared to that provided by ERPs, and the relationship between the neural activity of interest and the blood oxygenation levels analysed in fMRI remains unclear. It can therefore be argued that ERPs provide a more direct and unambiguous measure of neural activity than either blocked or event-related fMRI.

As with other neuroimaging techniques, ERPs can be employed in one of three principal ways (Rugg, 2001). One can use experimental manipulations to isolate a known cognitive process and identify its neural correlate. One can also investigate the pattern of neural activity associated with specific experimental manipulations, and use this information to make inferences about the cognitive processes engaged. A third approach is to investigate the circumstances under which a known cognitive process is engaged by using pre-existing knowledge about its neural correlate/s and assessing how these correlate/s are influenced by various experimental manipulations. The second and third approaches are of the most interest to cognitive psychology, as these employ neuroimaging techniques primarily to inform theories of cognitive function.

Electrogenesis

An understanding of the principles of electrogenesis and of the propagation of field potentials is of crucial importance in the interpretation of ERP data. Electrogenesis occurs at the level of individual neurons due to the bi-directional flow of positive and negative ions resulting from changes in the permeability of the cellular membrane. These individual electrical events are thought to consist largely of changes in the polarisation of cell bodies and dendrites of pyramidal cells as opposed to axonal action potentials (Allison, Wood, & McCarthy, 1986). The former are graded in magnitude, whereas the latter are all-or-none. When the membranes of large groups of neurons are polarised simultaneously, the resultant potentials undergo spatial summation resulting in a local field potential. The spatial
arrangement of the neurons constituting the generator determine whether the field is ‘open’ or ‘closed’ (Coles & Rugg, 1995). An open field consists of neurons of the same orientation arranged in parallel, and is essentially a dipole as it contains both positive and negative charges between which current can flow (see figure 2.1). A local field potential will only propagate throughout the brain, skull and scalp (which are conductive media) and contribute to the scalp EEG if it is generated by an open field, and if the neurons making up the field are synchronously active.

![Dipole](image)

Figure 2.1. Open field source configuration. Adapted from Kutas and Dale (1997).

A closed field is a group of neurons which are configured in such a way that the individual potentials cancel each other (Wood, 1987; see figure 2.2). For example, a closed field may consist of neurons of opposite orientation, or of neurons arranged radially so that current can only flow inwards (Kutas & Dale, 1997). The potential produced by a ‘closed’ field does not propagate beyond its generators and therefore cannot be detected at the scalp. The specificity of these constraints means that only a proportion of brain activity can be detected at the scalp. The principal brain structure that satisfies all of these constraints is the neocortex, 70% of which consists of pyramidal cells organised by groups in columns and oriented perpendicular to the surface of the cortex (Nunez, 1981). It is therefore thought that the primary source of scalp-recorded ERPs is the synchronous excitatory or inhibitory post-synaptic potentials generated by pyramidal cells in the neocortex (Kutas & Dale, 1997). The scalp-recorded ERP is rarely a measurement of a single local field potential, but is rather a summation of potentials from multiple open fields. Open fields linearly summate as they propagate throughout the brain and reach the scalp. The principle of ‘superposition’ states that the potential at any given point represents an algebraic sum of all fields that have propagated to that point. The amplitude and polarity of the scalp-recorded ERP also varies with the distance between the electrode and the active tissue (Wood, 1987).
ERP recording

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

Electrodes and the skin-electrode interface

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

Scalp-recorded ERPs contain both electromagnetic ‘noise’ from the environment (e.g. electrical experimental equipment such as the display monitor) in addition to the electrical brain activity of interest. Electromagnetic noise from the environment is removed by the use of differential amplifiers which allow electrical noise in-phase at inputs from a ground electrode and the electrode of interest (known as ‘common mode signals’) to be cancelled (Picton et al., 2000). As a potential is the difference between two points, all ERP recordings must also be made with respect to a reference electrode (Coles & Rugg, 1995). The location of the reference employed is of crucial importance when interpreting the scalp distribution and/or polarity of an ERP, as measurements of potentials are relative rather than absolute. The absolute values in referenced recordings will differ according to the location of the reference employed, although the shape of the topographic profile will remain constant.

**A/D conversion and filtering**

A/D converters sample the ongoing EEG, converting these signals from analogue into digital form to facilitate data analysis (Picton, Lins, & Scherg, 1995). The rate of A/D conversion is also referred to as the ‘sampling rate’, and this rate influences the temporal resolution of the ERP. The resulting ERP waveform is a sequence of data points sampled at discrete intervals, each of which represents the difference in potential between the electrode of interest and the reference electrode. Filtering enables the recording system to detect target electrical brain activity while rejecting frequencies that are unlikely to reflect the activity of interest. Filtering of the signal is generally performed at the same time as amplification. Low and high cut-off frequencies specify the bandpass of the amplifier, and frequencies that fall outside of this bandpass are rejected by the amplifiers.

**Signal extraction**

The steps described above record an EEG that captures the electrical brain activity of interest, and which contains minimal artefactual noise. Further processing is now required in order to extract the ‘signal’ (i.e. the ERP) from the ongoing EEG. These steps are described below.
Artifact detection and elimination

The data are examined to ensure that the ERPs only contain veridical brain activity. This is necessary because a number of artefacts can still be present in the data after recording. The waveforms are therefore usually analysed off-line in order to determine that all artefacts have been removed prior to analysis. These artefacts can take the form of baseline drifts, saturation and eye movement artefacts. A baseline drift takes the form of a linear slope which persists throughout the epoch, and may occur if the electrode potential becomes too high, or if the skin-electrode interface is ruptured. A saturation occurs when the voltage of the signal exceeds the bandpass of the amplifiers, and appears as a continuous flat line throughout the epoch. Eye movement artefacts can take the form of blinks or saccadic movements. Blink-related artefacts can be eliminated in one of two ways; blinks can either be discouraged and excluded, or the contribution of the blink artefact to all other recording channels can be estimated for each individual subject and algorithmically corrected. Blink-related artefacts were minimised by a blink correction algorithm in the present studies. The blink estimation and correction procedures employed in these studies also required the rejection of all trials containing saccadic eye movements.

Signal averaging

The EEG can be considered as consisting of two parts; the ‘signal’ and background noise (John, Ruchkin, & Vidal, 1978). The signal is usually smaller than the noise in which it is embedded, and it is therefore often impossible to observe the signal in single trials (Picton, Lins, & Scherg, 1995). It is assumed that the signal is invariant across trials of the same type and time-locked to the experimental event of interest, whereas the noise is random. Extraction of the signal from the ongoing EEG therefore requires the averaging of repeated time-locked epochs of EEG, all of which correspond to the same class of experimental event. This reduces the background noise, thus revealing the neural activity time-locked to the task (i.e. the ERP). Averaging is performed for each point by point digital value, and is performed only on artefact-free trials. The greater the number of trials contributing to each experimental condition, the higher the signal-to-noise ratio. Signal averaging gives an averaged ERP waveform for every condition at every electrode site for each subject. All statistical analyses are performed on these averaged data.
However, averaged ERPs should be interpreted with caution as signal averaging can lead to distortions of the original signal present in the single-trial data. It is possible for an averaged ERP waveform to bear little relation to the ERPs observed in individual trials, as trial-to-trial variability in either the latency or amplitude of the ERP can 'smear' the averaged ERP (Picton, Lins, & Scherg, 1995). For example, an ERP effect may differ quantitatively between two conditions, which would generally be interpreted as a graded difference in the activity of the same neural generator between the two conditions. However, it is also possible that the two conditions differed only in the proportion of trials in which the component was evident. An additional problem is that of 'latency jitter'. This refers to the phenomenon in which the timing of a component varies from trial to trial, resulting in a smeared averaged ERP with a long duration and a decreased amplitude. While it is theoretically possible to compare components in individual trials to the component observed in the average, this is not always possible if the signal-to-noise ratio is low. For a further discussion of how to quantify and compensate for the temporal jitter of signals, see (Picton, Lins, & Scherg, 1995).

Interpretation of the ERP

**ERP components**

There is no unique definition of an ERP component, as the descriptive framework employed depends on whether one is adopting a ‘physiological’ or a ‘functional’ approach. The former emphasises anatomical localisation and defines components as the activity of a single neural generator, whereas the latter emphasises the functional significance of ERP deflections and defines components in terms of the processing operations with which they are associated (these two approaches are discussed in greater detail shortly). These two approaches lie at opposite ends of a continuum, and in reality researchers take an interpretative approach that lies somewhere between these two extremes. However, it is generally agreed that a single ERP component should represent the activity of a pool of neurons correlated with a specific processing operation. Components can either be ‘exogenous’ or ‘endogenous’. The former are sensitive to the physical characteristics of the stimulus, whereas the latter reflect the operation of higher order cognitive processes. This distinction is not categorical, and components can show sensitivity both to the physical characteristics of the stimulus and to task demands.
ERP waveforms consist of a series of peaks and troughs which are generally described in terms of their latency, polarity, scalp distribution and amplitude, measured in relation either to the pre-stimulus baseline (i.e. the mean voltage level of the waveform in the period preceding stimulus presentation), or to another feature of the waveform. Traditionally, each deflection was defined as a single ‘component’, and was labelled either in terms of its polarity and serial order in the waveform (e.g. P1, N2), or in terms of its polarity and peak latency (e.g. P200). However, it has been argued that this ‘peak-picking’ approach is simplistic and misleading, as a single component identified in this way may in fact represent the summation of activity from multiple sources in the brain (Kutas & Dale, 1997). It is therefore inappropriate to infer that a component identified in this way reflects the activity of a single neural generator. Although this objection is less of a problem to researchers who identify ERP components with psychological function as opposed to neural generators, the problem remains that a single ERP deflection can reflect multiple concurrent processing operations. A once-popular method employed to extract different components from the ERP waveform is that of Principal Component Analysis (PCA), which investigates patterns of covariance between temporal changes in voltage, topographic changes in voltage and changes in voltage associated with experimental manipulations, and yields a set of components which are weighted for each time-point in the waveform. These weights indicate to what degree the various components are present in the waveform. However, the use of PCA can be misleading when different experimental conditions elicit the same component at different latencies, as it will identify spurious components (Coles & Rugg, 1995). It has also been demonstrated that PCA can ‘misallocate’ variance between supposedly orthogonal components (Wood & McCarthy, 1984).

An additional problem with the peak-picking approach is the fact that specific peaks and troughs may vary in appearance or latency according to factors such as experimental conditions or the age of subjects (Picton et al., 2000). An alternative to this method of component identification involves measuring the mean amplitude of the ERP across a specified latency region relative to the amplitude of the pre-stimulus baseline (Picton et al., 2000). The mean amplitude approach removes the focus of investigation away from ‘peak-picking’ and the functional significance of specific deflections, and instead examines how these mean amplitude measurements differ between various experimental conditions or response categories. These differences are known as ERP ‘effects’. Mean amplitude measurements also have greater stability than those of individual deflections in that they are
more resistant to residual noise. Specifying the latency region should preferably be done \textit{a priori} on the basis of previous studies, but should capture the main effect of interest.

\textbf{The 'physiological' approach}

For those taking the physiological approach, the defining characteristic of an ERP component is the anatomical source of its generator(s) within the brain, and little or no attempt is made to attribute a psychological function to the component. Components are defined as the contribution to an ERP field either of the activity of a single generator, or of a neural circuit containing multiple generators. While changes in the scalp distribution of an ERP component over time implies the involvement of several generators with different time-courses, the actual localisation of these generators is very difficult. The fact that deflections in the ERP waveform are likely to represent a summation of the activity of multiple generators means that some way of separating and identifying these contributing sources is necessary. As stated previously, the spatial resolution of ERPs is their greatest weakness, and this obviously creates significant problems when attempting to establish the neural basis of ERP components. Although it is possible to increase the spatial resolution of the scalp field by increasing the number of recording channels, it has been argued that over 100 channels are required before it becomes possible to distinguish the contribution of individual cortical generators to the ERP, and that even this information is unreliable due to the problem of signal distortion during volume conduction (Gevins, Leong, Smith, Le, & Du, 1995).

The difficulty in determining the neural generators of an ERP scalp field is known as 'the inverse problem'. Any attempt to solve the inverse problem is obstructed by the fact that there is no unique solution in terms of generators for any given pattern of scalp activity (Wood, 1982). Analytical procedures have been developed that allow one to directly infer candidate ERP sources from scalp fields. One such method is the Brain Electrical Source Analysis procedure (BESA; Scherg, 1990) which models the head as a number of shells, each of which constitutes the skull, scalp and brain tissue, and each of which has a different conductivity value. BESA solutions specify sources in terms of their quantity, anatomical location, orientation, time-course and relative strengths (Coles & Rugg, 1995). The contribution of each source is considered to be an independent ERP component. The validity of a BESA solution is assessed by computing the scalp field that would result from the putative configuration of generators, and comparing this with the scalp field observed
empirically. BESA generates multiple solutions, and these can be constrained by knowledge deriving from other methodological approaches such as the comparison of human intracranial recordings to scalp recordings (Halgren et al., 1980), fMRI or PET activations in analogous tasks, anatomical models drawn from animal research (Pineda & Swick, 1992) and neurological cases that allow one to relate brain lesions to distortions in scalp activity (see Knight, 1991 for review). More recent developments in the field of source localisation have applied assumptions drawn from neuroanatomical knowledge to apply specific constraints to source localisation (e.g. dipoles must be located in grey matter, dipoles must be oriented perpendicular to the cortical sheet, dipoles must possess locally coherent activity), and take advantage of information gained from haemodynamic imaging studies employing analogous tasks to produce a single solution of 'best fit' for any scalp field (Phillips, 2001). However, it should be noted that the coupling between electrophysiological and haemodynamic signals is not yet fully understood. Therefore, caution is advised when using haemodynamic measures to constrain the source localisation of ERP data.

The 'functional' approach
Cognitive psychologists commonly take the functional approach when interpreting ERP data, as greater emphasis is placed on the functional characteristics of an ERP component than the location of its anatomical source. Components are largely defined as specific variations in the waveform that are correlated with the cognitive process of interest. ERPs associated with different experimental conditions are subtracted from one another in order to isolate the ERP component elicited by the experimental manipulation. This component is then considered to be a correlate of whatever cognitive process is thought to differ between the two conditions. This ‘subtractive’ approach rests on the assumption of ‘pure insertion’ which states that the experimental conditions differ only in the cognitive process of interest (Coles & Rugg, 1995). The functional approach employs the spatio-temporal characteristics of ERP components to make inferences about the cognitive processes of interest. For example, the onset latency and duration of a component are thought to reflect the temporal dynamics of the corresponding information processing operation, although these measurements are not necessarily precise as they are susceptible to residual noise in the ERP waveform. The fact that ERPs yield so much information in terms of information processing is of far more interest to cognitive psychologists than information regarding the anatomical localisation of such processes. Therefore, the poor spatial resolution of ERP data is less problematic for cognitive
psychologists than for those taking the physiological approach. The problem of individual ERP components reflecting the activity of multiple generators is also more tractable in the functional than in the physiological approach, as it is generally assumed that these multiple neural generators (the anatomical specification of which is not usually required) comprise a functionally homogeneous unit (Donchin, Ritter, & McCallum, 1978), and that these multiple generators are responsible for parallel processing operations.

However, the fact that ERPs do directly reflect neural activity means that cognitive psychologists are required to assume some kind of relationship between the neural activity recorded and the cognitive process inferred, and opinion differs as to the nature of this relationship. At a basic level, it is assumed that ERPs reflect some aspect of neural activity, and that cognitive processes manifest themselves in this activity. In order to make functional inferences from ERP data, it is additionally assumed that the brain is functionally segregated with different regions responsible for different cognitive functions, and that the relationship between cognitive operations and their neural substrates is invariant. This assumption is known as 'the invariance assumption', and although it has not been contradicted by empirical evidence, it is nonetheless open to refute. The invariance assumption at its most basic level argues that an invariant 'one-to-one' mapping exists between cognitive functions and their neural substrates. It has been argued by those adopting a neural-network approach to cognition that it is more plausible that the nature of this relationship may in actuality be both 'one-to-many' and 'many-to-one' (Mesulam, 1990). This account states that a single cognitive process may be supported by multiple brain regions, and that each brain region may be recruited for multiple cognitive functions. According to this view, cognitive processes are the result of interactions between multiple networks, and as such, cannot be localised to a single neural substrate. Such an account is not necessarily problematic for functional interpretations of ERP data (which do not require the assumption that an ERP effect reflects the activity of a single neural generator), as long as these 'one-to-many' and 'many-to-one' mappings are themselves invariant. It would, however, be deeply problematic for many branches of cognitive neuroscience (including ERPs) if it was demonstrated that the same cognitive process can in fact be supported by more than one pattern of brain activity, as this would undermine the invariance assumption that in turn underpins the mapping of cognitive function to brain activity. However, no evidence has as yet been presented to suggest that this may be the case (Rugg, 1997).
Adoption of the invariance assumption allows one to make certain inferences from differences between the ERPs elicited in different experimental conditions. Inferential statistics (e.g. analysis of variance) are used to ascertain whether these differences are reliable or not. It is assumed that reliably different ERPs reflect changes in neural activity, and that these changes indicate cognitive processes that differ either in degree or in kind. The nature of these differences is inferred from whether the ERPs differs qualitatively or quantitatively. A qualitative difference is demonstrated when the scalp distribution associated with the ERPs differs, whereas a quantitative difference takes the form of ERPs that differ in magnitude but which have statistically equivalent scalp distributions. It is assumed that a qualitative difference between ERPs reflects the activation of at least partially non-overlapping neural populations, which in turn reflect functionally distinct cognitive operations. ERPs that differ quantitatively are generally assumed to reflect differential activity of the same neural population. It is inferred from a quantitative difference between ERPs associated with different experimental conditions that these conditions engage functionally equivalent cognitive processes to different degrees.

Two final notes of caution are required when interpreting ERP data. Firstly, it is important to remember that one can never prove that a two or more processes do not elicit qualitatively distinct patterns of electrophysiological activity through the use of ERPs, or to conclusively prove that an experimental condition is not associated with a specified ERP effect, as a null effect may occur either because the effect is taking in place in a closed field and is therefore undetectable to the scalp electrodes, or because the level of activity associated with the condition is too weak to be detected at the scalp. One can therefore never conclude that an experimental manipulation has no effect on brain activity simply because no difference is observed in the ERPs. Secondly, as with all neuroimaging techniques, ERPs are purely correlational. One cannot therefore establish a causal relationship between cognitive function and electrophysiological activity solely through the use of scalp-recorded ERPs. ERPs must be employed simultaneously with invasive techniques (e.g. pharmacological manipulations) in order to demonstrate a causal relationship between function and neural activity. For example, it was reported that the administration of cortisol selectively impaired performance during a recognition memory task and additionally suppressed an ERP effect previously identified as a correlate of recognition memory, thus providing substantial evidence indicative of a causal relationship between the two (McAllister-Williams & Rugg, 2000).
Chapter 3. ERPs and recognition memory

Methodological Issues

Functional neuroimaging methods allow an investigation of the way in which various experimental manipulations influence patterns of neural activity, and can therefore be employed to examine models of recognition memory. However, interpretation of neuroimaging data is predicated on a number of assumptions. As discussed in Chapter 2, the functional neuroimaging approach depends on the validity of the invariance assumption, which states that cognitive functions and their neural substrates share a one-to-one relationship in which the same brain regions are always recruited by a particular cognitive process. Adoption of the invariance assumption allows one to draw functional conclusions from patterns of ERP data. The finding that ERPs elicited by two different experimental conditions differ qualitatively (i.e. they have different scalp distributions) provides strong support for the conclusion that the two conditions engage the activity of at least partially non-overlapping neural populations. The finding that the ERPs merely differ quantitatively (i.e. they have the same scalp distribution, but differ in amplitude) would lead one to conclude that the two conditions engage the same neural population to differing degrees. The fact that ERPs provide a real-time record of neural activity (in the order of milliseconds) also allows one to make inferences about the dynamics of neural activity. Therefore, the strengths of the ERP approach in the study of recognition memory include the ability to detect qualitative differences between neural activity associated with familiarity and recollection, to identify which experimental manipulations these neural correlates are sensitive to, to differentiate these processes from post-retrieval processes, and to provide information regarding the dynamics of familiarity and recollection.

Obtaining qualitatively distinct ERPs associated with familiarity and recollection should also, in theory, allow one to investigate the various relational assumptions posited between these two processes by different formulations of the dual-process approach. For example, the finding that the correlate of recollection never occurs in the absence of the correlate of familiarity would support the argument that the relationship between familiarity and recollection is one of redundancy, whereas the finding that the correlates of the two processes never co-occur would imply a relationship of exclusivity. If the correlate of familiarity or recollection can occur both in the absence or in the presence of the other, a relationship of
independence would be confirmed. However, the fact that ERPs provide an averaged as opposed to a single-trial signal is problematic for this application. For example, the finding that the ERP associated with a correct recognition judgement contained both the correlate of familiarity and the correlate of recollection may appear to suggest either a relationship of redundancy or independence, whereas it may in fact be the case that a proportion of the trials which contribute towards the averaged signal contain only the familiarity signal, and that other trials contain only the recollection signal, thus supporting the exclusivity assumption. Therefore, unless one can be sure that performance on particular tasks represent process pure measures of familiarity and recollection, using the averaged ERPs to support a particular relational assumption is misleading.

A second problem arising from the fact that ERPs are averaged signals is that ERP data cannot be subjected to the equations delineated in the process dissociation procedure. Therefore, ERPs cannot be formed for estimates of familiarity and recollection as measured by the PDP. Although ERP studies can employ paradigms derived from the PDP in an attempt to separate recognition responses made on the basis of familiarity and recollection, it is unlikely that these responses (and the associated ERPs) will provide a process pure measure of either process. When using ERPs to test models of recognition memory, one should also be aware that an asymmetry exists in the technique’s ability to explore this issue. As stated in Chapter 2, ERPs provide an incomplete record of neural activity. Only the activity of neural populations with specific structural and temporal characteristics (i.e. ‘open field’ and synchronously firing) can be detected at the scalp. The neural activity of a large proportion of the brain cannot therefore be recorded using ERPs. This means that nothing can be inferred from a null result, as activity may be occurring in a region to which ERPs are ‘blind’. Therefore, whereas one can always claim that a qualitative dissociation observed between ERP correlates of familiarity and recollection support dual-process models, one can never confidently argue that the absence of a qualitative dissociation supports single-process models.

Finally, one must also decide what requirements must be satisfied in order to identify ERP effects as correlates of familiarity and recollection. As the defining characteristic of recollection is the retrieval of contextual information from the encoding episode, one would require the ERP correlate of recollection to be observed for correctly classified studied items associated with the retrieval of source information. One would also expect this correlate to
show sensitivity to manipulations known to influence recollection (e.g. levels-of-processing, read-anagram manipulations etc.). Defining the requirements for an ERP correlate of familiarity is more problematic, as this construct is subject to a greater amount of debate (see Chapter 1). As familiarity acts as a acontextual basis for a judgement of 'oldness', one would expect to observe an ERP correlate of familiarity for positive recognition responses. However, unlike recollection, this correlate would arguably not have to be associated with veridical recognition, as new items eliciting a sufficient degree of familiarity would also be attributed to the study phase in the absence of recollection. One would additionally have to demonstrate that ERP correlates of recollection and familiarity could not be explained in terms of priming (i.e. they should not be observed for 'miss' responses in which studied words are incorrectly classified as new), and that they are independent of response requirements (i.e. they do not merely reflect a positive recognition response). It is also important that ERP correlates of recollection and familiarity cannot be explained in terms of non-mnemonic factors such as relative probability, targetness or response time.

Models of Memory: ERP evidence

The rest of this chapter discusses those aspects of the ERP literature relevant to dual-process models of recognition memory. The evolution of the recognition memory ERP literature is briefly described prior to a detailed discussion of more recent ERP studies that have investigated models of recognition memory. Early work reviewed here pertaining to correlates of yes-no recognition is not intended to provide an exhaustive account of this line of research, but rather to provide a framework within which later, and more relevant, research can be understood. All of the studies reviewed below employed variations on a 'study-test' recognition memory paradigm, in which subjects are presented with a set of items to encode at study, and are then presented with these items together with a number of unstudied items at test. Test instructions require subjects to identify which items have been previously studied and which items have not.

The late positive component

A number of early ERP studies employed direct tests of recognition memory in which ERPs were obtained for correctly identified studied items (i.e. 'old') and for correctly identified unstudied items (i.e. 'new'). These studies reported an ERP effect in which old items elicited
greater positivity than new items, an effect which was maximal over parietal sites between approximately 500-800 msec (see figure 3.1) when the study-test interval exceeded a few minutes (e.g. Neville, Kutas, Chesney, & Schmidt, 1986; Rugg & Nagy, 1989; Friedman, 1990; Rugg & Doyle, 1992). This effect was referred to as ‘the late positive component’, and was initially identified with an established ERP component known as the P3. The P3 (or P300) is commonly observed within the latency region in which the late positive component occurs, and its sub-component (the P3b) is reliably elicited by target stimuli that have low subjective probability (Squires, Squires, & Hillyard, 1975; Horst, Johnson, & Donchin, 1980). It was initially argued that old words in recognition tasks are associated with lower subjective probability and higher ‘targetness’ than new words, and that the late positive component was not a direct correlate of recognition memory but was a modulation of the P3b (Neville, Kutas, Chesney, & Schmidt, 1986).

Figure 3.1 The ‘late positive component’. ERPs associated with correctly classified repeated items (i.e. ‘second presentation’) and correctly classified new items (i.e. ‘first presentation’) at the left parietal site in a direct test of recognition memory. Adapted from Rugg et al. (1992).

Smith and Guster (1993) directly investigated this hypothesis by recording ERPs during a recognition memory task in which ‘target’ words (which were alternately defined as old or new words in different stimulus sets) were rare events (i.e. targets: nontargets = 20:80). Only those items designated as targets required a keypress. This design allowed effects of targetness, probability and word repetition to be distinguished from genuine retrieval effects. If the late positive component merely reflects modulation of the P3b in response to low subjective probability targets, then no difference should have been observed between ERPs to new targets and old targets, or between ERPs to new nontargets and old nontargets. However, a late positive component was observed both between new and old targets, and between new and old nontargets. This effect of retrieval overlapped with the P3b both temporally and topographically, but remained independent of this component. The late
positive component was therefore identified as a retrieval-related component independent of subjective probability and targetness (Smith & Guster, 1993). The fact that both targets and nontargets elicited a late positive component indicated that this effect was also independent of response requirements.

Another study directly investigated the influence of response requirements on the late positive component (Rugg, Brovedani, & Doyle, 1992). Rugg et al. (1992) noted that all previous ERP studies of recognition memory had employed a one-to-one mapping between repetition of an item and the response required by that repetition, and argued that it could not therefore be ruled out that the late positive component was merely a consequence of response-related effects such as the differing speeds with which new and repeated items could be categorised and responded to accordingly. A continuous recognition paradigm was constructed in which items were repeated both across multiple test blocks and within each block. Subjects were instructed to respond 'new' to all items presented for the first time in each block (including both across-block repetitions and truly new words), and to respond 'old' to an item only when it was presented for the second time within a block. This design meant that the mapping of repetition to response type was inconsistent. Despite the fact that subjects were slower and less accurate when responding to across-block repetitions presented for the first time in a block than to truly new items, the late positive components elicited by across-block and within-block repetitions did not differ qualitatively. This study therefore ruled out the possibility that the late positive component was response-related as opposed to being a mnemonic effect.

The view that the late positive component reflects veridical recognition was further supported when it was demonstrated that neither false alarms (i.e. new words incorrectly classified as old) nor misses (i.e. old items incorrectly classified as new) elicited this effect (Rugg & Doyle, 1992; Rugg & Doyle, 1994). As it became increasingly clear that the late positive component was a correlate of veridical recognition, attention turned to dual-process models in an attempt to explain its functional significance. Rugg and Doyle (1992) reported that the late positive component associated with the recognition of low frequency words was larger in amplitude than that associated with the recognition of high frequency words, thus replicating and generalising the earlier finding that the late positive component was larger for the repetition of low frequency than of high frequency words in indirect tasks (Rugg, 1990). These late positive components were larger over left than over right parietal sites, and it was
argued that this lateralisation was a function of the verbal nature of the stimuli (Rugg & Doyle, 1992). Rugg and Doyle (1992) demonstrated via a series of experimental manipulations that the quantitative difference observed between late positive components elicited by low frequency and high frequency words could not be explained in terms of response confidence, reaction time or reaction time variability. It was hypothesised that the late positive component reflects familiarity-based recognition (Rugg, 1990; Rugg & Doyle, 1992) in accordance with the assumption that the word frequency effect (i.e. the finding that low frequency words are better recognised than high frequency words; Glanzer & Bowles, 1976) is accounted for by an increase in relative familiarity (Jacoby & Dallas, 1981).

However, as discussed in Chapter 1, it was later reported that the word frequency effect is carried primarily by recollection, although familiarity is also affected to a lesser extent (Guttentag & Carroll, 1997). The study by Rugg and Doyle (1992), therefore appears to have provided some of the first evidence indicating that the late positive component is in fact a correlate of recollection-based recognition. Over the next few years it was reported that a variety of experimental manipulations assumed to selectively influence recollection also influenced the late positive component, which was increasingly referred to as the ‘parietal old/new effect’ (this nomenclature is adopted for the remainder of this thesis). As time went on, other correlates of recognition memory were also reported that appeared to be neurally and functionally dissociable from the parietal old/new effect, and which were also largely interpreted within the dual-process framework. This literature is reviewed below.

**Dissociating ERP correlates of recognition memory.**

Normal populations

The majority of recent ERP studies have investigated recognition memory within a dual-process framework, and have employed a wide variety of paradigms in an attempt to dissociate ERP correlates of recollection and familiarity. Some of these studies have adopted the phenomenological approach and have obtained ERPs for Remember and Know responses. Other authors have drawn from the assumptions underlying the process dissociation procedure (PDP). Although ERP data cannot be transformed by the equations specified by the PDP, operationalising recollection as the retrieval and manipulation of specific contextual details has allowed researchers to employ ‘opposition’ paradigms (i.e. exclusion tasks) in an attempt to separate the contributions of these two processes to recognition memory (see Chapter 1). Others have simply separated ERPs to correct recognition responses according to
whether they are associated with correct versus incorrect source judgements, and employed these ERPs as correlates of recollection and familiarity respectively.

One of the first studies to explore recognition memory within a dual-process framework employed a one-stage Remember/Know procedure in which subjects were instructed to respond on one key for ‘New’ responses, on another key for ‘Remember’ responses, and on a third for ‘Know’ responses (Smith, 1993). Smith (1993) reported that whereas both Remember and Know responses elicited equivalent old/new effects at frontal sites onsetting at approximately 350 msec post-stimulus, a larger parietal old/new effect was elicited by Remember than by Know responses between 550-700 msec. It was concluded on the basis of this finding that the parietal old/new effect reflects recollection rather than familiarity (Smith, 1993). Although ERPs associated with Remember and Know responses differed quantitatively over parietal sites, they did not differ qualitatively, and therefore appeared to provide little support for dual-process accounts. However, as this study adopted a one-stage Remember/Know paradigm, it is possible that the ERPs associated with Remember and Know responses reflected differing degrees of response confidence rather than the phenomenological processes of recollection and familiarity (Hicks & Marsh, 1999; Knowlton, 1998). The finding that ERPs to Remember responses were more positive going than ERPs to Know responses over parietal sites (Smith, 1993) was questioned following a replication of this experiment (Spencer, Vila Abad, & Donchin, 2000). Spencer et al. (2000) replicated the finding that Remember responses were more positive going than Know responses over parietal sites. By examining the componential structure of this effect using principal components analysis (see Chapter 2), they argued that the parietal old/new effect elicited in these experiments was not retrieval related but was rather due to Remember responses being made at a more consistent latency than Know responses, and that the difference observed between ERPs to these two responses was in fact a P300 that was eliminated when the data were corrected for P300 latency jitter (Spencer, Vila Abad, & Donchin, 2000). However, the authors did not report whether the scalp distributions of the ERP effects observed before and after latency jitter correction were qualitatively identical. Re-examination of the data suggests these distributions were in fact distinct, indicating that latency jitter correction only eliminated one component of the parietal old/new effect observed prior to correction.
A second phenomenological ERP study employing a two-stage Remember/Know procedure reported dissociable patterns of neural activity associated with Remember and Know responses (Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997). Subjects were presented with sets of semantically related items at study, and were then presented with new items, studied items, and semantically related lures at test. Test instructions required subjects to make an initial old/new judgement, and then to make a second Remember/ Know judgement for those words judged to be old. The use of semantically related lures at test resulted in high levels of false recognition responses. Whereas Know responses were associated with greater positivity than new items over temporoparietal sites between 325-600 msec and greater negativity than new items over frontocentral sites between 600-1000 msec, Remember responses were associated with greater positivity than new items over bifrontal and left parietotemporal sites between 600-1000 msec. These ERP effects did not differ for items eliciting true versus false recognition. It was argued from the finding that Remember and Know responses were associated with different patterns of neural activity that episodic retrieval is comprised of two dissociable states of awareness (Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997). However, the fact that these data were not rescaled to eliminate differences due solely to amplitude renders these findings ambiguous, as no conclusions could be drawn with regard to whether the ERPs differed quantitatively or qualitatively.

An ERP study of recognition memory operationalising recollection and familiarity as recognition with and without the retrieval of source information respectively failed to demonstrate qualitative differences between ERPs associated with these two processes (Wilding & Rugg, 1996). Words were presented at study in one of two voices, and subjects were required at test to make an old/new judgement followed by a voice judgement (Wilding & Rugg, 1996). Correctly recognised items associated with correct source judgements were argued to be recollection-driven, whereas correctly recognised items associated with incorrect source judgements were argued to be familiarity-driven. All words correctly endorsed as being old elicited both a left-lateralised parietal old/new effect, and a second old/new effect which took the form of greater positivity over right frontal sites which was sustained until the end of the recording epoch (see figure 3.2). Although both of these old/new effects were larger for items that attracted correct source judgements than for items that did not, ERPs to these two types of recognition judgements were not associated with qualitatively different ERP old/new effects. It was therefore argued that these results offered little support for the view that recognition memory with and without the retrieval of source engage qualitatively
different memory processes, and the authors suggested that the difference between recollection and familiarity is one of degree rather than of kind (see also Wilding, Doyle, & Rugg, 1995). However, although certain items in Wilding and Rugg’s (1996) study may have attracted incorrect source judgements and were therefore categorised as being familiar, it is possible that some other contextual aspect of their presentation was recollected (i.e. noncriterial recollection; Yonelinas & Jacoby, 1996), and that no qualitative differences were observed between ERPs to recognition judgements attracting correct and incorrect source judgements because both type of responses engaged recollective processing of some kind. Evidence that the parietal old/new effect reflects recollection is consistent with this interpretation, as this effect was elicited by all correctly endorsed old items regardless of the accuracy of their associated source judgements.

Although the study by Wilding and Rugg (1996) did not provide evidence to support dual-process models of recognition memory, this study was key in that provided some of the first evidence indicating dissociable old/new effects associated with recollection. The late old/new effect observed over right frontal sites had rarely been observed in recognition memory studies requiring a simple old/new response, and it was therefore argued that this effect must be related to the requirement to retrieve contextual information from the encoding episode (Wilding & Rugg, 1996). Although both the parietal old/new effect and the right frontal old/new effect appeared to be recollection-related, the fact that they had different
spatio-temporal characteristics indicated that they reflected different cognitive processes; it was suggested that the parietal old/new effect may reflect successful retrieval of information from episodic memory, and that the right frontal old/new effect may reflect processes operating on the products of retrieval necessary for the retrieval of contextual information (Wilding & Rugg, 1996; Johnson, Kreiter, Russo, & Zhu, 1998).

Similar results were reported in a study comparing ERPs associated with the retrieval of contextual information with ERPs to Remember responses (Rugg, Schloerscheidt, & Mark, 1998). Subjects were auditorily presented with single words at study, and were instructed to state whether it was spoken in a male or in a female voice, and then to make a pleasantness-rating for the word. Subjects at test were required to discriminate between new and old items. For each word judged old, one task required subjects to recall the voice in which it had been spoken at study, whereas another task required subjects to respond Remember or Know according to the phenomenological experience with which the item was associated. A left-lateralised parietal old/new effect was observed for items correctly judged old and for which the voice-information could be recalled, whereas this effect was not observed for items correctly judged old but whose voice-information could not be retrieved. It was concluded from these findings that the parietal old/new effect reflects neural activity associated with the recollection of episodic information (Rugg, Schloerscheidt, & Mark, 1998). A second late old/new effect was elicited by correctly recognised items for which voice-information could be recalled, taking the form of greater positivity over right frontal than left frontal sites. Again it was argued that the right frontal old/new effect reflected post-retrieval monitoring operations as it was associated with the retrieval of contextual information (Rugg, Schloerscheidt, & Mark, 1998; Rugg, Schloerscheidt, Doyle, Cox, & Patching, 1996). Both the left parietal and right frontal old/new effects were also elicited by Remember responses (Rugg, Schloerscheidt, & Mark, 1998). A late negative wave maximal over the mid-parietal site was also elicited by old items in this experiment (see figure 3.3), an effect that was far larger in the source memory task than in the Remember/Know task (Rugg, Schloerscheidt, & Mark, 1998). It was hypothesised that the larger parietal old/new effect observed in the Remember/Know task than in the source memory task may have attenuated this negativity, and although no functional account of this negativity was discussed, it was observed that RTs to old items in the Remember/Know task were shorter than those in the source memory task (Rugg, Schloerscheidt, & Mark, 1998).
These findings were replicated by Donaldson and Rugg (1998) when they compared ERP correlates of associative recognition across two experiments. Unrelated word pairs were presented at study in both experiments. In Experiment 1, word pairs were either presented in the same pairing as at study ('intact') or were rearranged. Subjects were required to make an old/new judgement for each pair, and then to judge whether the word pair judged old was intact or rearranged. In Experiment 2, subjects merely had to make an old/new response for each word pair. In both experiments, intact and rearranged word pairs elicited a left-lateralised parietal old/new effect and a right frontal old/new effect. Both effects were larger in magnitude for intact word pairs rather than for rearranged word pairs (Donaldson & Rugg, 1998). On the basis of the findings of Yonelinas (1997), the authors proposed that intact pairs are more likely to elicit recollection than rearranged pairs, and that the enhanced left parietal and right frontal old/new effects therefore reflected recollection-related processing (Donaldson & Rugg, 1998). Again, it was suggested that the left parietal old/new effect reflects the successful recollection of associative information whereas the right frontal effect reflects processes that operate upon the products of this retrieval (Donaldson & Rugg, 1998). However, the fact that these two effects were also elicited in the yes/no recognition task in Experiment 2 indicated that the explicit retrieval of source information was not required to elicit either of these ERP old/new effects. Late parietal negativity was also observed for correctly identified rearranged pairs relative to new pairs in this study, although this effect was not evidence for correctly identified intact pairs.
A further study shed new light on the right frontal old/new effect, extending the hypothesis regarding its functional significance beyond ‘post-retrieval monitoring’ processes (Wilding & Rugg, 1997). This study employed a paradigm derived from the exclusion component of the process dissociation procedure (Jacoby, 1991). Subjects were presented with items in one of two voices at study, and were required to perform different encoding tasks on the item depending on the voice with which it was spoken. The design of this experiment differed from classical exclusion tasks as stimuli requiring differential encoding were interleaved rather than blocked. Items were presented visually at test, and subjects were instructed to press one key to old items that had been spoken in a particular voice at study (‘targets’) and another key both to old items that had been spoken in the other voice at study (i.e. ‘nontargets’) and to new items (Wilding & Rugg, 1997). A left-lateralised parietal old/new effect was observed for both targets and nontargets, although this effect was somewhat smaller for nontargets than for targets. This finding was in accordance with the assumption that subjects use recollection to correctly exclude nontargets during exclusion tasks (Jacoby, 1991). Both types of old item also elicited greater negativity than new items over parietal sites, onsetting at approximately 600 msec. The fact that this negativity was largest in magnitude for false alarms indicated that this effect could not be related to the recollection of contextual details. It was therefore hypothesised that this effect was response-related, as the amplitude of this effect was inversely proportional to the reaction times associated with the eliciting item (Wilding & Rugg, 1997). Surprisingly, a right frontal old/new effect was observed only for correctly classified targets and not for correctly classified nontargets.

Although Wilding and Rugg’s (1997) findings confirmed that the parietal and right frontal old/new effects were functionally dissociable, they also indicated that the processes reflected by the right frontal old/new effect were not necessary for the successful recollection of contextual information. The authors therefore argued that the processes reflected by the right frontal old/new effect may be closely tied to recollection, but that they may be strategic processes which vary with task demands rather than being obligatory processes (Wilding & Rugg, 1997). Findings consistent with this hypothesis came from a later ERP study which compared recognition memory for spoken words in two different retrieval tasks which either did or did not require source judgements (Senkfor & Van Petten, 1998). It was reported that a prefrontal old/new effect (which was not right-lateralised in this study) was observed only in the task requiring source judgements, but that this effect did not vary according to the accuracy of the source judgement (Trott, Friedman, Ritter.D., Fabiani, & Snodgrass, 1999).
The authors hypothesised that prefrontal positivity may reflect search processes which attempt to retrieve contextual details (Senkfor & Van Petten, 1998). Interestingly, a recent ERP study varying depth of processing at study reported an influence of this manipulation on the right frontal old/new effect in a direction inconsistent with this effect's hypothesised role as a correlate of recollection (Rugg, Allan, & Birch, 2001). Whereas words that had been deeply encoded at study (i.e. incorporated into a meaningful sentence) elicited a parietal old/new effect larger in amplitude than that associated with words that had been shallowly encoded (i.e. in an alphabetic judgement), the right frontal old/new effect was only evident for words that had been studied in the shallow task at study. Although confidence judgements had not been recorded during these tasks, the finding that deeply studied items were associated with greater accuracy and faster reaction times than shallowly studied items was used to suggest that these two types of item were made with high and low confidence respectively (Rugg, Allan, & Birch, 2001). It was therefore hypothesised that shallowly encoded items may have elicited a greater degree of monitoring and evaluation processes at test than deeply studied items, as the former were recognised with a lower degree of confidence (Rugg, Allan, & Birch, 2001). This was an important finding in terms of delineating the functional significance of the right frontal old/new effect, as it weakened the view that recollection is either necessary or sufficient to elicit this effect.

The studies described above repeatedly demonstrate that recognition memory is associated with two dissociable ERP old/new effects; the parietal old/new effect (which is often left-lateralised in verbal tests of recognition) and the right frontal old/new effect, which were thought to reflect successful recollective and monitoring processes respectively. However these studies provided little evidence in support of dual-process models of recognition, as no qualitatively distinct ERP effect was suggested as a correlate of familiarity-based recognition memory. More recently, a series of ERP studies have provided evidence supporting dual-process accounts of recognition memory (Curran, 1999; Curran, 2000; Curran, Schacter, Johnson, & Spinks, 2001; Rugg et al., 1998; Ullsperger, Mecklinger, & Muller, 2001). Curran (1999) presented subjects with an equal number of words and orthographically legal pronounceable nonwords at study, and then recorded ERPs to new and repeated items both during a direct recognition task, and during an indirect lexical decision task (Curran, 1999). A parietal old/new effect was elicited by repeated words both in the lexical decision task and in the recognition task, but was not elicited by pseudowords. This finding was cited to support the view that this ERP effect reflects recollection, as previous phenomenological
research had indicated that words attracted a greater number of Remember responses than pseudowords (Gardiner & Java, 1990). The finding that the parietal old/new effect did not interact with task was therefore argued to support the view that recollection can occur both incidentally and intentionally (Curran, 1999). A second old/new effect qualitatively distinct from the parietal old/new effect was also reported in this study; ERPs to repeated items were more positive going than ERPs to new items over left frontal sites between 300-500 msec (see figure 3.4), an effect that did not interact with stimulus type or task (Curran, 1999). Previous reports that a greater proportion of Know responses are elicited by pseudowords than by words were cited in the hypothesis that the early frontal effect reflects familiarity (Curran, 1999), although if this were the case one might have expected the early frontal effect to interact with stimulus type, and to be larger for pseudowords than for words. In the light of response deadline studies indicating that familiarity occurs prior to recollection (Yonelinas & Jacoby, 1994), the finding that this early frontal effect had an earlier time course than the parietal old/new effect thought to reflect recollection was argued to support the hypothesis that the early frontal effect reflects familiarity-based recognition.

![Figure 3.4 'Early frontal old/new effect' (arrows). ERPs associated with correctly classified shallowly studied ('SHALLOW') and deeply studied ('DEEP') items, and ERPs associated with correctly classified new items ('NEW') at left and right frontal sites. Adapted from Rugg et al. (1998).](image)

Curran (2000) repeated an earlier behavioural experiment (Hintzman & Curran, 1997) in which words presented at study were presented either in the same or in the reversed plurality at test, and subjects were required to respond on one key if the test item was in the same plurality at study and on another key for both new words and words in a reversed plurality. Through use of a response-deadline paradigm (see Chapter 1), Hintzman and Curran (1997) reported that subjects were able to discriminate old from new items at approximately 400...
msec, but could not discriminate studied from plurality-reversed words until approximately 550 msec (Hintzman & Curran, 1997). The highly similar plurality-reversed lures were assumed to elicit familiarity at a time when the episodic information required to make the plurality discrimination was not available (Hintzman & Curran, 1997). The ERP replication of this study reported a parietal old/new effect which was elicited only by correctly identified old items, and an early frontal effect (300-500 msec) in which correctly rejected new items elicited greater negativity than either correctly identified old items or incorrectly endorsed plurality-reversed lures (Curran, 2000). This early frontal effect was bilateral and maximal in amplitude at superior frontal sites when data were analysed using an averaged reference, but was left-lateralised and limited to a smaller area when analysed using a mastoid reference. As the incorrectly endorsed plurality-reversed lures were argued to reflect familiarity in the absence of recollection, the early frontal effect was hypothesised to reflect familiarity-driven recognition (Curran, 2000). The earlier time course observed for this effect than for that associated with recollection was consistent with the behavioural finding that familiarity is faster acting than recollection, and the qualitatively distinct scalp distributions associated with the two effects supported dual-process accounts of recognition (Curran, 2000). Late onsetting negativity at parieto-occipital sites was also evident in this experiment for studied items and lures relative to new words, although this aspect of the data was not discussed (Curran, 2000).

Converging evidence came from a similar ERP study (Curran, Schacter, Johnson, & Spinks, 2001) using a procedure in which sets of semantically associated items were presented at study, and ‘theme’ words were presented at test as semantically-related lures together with new words that were not semantically related to studied items (Roediger & McDermott, 1995). This paradigm typically produces high levels of false memory which have been employed as a measure of familiarity in accordance with the theory that computation of global similarity underlies the familiarity component of dual-process theories (Hintzman & Curran, 1994). It was therefore argued that differences between ERPs to incorrectly endorsed lures and correctly rejected new words would reflect familiarity, whereas differences between ERPs to correctly endorsed studied words and incorrectly endorsed lures would reflect recollection of details (Curran, Schacter, Johnson, & Spinks, 2001). Subjects were grouped according to their ability to discriminate between studied items and semantically-related lures. The parietal old/new effect observed between studied words and lures was significant only for those subjects who showed good discrimination, suggesting superior recollection in
this group. The early frontal effect reported by Curran (2000) was observed between ERPs to semantically-related lures and new words (Curran, Schacter, Johnson, & Spinks, 2001). This effect did not differ between good and poor subjects, and was more left-lateralised than that observed in the Curran (2000) study. A late right frontal effect observed between lures and new words was also significant only for subjects showing good discrimination. It was argued from this finding that the late right frontal effect reflected greater monitoring of retrieved information prior to responding, which enabled these subjects to distinguish studied items from semantically-related lures (Curran, Schacter, Johnson, & Spinks, 2001). Again, late onsetting parieto-occipital negativity associated with studied items and lures relative to new words can be observed in Curran et al.’s (2001) data, although this effect was not discussed.

Curran et al. (2001) argued that the finding that incorrectly endorsed lures elicited an early frontal effect supported the view that early frontal positivity reflects familiarity-based recognition. However, the view that false alarms to plurality-reversed and semantically-related lures reflect familiarity-based recognition memory can be criticised, as previous work has shown that false memories of this nature can take the form of false recollection as opposed to familiarity (Payne, Elie, Vlackwell, & Neuschatz, 1996; Roediger & McDermott, 1995). Nessler et al. (2001) virtually replicated both Curran et al.’s (2001) study and its findings by presenting subjects with auditorily presented studied words, semantically-related lures and new words (Nessler, Mecklinger, & Penney, 2001). Whereas an early frontal effect was elicited both by studied words and by lures between 400-600 msec, a parietal old/new effect was only elicited by studied items. Nessler et al. (2001) argued that the fact that no parietal old/new effect was elicited by lures in these studies suggested that false recognition was based on familiarity rather than recollection. Studied items, incorrectly endorsed lures and correctly rejected lures also elicited a significant right frontal old/new effect. It was argued that the right frontal effect does not reflect post-retrieval processing, but that it is rather influenced by the retrieval context, and actually reflects search processes which attempt to retrieve specific contextual information (Nessler, Mecklinger, & Penney, 2001). Finally, lures elicited a more negative-going waveform than studied items or new words at parietal sites, onsetting at approximately 600 msec. As in the Wilding and Rugg (1997) study, it was also reported that these items were associated with significantly slower reaction times, a finding which led the authors to agree with Wilding and Rugg’s (1997) proposal that late parietal negativity may be response-related (Nessler, Mecklinger, & Penney, 2001).
Convergent evidence supporting the view that early frontal positivity reflects familiarity-based recognition arose from a further study that reported greater positivity elicited by correctly endorsed old items than correctly rejected new items at frontal sites between 300-500 msec (Rugg et al., 1998). This effect was elicited prior to the onset of a left-lateralised parietal old/new effect, and the scalp distribution of the two effects differed qualitatively. It was argued that the early frontal old/new effect was a correlate of item familiarity as it appeared to be insensitive to a depth of processing manipulation at encoding, whereas the left parietal old/new effect was argued to reflect recollection as it was larger in amplitude for deeply encoded items than for shallowly encoded items. Evidence indicating that depth of processing does not reliably dissociate familiarity and recollection (Toth, 1996; Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998) somewhat weakens these conclusions. However, this experiment was key in that it was the first to demonstrate that the early frontal effect does not simply reflect priming-related processes; the early frontal effect was not evident in ERPs to incorrectly rejected studied items (i.e. ‘misses’), and could be dissociated from another ERP effect elicited by studied items including misses within the 300-500 msec latency region which was maximal over parietal sites. This latter effect was interpreted as a correlate of implicit memory. It therefore appears that the early frontal effect is not a correlate of priming, thus satisfying one of the criteria specified at the beginning of this chapter for an ERP correlate of familiarity.

A ‘directed forgetting’ paradigm was employed by a study reporting a comparable pattern of ERP data (Ullsperger, Mecklinger, & Muller, 2001). The term ‘directed forgetting’ referred to the phenomenon that words at study differentially tagged with ‘Remember’ and ‘Forget’ instructions are associated with high and low memory performance at test respectively. Ullsperger et al. (2001) argued that by delaying these instructions for each study item until it had been presented for a short duration, subsequent familiarity should not be affected by these instructions whereas subsequent recollection should be disrupted. This argument was based on the assumption that instructing subjects to Forget initiates a process which inhibits access to that item at retrieval (MacLeod, 1989), although it should be noted that alternative mechanisms have also been proposed to account for the phenomenon of directed forgetting (these are not discussed here). In accordance with the authors' predictions, both Forget and Remember words elicited an early frontal old/new effect, whereas a parietal old/new effect was observed for Remember words only (Ullsperger, Mecklinger, & Muller, 2001). A right frontal old/new effect was larger in amplitude for Forget words than for Remember words, a
finding which surprised the authors who had been working under the assumption that this old/new effect is related to monitoring contingent on successful retrieval. Together with the poor memory performance observed for Forget items, the finding that the right frontal old/new effect was greater for Forget items was interpreted as evidence that this ERP old/new effect reflects evaluation processes that are engaged to a greater degree either when retrieval is poor, or when the salience of items increases (Ullsperger, Mecklinger, & Muller, 2001).

The first of these two possibilities is consistent with the view that the right frontal old/new effect is larger when recognition responses are associated with low confidence, as a greater degree of evaluation has to be performed prior to responding (Rugg, Allan, & Birch, 2001).

Despite the volume of evidence indicating that the early frontal and parietal old/new effects reflect familiarity and recollection respectively, other evidence suggests that the functional significance of these two ERP effects may in fact be more complex. A recent study recording ERPs from young and old participants employed a paradigm in which subjects were required to respond positively to studied items, and to reject both new items and repeating lures (Dywan, Segalowitz, & Webster, 1998). Although this study had a poor signal-to-noise ratio and employed too few electrodes to allow detailed analysis of the spatial fields of the ERP effects, it nonetheless reported some interesting data. Whereas old subjects were relatively poor at rejecting repeating lures and showed parietal old/new effects for both these items and for studied items, young subjects showed a superior ability to reject repeating lures but exhibited a parietal old/new effect for studied items only. This finding was surprising given the assumption that correctly excluded old items are excluded on the basis of recollection (Jacoby, 1991), as this assumption would lead one to predict that correctly excluded items would also elicit a parietal old/new effect. Under divided attention conditions, the young participants showed the same pattern of behaviour as the old subjects, both behaviourally and electrophysiologically, (Dywan, Segalowitz, & Webster, 1998). Dywan et al. (1998) argued that younger subjects exercised greater inhibitory control, and that the fact that repeating lures did not elicit a parietal old/new effect reflected this control. This finding has not thus far been replicated, but it suggests that the parietal old/new effect may be sensitive to factors other than recollection. Dywan et al. (1998) did not discuss at what level this ‘inhibitory control’ was hypothesised to operate; it is possible that recollection of nontargets was itself inhibited. Alternatively, nontarget information may have been available to episodic retrieval, but control processes prevented this information from being attended to. This point shall be returned to later in this thesis.
Similarly, it has recently been reported that the early frontal effect may not be an obligatory correlate of familiarity-based recognition memory (Tsivilis, Otten, & Rugg, 2001). This study explores the effects of context on ERP correlates of recognition memory. Subjects at study were presented with complex stimuli which consisted of an item superimposed onto a background scene. Five classes of stimuli were presented at test; the same item-background pairing as at study (‘SAME’), a different pairing of a studied item and a studied background (‘REARRANGED’), a new item on a studied background (‘NEW-OLD’), a studied item on a new background (‘OLD-NEW’), and a new item on a new background (‘NEW-NEW’).

Subjects were required to make old/new judgements for the item component of stimuli presented at test. Interestingly, although correctly recognised SAME and REARRANGED stimuli elicited greater positivity than novel stimuli over frontal sites between 300-500 msec, correctly recognised OLD-NEW stimuli did not. The finding that behavioural performance did not differ between REARRANGED and OLD-NEW stimuli was cited to suggest that processing reflected by the early frontal effect may not be directly related to a familiarity-driven recognition response (Tsivilis, Otten, & Rugg, 2001). It was instead hypothesised that the early frontal effect may reflect processing ‘downstream’ from that responsible for familiarity-based recognition, and may instead be sensitive to novel components of a stimulus (Tsivilis, Otten, & Rugg, 2001).

Different functional characteristics for a number of the ERP effects described above were proposed by Cycowicz et al. (2001). Subjects were presented with coloured pictures at study, and were then presented with one of two types of test. In an item recognition test subjects were merely required to respond ‘old’ to any studied item. In an exclusion task, subjects were required to respond on one key if the picture had been presented at study in a specified colour (‘targets’), and to respond on an alternative key either if the item had been presented at study in another colour (‘nontargets’) or if the item was new (Cycowicz, Friedman, & Snodgrass, 2001). A parietal old/new effect was observed both for correctly recognised items in the item recognition task, and for correctly classified targets and nontargets in the exclusion task. However, a parietal old/new effect was also observed for incorrectly classified targets and nontargets in the exclusion task. It was argued from this finding that the parietal old/new effect reflects familiarity rather than recollection (Cycowicz, Friedman, & Snodgrass, 2001). However, as stated previously, the fact that subjects in exclusion-based tasks do not accurately retrieve the source information specified by the experimenter does not
necessarily mean that no contextual information is retrieved for these items. It is therefore possible that a parietal old/new effect was observed for incorrect source attributions in Cycowicz et al.'s (2001) study because these items elicited noncriterial recollection as opposed to acontextual familiarity. Greater negativity was also reported for old items in the source memory task only, peaking at approximately 850 msec and maximal at parieto-occipital sites (Cycowicz, Friedman, & Snodgrass, 2001). The fact that late onsetting negativity was observed only in the source memory task led the authors to suggest that this effect may reflect processes related to the contextual retrieval of perceptually-specific information (Cycowicz, Friedman, & Snodgrass, 2001). This contradicted Wilding and Rugg’s (1997) hypothesis that late onsetting parietal negativity was response-related rather than mnemonic, as did the finding that RTs to new and old items did not differ significantly in Cycowicz et al.'s (2001) experiment. No right frontal effect was observed in Cycowicz et al.'s (2001) study. It was suggested that the extent of negativity observed over parietal sites may have attenuated the right frontal effect to the point of apparent elimination, as the two effects occur within the same latency region (Cycowicz, Friedman, & Snodgrass, 2001).

Neuropsychological populations
A number of studies investigating ERP correlates of recognition memory in various neuropsychological populations have interpreted differences observed between ERPs to recognised and new items within a dual-process framework (Smith & Halgren, 1989; Tendolkar et al., 1999; Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997). A key finding in the recognition memory ERP literature was that the difference observed between ERPs to correctly recognised items and to new items can be fractionated into the modulation of two different components (Smith & Halgren, 1989). ERPs were recorded both from unilateral anterior temporal lobectomy patients and from normal controls across multiple test blocks of visually presented words, during which the same ten studied words were presented together with an equal number of new words that changed with each block (Smith & Halgren, 1989). Subjects were instructed to respond only to studied items. Controls and right-sided patients showed normal immediate recognition, normal improvement over repetitions, and an ERP old/new effect which dissociated into an early component and a late component on the basis of their differing scalp distributions. Left-sided patients were impaired on immediate recognition and showed neither component of the ERP old/new effect, but did show memory improvement over repetitions at a normal rate. As recognition performance was only mildly impaired in left-sided patients, it was argued that these patients must have performed the task
on the basis of familiarity-based recognition, and that the modulation of both ERP components must therefore reflect recollection-related processing (Smith & Halgren, 1989). The early component was argued to reflect the formation of an episodic trace, and the late component was hypothesised to reflect the retrieval of that trace (Smith & Halgren, 1989). No ERP effect was proposed to reflect familiarity-based recognition.

More recently, Tendolkar et al. (1999) recorded ERPs from patients suffering from Alzheimer's Disease and from controls. All subjects were engaged in a test of verbal recognition memory accompanied by a source decision (colour of item at study). Despite showing relatively unimpaired recognition, Alzheimer patients manifested a severe disability to recollect contextual information. The only old/new effect observed in the ERPs recorded from the Alzheimer group was between 300-500 msec at frontal sites, whereas ERPs recorded from the control group showed additional old/new effects over left temporoparietal and right frontal sites between 300-900 msec (Tendolkar et al., 1999). As the Alzheimer patients could not accurately retrieve contextual information, it was argued that the preserved recognition memory performance observed in mild Alzheimer's Disease is familiarity-based and independent of the hippocampally-mediated processes which have been proposed to underlie the recollection of episodic memories (Aggleton & Brown, 1999). It was therefore concluded that the early frontal effect must reflect familiarity-based recognition memory, whereas the left parietal and right frontal old/new effects must be related to the retrieval of contextual information characteristic of recollection (Tendolkar et al., 1999). Consistent with this finding, Duzel et al. (2001) compared ERPs recorded from an amnesic patient (Jon) with ERPs recorded from normal controls. Jon suffers from early hippocampal damage, but shows relatively normal recognition performance. Subjects were required either to make living/nonliving or concrete/abstract judgements at study, followed by a recognition memory task in which studied words were presented with an equal number of new words. Subjects at test were required to make an old/new judgement for each word. Although Jon’s recognition performance was below that of the controls, it remained above chance. Control subjects showed both an early old/new effect between 300-500 msec with an anterior distribution, and a parietal old/new effect between 500-700 msec. However, Jon only showed the early frontal old/new effect. It was concluded that whereas controls used both familiarity and recollection during the recognition task, Jon relied solely on familiarity during this task (Duzel, Vargha-Khadem, Heinze, & Mishkin, 2001). This study therefore provided further evidence to support the view that the early frontal effect reflects the operation of familiarity-related
processing, whereas the parietal old/new effect reflects recollection-based recognition memory. Duzel et al. (2001) also replicated Rugg et al. (1998) in demonstrating that the old/new effect elicited by misses between 300-500 msec was topographically distinct from that associated with correctly recognised items, the former having a posterior distribution and the latter being maximal at mid-frontal sites.

**Discussion**

As can be seen from the literature discussed above, a wealth of convergent evidence from cognitive and neuropsychological studies employing ERPs indicates that recognition memory is associated with a number of dissociable ERP correlates. These components have largely been interpreted within a dual-process framework. Two of these effects, the parietal old/new effect and the early frontal effect, are thought to reflect recollection and familiarity respectively. Two other ERP effects, the right frontal old/new effect and late parietal negativity, do not appear to be directly related either to recollection or familiarity, but rather appear to be influenced by the requirement to monitor or evaluate retrieved information. These four recognition-related ERP effects are delineated in table 3.1, and are discussed in greater detail below together with the implications of the ERP data discussed above for models of recognition memory.

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<th>Latency region</th>
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<td>300-500 msec</td>
<td>Mid-frontal sites</td>
<td>Correlate of familiarity</td>
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<td>Parietal old/new effect</td>
<td>500-800 msec</td>
<td>Parietal sites (often left-lateralised)</td>
<td>Correlate of recollection</td>
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<td>Right frontal effect</td>
<td>800-1400 msec</td>
<td>Right frontal sites</td>
<td>Post-retrieval processing</td>
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<td>Late negative wave</td>
<td>800-1400 msec</td>
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Table 3.1 Summary of the principal ERP effects of interest in studies of recognition memory.
**ERP old/new effects**

The parietal old new effect

The first ERP correlate of recognition memory to be identified was the parietal old/new effect, which is also referred to as the ‘late positive component’ in some studies. The parietal old/new effect is almost always elicited in tests of recognition memory by correctly identified studied items relative to correctly rejected unstudied items, and is maximal at parietal sites between approximately 500-900 msec whenever the interval between study and test exceed a few minutes. The scalp distribution of this effect differs depending on the type of task, study-test delay and nature of the materials employed as stimuli. For example, whereas the parietal effect is usually bilateral in tests of continuous recognition (e.g. Rugg, Brovedani, & Doyle, 1992), it is often left-lateralised in study-test designs employing verbal stimuli (e.g. Wilding & Rugg, 1996). Although it was initially hypothesised that the parietal old/new effect reflected familiarity-based recognition memory (Rugg & Doyle, 1992), it quickly became apparent that this ERP effect was in fact a correlate of recollection-based recognition, as further studies demonstrated that the amplitude of this effect was larger for Remember than Know judgements (Smith, 1993; Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997), deep compared to shallow encoding (Rugg et al., 1998) and recognition accompanied by the retrieval of contextual information (Wilding & Rugg, 1996; Donaldson & Rugg, 1998; Curran, 2000; Curran, Schacter, Johnson, & Spinks, 2001). Reports that the parietal old/new effect was not elicited in patient groups thought to have a selective impairment in recollection supported the view that this effect is a correlate of recollection-based recognition (Tendolkar et al., 1999; Duzel, Vargha-Khadem, Heinze, & Mishkin, 2001). Other work confirmed that the parietal old/new effect was a mnemonic effect rather than an effect sensitive to factors such as probability, targetness (Smith & Guster, 1993) or response requirements (Rugg, Brovedani, & Doyle, 1992). Additionally, it was reported that this effect was elicited only by veridical recognition memory judgements, as it was not observed for incorrectly rejected studied items or for incorrectly endorsed unstudied items (Rugg & Doyle, 1992; Rugg & Doyle, 1994). This ERP effect therefore satisfies all of the criteria specified at the beginning of this chapter for a correlate for recognition memory.

The parietal old/new effect, therefore, is currently considered to be a correlate of recollection-based recognition memory. In an alternative account proposed by Cycowicz et al. (2001), the parietal old/new effect is viewed as a correlate of familiarity-based recognition as opposed to recollection, an argument based on the finding that a parietal old/new effect was elicited both
by correctly recognised items associated with correct source judgements and by correctly recognised items associated with incorrect source judgements (Cycowicz, Friedman, & Snodgrass, 2001). However, this finding can also be cited to illustrate a key methodological point delineated at the beginning of this chapter; as ERPs cannot be transformed by the equations outlined in the process dissociation procedure (Jacoby, 1991), attempts to separate recognition responses based on familiarity from those based on recollection are inevitably confounded by the issue of process purity. It is therefore unlikely that any ERP correlate of recognition memory will provide a process-pure measure either of familiarity or of recollection. By operationalising familiarity as correctly recognised items for which specified contextual information is not retrieved, one runs the risk of this putative measure of familiarity being contaminated with noncriterial recollection. This is a criticism that has also been levelled at the process dissociation procedure itself (see Chapter 1). It is therefore possible that Cycowicz et al.'s (2001) finding that a parietal old/new effect was elicited by correctly recognised items associated with incorrect source judgements actually reflected the fact that these items were associated with noncriterial recollection rather than no recollection at all.

A more interesting development in recent years was the finding that a parietal old/new effect was not elicited by correctly excluded items amongst young subjects who showed good discrimination between to-be-included and to-be-excluded old items, but a parietal old/new effect was elicited by to-be-excluded items amongst old subjects who showed poor discrimination even when these items were correctly excluded (Dywan, Segalowitz, & Webster, 1998). This finding was particularly surprising given the assumption that the majority of correctly excluded old items are excluded on the basis of recollection (Jacoby, 1991), and either implies that this assumption is incorrect or implies that the parietal old/new effect is sensitive to additional factors contingent on recollection. A possible explanation for this pattern of results was presented on the basis of a secondary finding that dividing attention both decreased young subjects' discrimination accuracy and caused to-be-excluded old items to now elicit a parietal old/new effect (Dywan, Segalowitz, & Webster, 1998); it was proposed that young subjects are usually able to bring attentional resources to bear when engaged in tasks requiring differential responding according to retrieved contextual information, and it was therefore suggested that the parietal old/new effect may additionally be sensitive to these attentional processes or may be sensitive to item salience (Dywan, Segalowitz, & Webster, 1998). This finding has not since been replicated, and no additional
evidence has been presented to suggest that the parietal old/new effect is indeed sensitive to attentional factors. However, further work is required to investigate Dywan et al.'s (1998) findings, particularly given the technical limitations of that study. This point is again addressed later in this thesis.

Many researchers have speculated with regard with the possible neural generators of the parietal old/new effect, drawing from haemodynamic and neuropsychological studies of recognition memory. One must exercise extreme caution when attempting to link ERP data to haemodynamic data, as the relationship between haemodynamic variables and electrical activity in the brain is not yet understood. However, convergent evidence from fMRI, PET and neuropsychology can be used to suggest possible candidates for the generators of the ERP effects described above. Wilding and Rugg (1996) argued that the parietal old/new effect reflected the retrieval of item and contextual memory supported by the medial temporal lobe memory system. Although it has been argued that recollection engages the hippocampus (Schacter et al., 1996; Aggleton & Brown, 1999; Yonelinas, Hopfinger, Buonocore, Kroll, & Baynes, 2001), it is unlikely that activity in this region contributes to the parietal old/new effect as this is a region that ERPs are largely 'blind' to. It has rather been suggested that the parietal old/new effect reflects stimulus locked changes in cortical activity produced by the cortico-hippocampal interactions thought to underlie episodic memory retrieval (Wilding & Rugg, 1996; Rugg & Allan, 2000; McClelland, McNaughton, & O'Reilly, 1995). Support for this hypothesis came from a PET study which demonstrated that deep processing elicited greater activation than shallow processing in the left hippocampal formation and regions of the temporal and frontal cortex of the left hemisphere (Rugg, Fletcher, Frith, Frackowiak, & Dolan.R.J., 1997), as this finding paralleled reports that depth of processing influences the amplitude of the parietal old/new effect (Rugg et al., 1998).

More recently, event-related fMRI has been employed in a number of recognition memory studies which have indicated that recollection may be associated with activations in parietal cortex. One such study presented recently studied words with twice as many unstudied words at test, and found activations elicited by correctly classified studied items (compared against correctly classified unstudied items) in bilateral inferior and superior lateral and medial parietal cortex, in addition to a number of activations in several regions of the prefrontal cortex (Konishi, Wheeler, Donaldson, & Buckner, 2000). The fact that only one third of test items had been studied rendered these findings somewhat ambiguous, as previous studies had
reported activations in these regions for rare event-types that do not require episodic retrieval (e.g. Stevens, Skudlarski, Gatenby, & Gore, 2000). However, correctly classified studied items were also associated with activations in medial and bilateral parietal cortex in two event-related fMRI studies which presented equal numbers of studied and unstudied items at test (Donaldson, Peterson, Ollinger, & Bucker, 2001; Henson, Rugg, Shallice, & Dolan, 2000). These activations were left lateralised in the Henson et al. (2000) study. In addition to replicating the finding that activations in parietal cortex are associated with retrieval success, at least three fMRI studies have identified these activations with recollection-based recognition memory (Henson, Rugg, Shallice, Josephs, & Dolan, 1999; Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000; McDermott, Jones, Peterson, Lageman, & Roediger, 2000). Two of these studies were reviewed in Chapter 1 (Henson, Rugg, Shallice, Josephs, & Dolan, 1999; Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000), and are therefore not discussed fully here. To summarise, Henson et al. (1999) used a one-stage Remember/Know procedure and reported greater activity for Remember than for Know responses in inferior and superior lateral parietal cortex, left dorsal anterior prefrontal cortex and posterior cingulate. Eldridge et al. (2000) employed a two-stage Remember/Know procedure and reported greater activity for Remember than for Know responses in left dorsolateral prefrontal cortex, right inferior prefrontal cortex, bilateral inferior parietal cortex, posterior cingulate cortex and left hippocampus. A further event-related fMRI study identified activations associated with recollection by comparing correctly classified studied items with familiar ‘lures’ (McDermott, Jones, Peterson, Lageman, & Roediger, 2000). Subjects were presented with compound words (e.g. ‘nosebleed’ and ‘skydive’) at study, and were then presented at test with new words, studied words, and new lures consisting of recombinations of elements of studied compound words (e.g. ‘nosedive’). McDermott et al. (2000) argued that recollection was required to oppose the familiarity of the lures, and that the majority of correctly classified studied items and correctly rejected lures would therefore be recollected. Activations associated with both these response types (relative to correct rejections of unrelated new items) were observed in right superior parietal cortex, bilateral inferior cortex, and in bilateral anterior prefrontal regions (McDermott, Jones, Peterson, Lageman, & Roediger, 2000). In the light of the findings described above, it is hypothesised that the activations observed in lateral and medial parietal cortex associated with retrieval success may give rise to the parietal old/new effect observed in ERP studies of recognition memory, as the amplitudes of both fMRI activations in these regions and of the
The early frontal effect

While initial attempts to find ERP correlates of familiarity met with little success, a number of recent cognitive and neuropsychological studies have reported an early frontal effect associated with positive recognition responses that dissociates qualitatively from the parietal old/new effect held to reflect recollection-based recognition memory (Curran, 1999; Curran, 2000; Curran, Schacter, Johnson, & Spinks, 2001; Rugg et al., 1998; Duzel, Vargha-Khadem, Heinze, & Mishkin, 2001; Tendolkar et al., 1999). This effect takes the form of a more positive going waveform for items judged old relative to items judged new, maximal over frontal sites between approximately 300-500 msec. As with the parietal old/new effect, the distribution of this effect appears to vary across studies from a left frontal focus to a mid-frontal or fronto-temporal focus. While studies to date have not demonstrated conclusively that the early frontal effect is a direct correlate of familiarity, and although a number of these studies can be criticised on one or more counts, the weight of the evidence suggests that this effect is related to familiarity-based recognition. Reports that the early frontal effect shows less sensitivity to depth of processing than the parietal old/new effect (Rugg et al., 1998), is insensitive to word/pseudoword manipulations (Curran, 1999) and is elicited both by correctly endorsed old items and false alarms to plurality-reversed and semantically related lures (Curran, 2000; Curran, Schacter, Johnson, & Spinks, 2001), together with the fact that this effect onsets prior to the parietal old/new effect (a finding consistent with response deadline studies of familiarity and recollection, see Chapter 1) all suggest that the early frontal effect is a good candidate for an electrophysiological correlate of familiarity-based recognition memory. Similarly, reports that the early frontal effect is elicited by neuropsychological patients who show only mild impairments in recognition performance despite suffering from impaired recollection also support the view that this effect is related to familiarity-based recognition memory (Tendolkar et al., 1999; Duzel, Vargha-Khadem, Heinze, & Mishkin, 2001).

In addition to the sensitivity of the early frontal effect to several manipulations thought to influence familiarity-based recognition, the finding that this effect is not elicited by incorrectly rejected studied items (i.e. misses) suggests that it cannot be explained in terms of priming (Rugg et al., 1998; Duzel, Vargha-Khadem, Heinze, & Mishkin, 2001). Indeed the
early frontal effect dissociates from a posteriorly distributed ERP old/new effect that is
elicted within the same latency region by misses and which is associated with implicit
memory (Rugg et al., 1998; Duzel, Vargha-Khadem, Heinze, & Mishkin, 2001). The ERP
literature pertaining to the early frontal effect has not yet sufficiently developed to have ruled
out the influence of response-related factors. Although it certainly appears to be the case that
the early frontal effect is not a necessary consequence of a positive recognition response
(Tsivilis, Otten, & Rugg, 2001), it has yet to be demonstrated that an early frontal effect can
be elicited by familiar stimuli irrespective of response requirements. Demonstrating such a
dissociation is problematic, as one would expect a correlate of familiarity only to be elicited
by recognised items. Further work using exclusion-based tasks may clarify this matter, as to-
be-included and to-be-excluded old items are both expected to elicit familiarity based

It has recently been reported that although the early frontal effect may reflect processing
which contributes to familiarity-based recognition responses in single-item tests of
recognition memory, this effect may actually be a more indirect correlate of familiarity than
previously supposed. The finding that the early frontal effect is not elicited by complex
stimuli in which one attribute is correctly recognised but which also contain a novel
component suggests that this effect may be sensitive to novelty rather than directly reflecting
a recognition judgement made on the basis of familiarity (Tsivilis, Otten, & Rugg, 2001).
Although this interpretation may appear to be a reformulation of the view that the early
frontal effect reflects familiarity (after all, the converse of novelty detection is familiarity
detection), this functional specification takes a more bottom-up approach in specifying the
level at which the processing that this effect reflects may operate, rather than the top-down
approach which states that the early frontal effect is a correlate of familiarity-based
recognition judgements. The latter view should predict that the phenomenological experience
of familiarity as reflected by Know responses should elicit an early frontal effect, and of
course this finding has not thus far been reported. Tsivilis et al. 's (2001) finding has yet to be
replicated, but should be important in guiding future work investigating the functional
significance of the early frontal effect.

The right frontal effect
The right frontal effect emerged as recognition memory paradigms employed in ERP studies
became more complex and began to require subjects to retrieve contextual details from the
encoding episode (Wilding & Rugg, 1996; Rugg, Schloerscheidt, & Mark, 1998; Rugg, Schloerscheidt, Doyle, Cox, & Patching, 1996; Donaldson & Rugg, 1998). This effect took the form of greater positivity for correctly classified studied items relative to correctly classified unstudied items, onsetting at approximately 500 msec at right frontal sites and remaining sustained until the end of the recording epoch. The fact that the right frontal old/new effect was first observed in studies requiring the retrieval of contextual information led early researchers to argue that this effect reflected post-retrieval processing of the products of retrieval necessary to make accurate source judgements (Wilding & Rugg, 1996; Rugg, Schloerscheidt, & Mark, 1998; Rugg, Schloerscheidt, Doyle, Cox, & Patching, 1996; Donaldson & Rugg, 1998). However, further work indicated that successful recollection was neither necessary nor sufficient to elicit the right frontal old/new effect (Wilding & Rugg, 1997; Senkfor & Van Petten, 1998; Trott, Friedman, Ritter.D., Fabiani, & Snodgrass, 1999; Ullsperger, Mecklinger, & Muller, 2001). Reports that right frontal old/new effects were larger for shallowly encoded items than for deeply encoded items (Rugg, Allan, & Birch, 2001), and for items tagged 'Forget' than for items tagged 'Remember' in directed forgetting tasks (Ullsperger, Mecklinger, & Muller, 2001) led to a reformulation of the functional significance of the right frontal old/new effect; rather than being associated with successful recollection, it is currently thought that the right frontal effect may reflect the extent to which monitoring and evaluation processes have to be employed in order to respond accurately in a recognition memory task. This may often occur in tasks which require subjects to respond differentially on the basis of retrieved contextual information, but may also occur in yes-no recognition tests when memory is relatively poor.

The diverse findings described above pertaining to the right frontal old/new effect also point to the possibility that positivity at right frontal sites is in fact functionally heterogeneous. Right frontal positivity is usually analysed within a relatively long latency region, and this fact together with the lack of spatial resolution inherent in the ERP technique means that it is difficult to establish whether the ‘right frontal effect’ is in fact one effect or a combination of a number of effects. Evidence from fMRI indeed suggests that the frontal lobes are functionally heterogeneous with highly specialised areas responsible for different types of processing, and it is likely that this heterogeneity is reflected in ERPs recorded over right frontal regions. It is often argued that the right frontal old/new effect observed in ERP studies of recognition memory reflects activity in the right prefrontal cortex (Rugg & Allan, 2000; Mecklinger, 2000). Evidence from various haemodynamic imaging studies suggests
that whereas some regions of the right prefrontal cortex are activated simply by being in retrieval ‘mode’ (i.e. thinking back to the past, for review see Lepage, Ghaffer, Nyberg, & Tulving, 2000), right dorsolateral prefrontal regions show a greater response for recognised items that require a greater degree of evaluation (Henson, Rugg, Shallice, Josephs, & Dolan.R.J., 1999; Henson, Rugg, Shallice, & Dolan.R.J., 2000) and right anterior ventral prefrontal regions appear to be activated by retrieval success (Henson, Rugg, Shallice, & Dolan.R.J., 2000).

Late parieto-occipital negativity
A number of studies in recent years have reported a late negative wave elicited by old item maximal over parietal regions, onsetting at approximately 600 msec and persisting until the end of the recording epoch (Wilding & Rugg, 1996; Wilding & Rugg, 1997; Rugg, Scholerscheidt, Doyle, Cox, & Patching, 1996; Rugg, Scholerscheidt, & Mark, 1998; Curran, 2000; Curran, Schacter, Johnson, & Spinks, 2001; Cycowicz, Friedman, & Snodgrass, 2001). These studies typically require subjects to retrieve contextual information. Indeed, in a direct comparison of a task requiring yes-no item recognition and a task requiring differential responding on the basis of source information, it became apparent that late parietal negativity was only elicited in the source memory task (Cycowicz, Friedman, & Snodgrass, 2001). The circumstances in which late negativity is elicited has led to two competing hypotheses pertaining to the functional significance of this effect; a number of these studies have reported significantly longer reaction times associated with items eliciting late parietal negativity, and have therefore argued that rather than being mnemonic, this effect may simply be response related (Wilding & Rugg, 1996; Wilding & Rugg, 1997; Nessler, Mecklinger, & Penney, 2001). However, this hypothesis was undermined by the finding that reaction times to old and new items did not differ in a study reporting late parietal negativity elicited by old items (Cycowicz, Friedman, & Snodgrass, 2001). Drawing from the finding that this negativity was elicited in a source memory task and not in an item memory task, Cycowicz et al. (2001) put forward a competing hypothesis that late parietal negativity reflected the search for, or evaluation of, contextual information. Although this interpretation accounts for the majority of findings, late parietal negativity was not elicited in Donaldson and Rugg’s (1998) study by intact word-pairs when subjects were required to retrieve source information, but was elicited by rearranged word-pairs when subjects were not required to retrieve source information. It may be the case that neither longer reaction times nor retrieval of source
information are necessary or sufficient to elicit late parietal negativity, but that this effect reflects processing often associated with both of these factors.

Mecklinger (2000) replicated the study in which semantically related lures elicited late parietal negativity (Nessler, Mecklinger, & Penney, 2001) using fMRI, and used this information to constrain estimations of the neural generators of this effect. The contrast between correctly rejected new words and incorrectly classified lures revealed a significant activation in the anterior cingulate cortex, a region considered to be part of an attention network which is activated under conditions of response competition (Mecklinger, 2000). Citing from studies which found that response competition occurs when response selection requirements are demanding and the likelihood of error is high (e.g. Carter et al., 1998; Turken & Swick, 1999), Mecklinger (2000) hypothesised that anterior cingulate cortex activation and the late parietal negative wave may reflect enhanced response conflict when subjects are required to classify familiar items as new. This interpretation does not, however, explain why correctly classified targets in exclusion tasks also elicit a late negative wave. The response competition hypothesis may have more explanatory power if it does not restrict response competition only to those old items that require a new response. It may instead be the case that response competition is experienced whenever recognition of any item can lead to more than one response, and that a late negative wave is accordingly observed for all types of recognised item in an exclusion task. Again, this point shall be discussed more fully later in this thesis.

**Implications for models of memory**

The finding that recollection-based and familiarity-based recognition memory are associated with qualitatively distinct ERP old/new effects can be cited to support dual-process models of recognition memory. It is, however, interesting that early ERP studies exploring recognition memory did not report the early frontal effect in addition to the late parietal old/new effect (e.g. Smith, 1993; Wilding & Rugg, 1996). As Smith (1993) used a one-stage Remember/Know procedure when attempting to dissociate correlate of familiarity and recollection, it is possible that ERPs associated with Remember and Know responses did in fact reflect differing degrees of response confidence rather than the phenomenological experiences typically associated with these two responses, as one-stage Remember/Know paradigms have been previously criticised for this reason (see Chapter 1). However, an early
frontal old/new effect was in fact described in this study for both Know and Remember responses, despite the fact that this effect was not linked to familiarity-based recognition (Smith, 1993). Wilding and Rugg (1996) attempted to dissociated recognition responses made on the basis of recollection and familiarity by operationalising these two processes as correct recognition judgements with and without the retrieval of source information respectively. It was argued that recollection and familiarity may differ in degree rather than in kind following the finding that no qualitative differences was observed between ERPs to these two types of response (Wilding & Rugg, 1996). As argued above, it is possible that although subjects could not retrieve the specified contextual information for certain items, items designated as familiar on this basis were in fact contaminated with noncriterial recollection. However, reexamination of the data indicates that early frontal effects were in fact elicited by studied items in Wilding and Rugg’s (1996) experiment (see figure 3.2), despite the fact that these effects were not quantified or reported.

Even if Smith (1993) and Wilding and Rugg (1996) conclusively demonstrated that measures of familiarity and recollection were indeed process pure, and that no qualitative differences existed between ERPs associated with these processes, these findings could not be cited to invalidate dual-process models. As stated at the beginning of this chapter, the use of ERPs to investigate models of recognition memory is asymmetric. Whereas evidence of a qualitative dissociation between ERP correlates of familiarity and recollection can always be cited to support dual-process models of recognition memory, a null finding (i.e. no qualitative dissociation) cannot be used to support single process models. This is because qualitatively distinct patterns of neural activity can be elicited in parts of the brain undetectable to scalp electrodes. However, a wide variety of studies have since reported dissociations that actively support the view that familiarity and recollection are distinct processes as opposed to points on a continuum of trace strength (Curran, 1999; Curran, 2000; Curran, Schacter, Johnson, & Spinks, 2001; Nessler, Mecklinger, & Penney, 2001; Rugg et al., 1998). The fact that these studies have employed a wide variety of paradigms and subject populations, and have still reported comparable results lends validity to the view that the parietal old/new effect and the early frontal old/new effect reflect dissociable recollection and familiarity processes respectively. Reports that the scalp distributions of the ERPs associated with familiarity and recollection are qualitatively distinct support the assertion that these two processes elicit the activity of at least partially non-overlapping neural populations. A variety of convergent ERP evidence both from cognitive and from neuropsychological studies therefore supports dual-
process models of recognition memory that propose two dissociable processes underlying recognition memory, indicating an early frontal effect sensitive to automatic acontextual influences of memory and a parietal old/new effect sensitive to the controlled retrieval of contextual information. The time-courses of these two ERP effects are consistent with response deadline studies which have reported that familiarity is available prior to recollection (e.g. Yonelinas & Jacoby, 1994).

However, it should also be acknowledged that the majority of the findings described above do not necessarily compel a dual-process interpretation. The common finding in the studies described above is that the early frontal effect is observed for both familiar and recollected items, whereas the parietal old/new effect is observed for recollected items only. As argued in the review of fMRI data in Chapter 1, the finding that activity associated with familiarity is a subset of activity associated with recollection can also be accounted for by single-process models, if it is argued that processing reflected by the parietal old/new effect was not sufficiently complex or 'strong' to be detected in the ERPs to familiar items. This interpretation derives from the fact that one can never conclude that no activity is elicited by a response category on the basis of a null effect. However, the finding that a levels-of-processing manipulation selectively influenced the amplitude of the parietal old/new effect without affecting the amplitude of the early frontal effect (Rugg et al., 1998) provides a dissociation between the two ERP effects indicative of two independent processes.

**Relational assumptions**

As noted at the beginning of this chapter, although ERP data can in theory be used to examine the various relational assumptions proposed to exist between familiarity and recollection (Jones, 1987), in reality one must exercise caution as the practice of averaging can produce deceptive results. Bearing this in mind, tentative inferences can be drawn from the ERP literature reviewed in this chapter. While a number of studies have reported ERPs associated with recognition that contain both the early frontal effect associated with familiarity and the parietal old/new effect associated with recollection (Rugg et al., 1998; Curran, 1999; Curran, 2000), ERP data have also been reported that either contain only the parietal old/new effect (e.g. Rugg, Schloerscheidt, & Mark, 1998; Rugg, Schloerscheidt, Doyle, Cox, & Patching, 1996; Tsivilis, Otten, & Rugg, 2001) or contain only the early frontal old/new effect (Curran, 2000; Rugg et al., 1998). It therefore appears that familiarity
and recollection do not share a relationship of redundancy; the redundancy assumption states that a proportion of all familiar items are recollected and that an item cannot be recollected in the absence of familiarity. However, the data appear to show that items can elicit recollection in the absence of familiarity. On the basis of this finding, it is tempting to concluded that a relationship of redundancy is not supported by the data. It is not, however, possible to distinguish between the alternatives; independence and exclusivity. Although the data appear to suggest that familiarity and recollection can either co-occur or operate independently (thus supporting the independence assumption), it may be the case that familiarity and recollection never co-occur but actually occur independently on each trial.

Such inferences are of course based on the assumption that the early frontal effect and the parietal old/new effect truly reflect familiarity-based recognition and recollection-based recognition respectively. In the light of Tsivilis et al. (2001), this assumption may not be accurate if the early frontal effect is in fact an indirect correlate of familiarity sensitive to low level differences in stimulus novelty. Similarly, evidence now exists to suggest that the parietal old/new effect may be sensitive to factors additional to recollection (Dywan, Segalowitz, & Webster, 1998). Further work is obviously required to clarify the functional characteristics of each of the ERP correlates of recognition memory discussed above. Only when the functional significance of each ERP old/new effect is fully understood can they be reliably employed to examine various assumptions underlying different models of memory.
Chapter 4. General Methods

This chapter delineates the methodology common to all five experiments. Experimental procedures specific to each study are described in the relevant method sections. All studies employed the same selection criteria for subjects, and similar experimental materials. All experimental designs were variations on a basic recognition memory exclusion paradigm similar to that employed in the process dissociation procedure (Jacoby, 1991). The ERP recording parameters were identical for Experiments 1 and 2. Adoption of a new ERP recording system following the completion of Experiment 2 meant that electrode placement differed slightly between Experiments 1 - 2 and Experiments 3 - 5. Experiments 3, 4 and 5 all employed the new ERP recording system. Data processing and data analysis also remained constant across the five studies. All experiments were approved by the joint ethics committees of the University College London and the University College London Hospitals.

Subjects

Experimental subjects were recruited from the undergraduate and postgraduate student populations of UCL. All subjects were right-handed, native English speakers, were aged between 18 and 35, and had normal (or corrected-to-normal) vision. Subjects were screened for neurotropic medication, and were remunerated at the rate of £5.00/hr (Experiments 1, 2, & 3) and £7.50/hour (Experiments 4 & 5). Subjects were also reimbursed for travelling expenses.

Materials

Stimulus lists were constructed from a pool of 560 concrete nouns ranging in frequency between 1-30 per million (Kucera & Francis, 1967) and in length between 4 and 9 letters. Experimental stimuli were presented visually as upper case white letters on a black background. Stimuli were presented centrally on a computer monitor, and subtended an approximate vertical visual angle of 0.4 degrees and a maximum horizontal visual angle of 2.0 degrees.
Experimental procedures

A basic three phase recognition memory paradigm derived from the exclusion component of the process dissociation procedure (Jacoby 1991) was employed in all five experiments, although certain aspects of this design varied between experiments. Exclusion instructions in recognition memory studies direct subjects to respond positively to old items from a specified source, and to select against old items from an alternate source. An exclusion task is typically used in conjunction with an inclusion task (in which subjects respond positively to all old items) as a method of separating estimates of the contributions of familiarity and recollection to overall recognition performance (Jacoby, 1991). The exclusion task was used in isolation in the following studies, and was manipulated in a number of different ways in order to investigate the functional characteristics of ERP correlates of recognition memory.

Subjects were fitted with an ERP recording cap (described below) prior to the experiment, and were then seated in a sound-attenuated recording booth situated approximately one metre in front of a computer monitor. It was explained that the experiment would consist of three tasks, each of which focused on a different aspect of word processing. Subjects were not informed that they were participating in a memory experiment. They were instructed to relax, to keep still, and to maintain fixation at the centre of the screen. During study phase 1, subjects were required to carry out a specified encoding task on visually presented words. Subjects were required to carry out a different encoding task on visually presented words during study phase 2. In Experiments 1-3, words presented in the two study phases were overlapping to a varying extent (i.e. 50% or 100% of study phase 2 words had been previously been presented in study phase 1). In Experiments 4-5, words presented in the two study phases were non-overlapping. During the test phase in all five experiments, subjects were presented with old items from both study phases along with new items. They were instructed to respond ‘old’ to recognised items from study phase 2, and to reject both new items and items from study phase 1.

ERP recording

Experiments 1 - 2

The EEG recording locations employed in Experiments 1 and 2 were based upon the international 10-20 system (Jasper, 1958). EEG was recorded from 25 tin electrodes
embedded in an elastic cap, with an additional electrode placed on the right mastoid (see figure 4.1). All EEG channels were referenced on-line to an electrode placed on the left mastoid electrode, and were subsequently re-referenced off-line to linked mastoids. EOG (electro-oculogram) was recorded bipolarly from one electrode placed on the outer canthus of the left eye and a second electrode placed above the supraorbital ridge of the right eye. EEG recording locations consisted of three midline sites [Fz,Pz,Cz]; left and right hemisphere sites [FP1/FP2, F3/F4,F7/F8] and additionally LF/RF (frontal, 75% of the distance between FZ and F7/F8); C3/C4, T3/T4 and additionally LT/RT (anterior temporal, 75% of the distance between CZ and T3/T4); P3/P4, T5/T6 and additionally LP/RP (parietal, 75% of the distance between PZ and T5/T6) and occipital sites [O1,O2].

Figure 4.1. Selected sites from the international 10/20 system employed in Experiment 1-2.
Experiments 3 - 5

EEG was recorded from 31 silver/silver chloride electrodes, 29 of which were embedded in an elastic cap, and 2 of which were placed on the right and left mastoids (see figure 4.2 for montage). The 31 site montage employed selected sites from the montage 10 61 channel equidistant montage (http://www.easycap.de/easycap/english/schemae.htm). Twenty-five of these sites were comparable to those employed in the 10/20 montage described for Experiments 1 and 2. An additional four sites were located over inferior lateral frontopolar and occipital regions. All channels were referenced to Fz during recording, and were subsequently re-referenced off-line to linked mastoids. Horizontal EOG was recorded bipolarly from electrodes on the outer canthus of each eye, and vertical EOG was recorded bipolarly from electrodes placed above and below the centre of the right eye.

Figure 4.2. Selected sites from the montage 10 61 channel equidistant montage employed in Experiment 3-5.
**Experiments 1 - 5**

The following EEG recording parameters remained constant across all five experiments. Online sampling was performed with a sampling interval of 6 msec per point for a total of 1,536 msec. This included a 102 msec pre-stimulus baseline period, resulting in a post-stimulus recording epoch of 1434 msec. All channels were amplified with a bandpass of 0.03 - 30Hz (3 dB roll-off).

**Data processing**

Trials on which baseline drift exceeded 54.9 microvolts at any site were rejected, as were trials containing A/D saturation. Blink artefacts were minimized by estimating and correcting the contribution of the vertical EOG channel to the ERP waveforms via a regression technique. Trials exhibiting horizontal movements and non-blink vertical eye movements were identified during visual inspection and rejected. Waveforms in all experiments were re-referenced to linked mastoids, and were digitally smoothed with a low-pass frequency of 17 Hz (roll off 3Db). Averaged ERP waveforms were formed for each of the response categories of experimental interest (defined within each experimental chapter) for each subject. Only subjects contributing a minimum of 16 artefact-free ERP trials to each of the critical response categories were included in subsequent statistical analyses both of ERP and of behavioural data. This criterion was imposed in order to achieve an adequate signal-to-noise ratio in the ERP data. A minimum of 16 subjects contributed ERP data towards the analysis of each critical response category.

**Data analyses**

Both behavioural and ERP data were analysed by repeated measures ANOVAs (with exception of Experiment 3, which employed ANOVAs of a mixed design with one between-subjects factor). The Geisser-Greenhouse correction for inhomogeneity of covariance (Greenhouse & Geisser, 1959) was implemented in all analyses. This procedure is necessitated by the fact that all data analysed does not necessarily exhibit the sphericity assumed by the ANOVA model. Sphericity is characterised as homogeneity of covariance between levels of factors. Although this issue is relevant to of all types of data, it is particularly pertinent to the analysis of ERP data. ERP analyses treat each electrode site location as a separate observation. However, the covariance shared by two geographically
close electrodes is likely to be greater than the covariance shared by two geographically
distant electrodes. ERP data can therefore easily violate the sphericity assumption. The
Geisser-Greenhouse correction procedure estimates the extent to which the sphericity
assumption has been violated, and reduces the degrees of freedom employed by the ANOVA
accordingly, thus reducing the probability of a type I error.

F ratios are reported with the corrected degrees of freedom where appropriate. Analyses were
performed on accuracy and reaction time (RT) data from all subjects contributing ERP data.
Observed interactions in the behavioural analyses were decomposed by means of targeted
Bonferroni corrected t-tests. Averaged ERP data associated with the critical response
categories were subjected to two types of analyses.

**Magnitude analyses**

Averaged ERP waveforms associated with each of the response categories of experimental
interest were contrasted in order to determine the extent to which they differed in amplitude.
Magnitude analyses were also used to investigate the scalp location/s over which ERP effects
were maximal in amplitude. ERP data were quantified by measuring the mean amplitudes
associated with the various response categories of interest within specific latency regions,
relative to the mean of the pre-stimulus baseline.

Two sets of magnitude analyses were carried out for each study. Both sets of analyses altered
slightly between Experiments 1-2 and 3-5 due to the adoption of the new electrode placement
system. One set of analyses employed a grid of distributed sites selected to permit an
assessment of which scalp locations were sensitive to the experimental manipulations. In
Experiments 1-2 these global analyses employed the factors of response category (defined
within each experiment) and three site factors (frontal/temporal/parietal location, left/right
hemisphere and inferior/mid-lateral/superior site). Global analyses in Experiments 1–2
included lateral frontal sites (F7, LF, F3, F4, RF, F8), lateral temporal sites (T3, LT, C3, C4,
RT, T4) and lateral posterior sites (T5, LP, P3, P4, RP, T6). In Experiments 3–5, global
analyses employed the factors of response category (defined within each experiment) and
three site factors (frontopolar/frontal/parietal/occipital location, left/right hemisphere and
inferior/superior site), and included lateral frontopolar (49, 50, 37, 36), lateral frontal (33, 19,
9, 22), lateral parietal (30, 29, 25, 26) and lateral occipital sites (45, 44, 41, 42) sites. A
second set of analyses were guided *a priori* by the ERP literature. Two principle ERP
old/new effects have been associated with dual-process models of recognition memory in the ERP literature; the early frontal old/new effect and the later parietal old/new effect. This literature is reviewed in full in Chapter 3. However, these effects are briefly summarised below in order to explain the rationale underlying the ERP analysis strategies adopted in the following studies. As the aim was to fractionate established ERP correlates of recognition memory and to investigate their functional characteristics, it was desirable to maximise sensitivity to the presence or absence of these effects under various experimental manipulations. Focused analyses on the sites of interest permitted a sensitivity which is often lost in more general global ERP analyses.

Data from mid-frontal sites were analysed during the 300-500 msec latency region. These analyses were guided by previous findings indicating an early frontal positivity associated with old items and familiar lures relative to new items within this latency region (Curran, 1999; Curran, 2000; Rugg et al., 1998). This effect has been linked to familiarity-based recognition memory, as it is associated with a positive recognition response rather than veridical recognition. Magnitude analyses within the 300-500 msec latency region were restricted to three mid-frontal sites in order to explore this effect. The mid-frontal sites employed in Experiments 1 and 2 were F3, Fz and F4, whereas the sites employed in Experiments 3–4 were sites 19, 8 and 9. Mid frontal analyses in all five experiments employed the factors of response category and site. Many previous studies have also reported parietal positivity associated with old relative to new items within the 500-800 msec latency region, an effect that is often left-lateralised and has been linked to recollection (Wilding & Rugg, 1996; Smith, 1993; Wilding, 2000). This ERP effect is often referred to as the 'parietal old/new effect’. Consequently, magnitude analyses carried out within the 500-800 msec latency region focused upon lateral parietal sites. In the 10/20 system employed in Experiments 1 and 2 these sites comprised T5, LP, P3, P4, RP and T6. In the montage 10 6 1 channel equidistant montage employed in Experiments 3-5 these sites consisted of sites 46, 30, 29, 26, 25 and 40. A priori analyses at parietal sites in all five experiments employed the factors of response category, hemisphere and site.

It should be noted that post-hoc analyses of ERP data are rarely corrected for multiple comparisons, and this is true of the analyses presented within this thesis. There are two principle reasons for this. Firstly, ERP analyses contain a number of electrode site location factors in addition to factors relevant to specific experimental manipulations. Post-hoc
analysis of ERP data do not therefore merely focus on interactions between factors pertaining
to experimental manipulations, but also on interactions between these and electrode site
location factors in an attempt to determine the scalp distribution of each ERP effect of
interest. As a relatively large number of post-hoc analyses are required to meet both of these
aims, correcting for multiple comparisons would result in a greater number of Type 2 errors
and might therefore be overly conservative. Secondly, ERP data is particularly susceptible to
violations of sphericity as is discussed above. Therefore, any post-hoc analysis technique
must be able to correct for these violations of sphericity. No satisfactory technique has yet
been developed which corrects for violations of sphericity and which is suitable for the post-
hoc analysis of ERP data. Although it is acknowledged that post-hoc analyses that do not
correct for multiple comparisons are unsatisfactory, they are currently necessitated by
inadequate statistical techniques. In order to protect against Type 1 errors, the majority of
ERP research relies instead on the replicability of results, and draws on previous findings in
the ERP literature both to minimise the number of post-hoc comparisons required and to
interpret the results of these comparisons. This approach is adopted throughout this thesis.

**Topographic analyses**

Where appropriate, topographic analyses were conducted in order to determine the scalp
distribution of ERP effects identified in the magnitude analyses. Topographic analyses are
employed only when one wishes to demonstrate a qualitative dissociation between an ERP
effect at a particular latency region either with a second ERP effect, or with the same ERP
effect at a different latency region. These analyses are carried out on ‘difference’ waveforms
(i.e. differences between the ERPs to the two response categories forming the contrast of
interest). A potentially problematic characteristic of ERP data is that any change in the
activity of an underlying generator has multiplicative effects on the amplitude of activity
detectable at the scalp. This characteristic is at odds with the ANOVA model, which assumes
that the same change in generator activity will produce additive effects. If an experimental
manipulation elicits a change in dipole strength, this will not produce a constant change
across electrode sites (which would result in a main effect of condition), but will produce
different changes at different electrode sites, thus resulting in a condition/site interaction.
Consequently, magnitude analyses do not dissociate qualitative differences from quantitative
differences. Topographic analyses detect qualitative differences between response contrasts
as they are performed on data rescaled to satisfy the additivity assumptions of the ANOVA (McCarthy & Wood, 1985).

The rescaling method employed in the following studies was formulated by McCarthy & Wood (1985), and calculates the amplitude of the ERP effect of interest at each electrode site relative to all other sites. The rationale underlying this form of rescaling can be understood by representing ERP data as points in multidimensional space (McCarthy & Wood, 1985). The scalp distribution of an effect is represented as a vector in N-space, with each axis reflecting the voltage at each electrode site. The shape of the distribution is a function of the vector’s orientation. The length of the vector represents the amplitude of the distribution, and is derived by calculating the square root of the sum of squared voltages over all electrode sites. The aim of rescaling is to maintain differences in shape while eliminating differences in amplitude. This is achieved by scaling the voltage at each electrode site by the vector length associated with the distribution. The scalp distribution of the effect is thus maintained while removing differences in amplitude (McCarthy & Wood, 1985). Any resulting interactions between response category and electrode site can then be cited to support the assertion that the response categories of interest reflect the activity of at least partially non-overlapping neural populations. However, the drawback of topographic analyses is that they cannot detect main effects of condition. It is therefore desirable to carry out magnitude analyses in order to identify main effects and differences in amplitude prior to conducting topographic analyses.

Spline maps are employed in each experiment to display the scalp distributions of various ERP effects. These maps show the relative size of the effect (in microvolts) over the surface of the scalp. The amplitude of each effect is known at specific points on the scalp from the recordings obtained at each electrode site. The size of the effect between these known points is estimated by a cubic spline interpolation in 2 dimensions (‘thin plate spline’). This provides a smooth interpolation between the data points by minimising the 'bending energy' of the interpolated surface. Any interpolated value takes into account information from all electrode sites (though predominantly locally), and the surface has the incidental property that maxima may occur between the original data points (as implemented in MATLAB v5.3, http://www.mathworks.com).
Chapter 5. Experiment 1: An investigation of dual-process models of recognition memory employing a shallow preexposure manipulation.

Introduction

Experiment 1 investigated dual-process models of recognition memory. The dual-process approach asserts that recognition memory is comprised of two separate processes: recollection and familiarity. Recollection is operationalised as the retrieval of spatio-temporal contextual information from the encoding episode, whereas familiarity is defined as an acontextual, fast-acting and relatively automatic method of retrieval (Mandler, 1980; Jacoby, 1991; Yonelinas & Jacoby, 1994; Jacoby, Jones, & Dolan P.O., 1998; Hintzman & Curran, 1997). Behavioural evidence as to whether these two processes differ qualitatively or quantitatively is mixed (see Chapter 1). Comparatively recently, event-related potentials (ERPs) have been employed to study recognition memory (see Chapter 3 for review). A core assumption of cognitive electrophysiology is that qualitatively distinct ERPs reflect functionally distinct cognitive processes. By obtaining ERPs associated with recollection and familiarity, one can assess whether these ERPs are qualitatively or quantitatively distinct. The former pattern of results would support the dual-process approach which states that recollection and familiarity differ in kind, whereas the latter would support single-process models which state that the two processes differ only in degree.

Although initial ERP studies of recognition memory provided little support for the dual-process approach (Smith, 1993; Wilding, Doyle, & Rugg, 1995; Wilding & Rugg, 1996; Donaldson & Rugg, 1998), researchers have more recently identified a second ERP effect associated with positive recognition responses that dissociates from the parietal old/new effect both temporally and topographically, and which is characterised by a greater positivity associated with positive recognition responses relative to correctly endorsed new words maximal in amplitude at frontal sites between 300-500 msec (Curran, 2000; Curran, 1999; Rugg et al., 1998). The finding that this early frontal positivity is elicited by both correctly identified old items and incorrectly endorsed familiar lures led to the argument that this effect reflects item familiarity in the absence of recollection (Curran, 2000). However, this interpretation is open to criticism as it assumes that lures are incorrectly endorsed on the basis of familiarity, despite the fact that evidence exists to suggest that this phenomenon can
instead occur on the basis of false recollection (Payne, Elie, Vlackwell, & Neuschatz, 1996; Roediger & McDermott, 1995). A further study reporting early frontal positivity for correctly identified old items between 300-500 msec demonstrated that the amplitude of this effect was insensitive to depth of processing at study (Rugg et al., 1998). Based on the assumption that familiarity is unaffected by depth of processing at study (Gardiner, 1988), it was again argued that this effect reflects item familiarity (Rugg et al., 1998). However, this position was weakened by evidence indicating that familiarity does in fact show sensitivity to depth of processing manipulations (Toth, 1996; Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998).

The present study took a novel approach in attempting to identify and contrast ERP correlates of familiarity and recollection. The paradigm employed in this experiment was derived from the exclusion task component of the process dissociation procedure (Jacoby, 1991). As ERP data cannot be transformed by the equations delineated in the process dissociation procedure, it was intended that unstudied items incorrectly attracting an ‘old’ response (i.e. ‘false alarms’ or ‘exclusion errors’) would provide an index of familiarity in the absence of recollection (Schacter, Norman, & Koutstaal, 1998; Endl, Walla, Lindlinger, Deecke, & Lang, 1999; Jacoby, 1991). ERPs associated with false alarms were therefore employed as a correlate of familiarity, whereas ERPs associated with ‘hits’ (i.e. correctly endorsed studied items) were employed as a correlate of recollection, although a proportion of recollected hits were also expected to be familiar in accordance with independence models of recognition memory (Jacoby, 1991). It was also anticipated that a number of hits would be made purely on the basis of familiarity in the absence of recollection. It was therefore predicted that any ERP effect elicited by false alarms would also be observed for hits. False alarms and hits were compared primarily with correctly identified unstudied items (i.e. ‘correct rejections’), and were additionally compared with each other. The aim of Experiment 1 was to ascertain whether ERP correlates of familiarity and recollection differ qualitatively or quantitatively.

A large number of false alarms were required to form an associated ERP waveform with a high signal-to-noise ratio. The experiment was therefore designed to ensure that sufficient false alarms were made at test without inducing an unduly liberal response criterion, as this would result in a large number of false alarms associated with a relatively weak level of familiarity. To this end, half of the experimental stimuli were preexposed in a shallow encoding task (study phase 1) which oriented subjects’ attention to the perceptual features of the stimuli (alphabetic ordering). Half of the items seen in study phase 1 went on to be
presented in study phase 2 with an equal number of new items. All items in study phase 2 were judged for animacy. At test, participants were required to respond ‘old’ only to words seen in study phase 2 (which shall be referred to as ‘studied items’), and to reply ‘new’ to any other word (which shall all be referred to as ‘unstudied items’, despite the fact that some of these items were presented in study phase 1). This experimental design allowed the preexposure manipulation to elevate the number of false alarms while permitting this manipulation to be controlled during analysis, as preexposed false alarms could be compared with preexposed hits and correct rejections as opposed to non-preexposed hits and correct rejections. By comparing preexposed false alarms with preexposed correct rejections and preexposed hits, conclusions could be drawn with regard to differences in the ERPs to these response categories without confounding them with preexposure. It was also possible to investigate how preexposure influences old/new effects (i.e. differences in the ERP waveforms between hits and correct rejections), as the design permitted hits and correct rejections to items presented in study phase 1 to be compared with hits and correct rejections to items not presented in study phase 1. However, it should be noted that this design did not permit subjects to adopt a retrieval strategy in which they could reject non-studied items presented in study phase 1 on the basis of recollection, as half of all studied items had also been presented in this phase.

Although it was noted in Chapter 1 that the PDF can be criticised on a number of counts, the logic underlying the PDF was adopted in this experiment for two reasons; firstly, the criticism that the PDF can lead to inaccurate estimates of the relative contributions of familiarity and recollection to recognition performance was not particularly problematic in this experiment, as the principal aim was merely to increase the number of exclusion errors (or false alarms) in order to obtain an associated ERP with a good signal-to-noise ratio. Secondly, the adoption of a relatively easy criterial question (subjects could use either temporal information or encoding task information to discriminate targets from nontargets) together with the use of a shallow encoding task in study phase 1 was intended to minimise the contamination of exclusion errors with noncriterial recollection. However, it is acknowledged that many of the assumptions underlying the PDF can be easily violated, and data pertaining to this issue shall be presented and discussed later in this thesis.
Method

Subjects
31 undergraduates participated. 14 sets of test data were discarded prior to analysis due to excessive EOG artefact, or failure to provide more than 16 artefact-free trials for one or more of the critical ERP conditions. The average age of the 17 subjects contributing data was 24 years. Eight of these subjects were male.

Stimuli and Design
The experiment employed a 2 x 2 design, in which the factor of preexposure was crossed with the factor of study history (i.e. studied/unstudied), and consisted of three phases; study phase 1, study phase 2 and test. Figure 5.1 shows the design of Experiment 1.

![Figure 5.1 Design of experiments 1 and 2. Subjects instructed to respond on key X for items presented in study phase 2, and to respond on key Y for all other items.](image)

Critical stimuli consisted of 320 visually presented concrete nouns (see Chapter 4) and 20 filler words. Study phase 1 lists consisted of 164 randomly ordered words (including two filler words at the beginning and two filler words at the midpoint of each list). Study phase 2 lists consisted of 164 randomly ordered words, half of which had been presented in study phase 1, and half of which were new. These lists included two filler words at the beginning and two filler words at the midpoint of each list. Test lists contained all 320 critical items. Two filler words were added to the beginning of each test list. Additional pairs of filler words were added after 80, 160 and 240 items in each list, as subjects were offered the opportunity to take short breaks at these points. 80 items had been presented in study phase 1
alone (new preexposed), 80 had been presented in both study phases (old preexposed), 80 had been presented in study phase 2 alone (old non-preexposed), and 80 were new words (new non-preexposed). All items were fully counterbalanced so that they appeared with equal probability across phases. The 320 critical items were split into 4 lists of 80 stimuli each; A, B, C and D. Two study phase 1 lists were created, each of which consisted of lists A + C and B + D respectively. Four study phase 2 lists were created to be used in conjunction with study phase 1 list A + C (which were comprised of lists A + B, A + D, C + B and B + D) and another four study phase 2 lists were created to be used in conjunction with study phase 1 list B + D (which were comprised of lists A + B, B + C, D + A and D + C). Two test lists were created, each of which consisted of all four lists but which were created in two differently randomised orders. Counterbalancing resulted in 16 combinations of study phase 1, study phase 2 and test lists. Each of the subjects contributing test data was presented with one of these combinations, and one combination was presented to two subjects1. An interval of around 5 minutes separated each phase of the experiment. Subjects were instructed to relax during this time.

**Procedure**

Details of the procedure common to this and other experiments are reported in Chapter 4. During study phase 1, subjects were instructed to respond with one hand if the first and last letters of each word were in alphabetical order, and with the other hand if the first and last letters were presented in the reverse order. During study phase 2, subjects were instructed to make an animacy judgement for each word, responding with one hand for animate words and with the other hand for inanimate words. The mapping between hand use and response type was fully counterbalanced in both study phases. The sequence of events in each trial during both study phases consisted of a fixation point ** that remained on the screen for 1100 msec, after which the screen was blanked for 122 msec. The stimulus was then presented for 300 msec, followed by a blank screen for 1700 msec, during which time the subject was required to make a response. In the test phase, subjects were instructed to indicate whether or not the

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1 A sample size of 16 subjects was set for this experiment, and the counterbalancing of stimuli was therefore carried out for 16 subjects. As a blink correction algorithm was developed after data collection, an additional set of data that had previously been rejected due to blink artefact was subsequently corrected and included in the analyses. For this reason, Experiment 1 contains data from 17 subjects, 2 of whom were presented with the same combination of study lists.
word had been presented in study phase 2 and how confident they were of their decision. These two decisions were made concurrently, so that a single response was required on one of four keys which corresponded with ‘confident studied’, ‘non-confident studied’, confident unstudied’ and ‘non-confident unstudied’ respectively. Subjects were also instructed to respond as quickly and as accurately as possible. The sequence of events during each trial in the test phase consisted of fixation point ‘*’ which remained on the screen for 1100 msec, after which the screen was blanked for 122 msec. The stimulus was then presented for 300 msec, after which the screen was again blanked for 2700 msec (during which time the subject was required to make a response). Responses faster than 300 msec and slower than 2700 msec were excluded.

Results

Behaviour

Table 5.1 displays the proportion of each type of behavioural response to the four classes of test item, together with their associated RTs. Mean proportions of confident and non-confident hits, correct rejections and false alarms to the 4 word categories (studied preexposed, studied non-preexposed, unstudied preexposed, unstudied non-preexposed) were subjected to a 3 x 2 x 2 ANOVA (hits/correct rejections/false alarms x preexposure x confidence) in order to clarify how preexposure affected response type and confidence. An interaction was observed between response type (hits/correct rejections/false alarms), preexposure and confidence $F (1.9, 29.6) = 9.25, p < 0.001$. Bonferroni corrected t-tests (adjusted alpha-level = .0083) indicated that whereas the proportions of confident hits, non-confident hits and non-confident correct rejections were not significantly influenced by preexposure, preexposure significantly decreased the proportion of confident correct rejections $t (16) = 6.99, p < 0.001$ and increased the proportions of both confident false alarms $t (16) = 5.41, p < 0.001$ and non-confident false alarms $t (16) = 3.56, p < 0.005$. Recognition accuracy was determined by the discrimination index $\text{pHit} - \text{pFalse Alarm}$ (Snodgrass & Corwin, 1988), with both hits and false alarms collapsed across confidence. One-sample t-tests indicated that recognition accuracy associated with preexposed items was significantly greater than zero $t (16) = 11.57, p < 0.001$, as was recognition accuracy associated with non-preexposed items $t (16) = 14.72, p < 0.001$. A paired samples t-test indicated that recognition accuracy was significantly higher for non-preexposed items (0.57) than for preexposed items (0.42) $t (16) = 4.75, p < 0.001$. 128
<table>
<thead>
<tr>
<th>Stimuli type</th>
<th>Response Category</th>
<th>Proportion (SD)</th>
<th>RT (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Old preexposed</strong></td>
<td>Total Hits</td>
<td>.84 (.11)</td>
<td>1128 (218)</td>
</tr>
<tr>
<td></td>
<td>Confident</td>
<td>.69 (.18)</td>
<td>1072 (206)</td>
</tr>
<tr>
<td></td>
<td>Non-confident</td>
<td>.15 (.12)</td>
<td>1464 (256)</td>
</tr>
<tr>
<td></td>
<td>Total Misses</td>
<td>.16 (.10)</td>
<td>1462 (296)</td>
</tr>
<tr>
<td></td>
<td>Confident</td>
<td>.06 (.05)</td>
<td>1385 (380)</td>
</tr>
<tr>
<td></td>
<td>Non-confident</td>
<td>.10 (.08)</td>
<td>1524 (327)</td>
</tr>
<tr>
<td><strong>Old non-preexposed</strong></td>
<td>Total Hits</td>
<td>.80 (.12)</td>
<td>1132 (197)</td>
</tr>
<tr>
<td></td>
<td>Confident</td>
<td>.63 (.18)</td>
<td>1098 (189)</td>
</tr>
<tr>
<td></td>
<td>Non-confident</td>
<td>.17 (.11)</td>
<td>1386 (342)</td>
</tr>
<tr>
<td></td>
<td>Total Misses</td>
<td>.18 (.12)</td>
<td>1395 (248)</td>
</tr>
<tr>
<td></td>
<td>Confident</td>
<td>.07 (.08)</td>
<td>1306 (279)</td>
</tr>
<tr>
<td></td>
<td>Non-confident</td>
<td>.11 (.09)</td>
<td>1467 (376)</td>
</tr>
<tr>
<td><strong>New preexposed</strong></td>
<td>Total Correct Rejections</td>
<td>.56 (.13)</td>
<td>1433 (219)</td>
</tr>
<tr>
<td></td>
<td>Confident</td>
<td>.28 (.14)</td>
<td>1370 (251)</td>
</tr>
<tr>
<td></td>
<td>Non-confident</td>
<td>.28 (.14)</td>
<td>1517 (214)</td>
</tr>
<tr>
<td></td>
<td>Total False alarms</td>
<td>.42 (.13)</td>
<td>1286 (188)</td>
</tr>
<tr>
<td></td>
<td>Confident</td>
<td>.24 (.13)</td>
<td>1170 (192)</td>
</tr>
<tr>
<td></td>
<td>Non-confident</td>
<td>.18 (.10)</td>
<td>1484 (249)</td>
</tr>
<tr>
<td><strong>New non-preexposed</strong></td>
<td>Total correct rejections</td>
<td>.75 (.10)</td>
<td>1386 (243)</td>
</tr>
<tr>
<td></td>
<td>Confident</td>
<td>.45 (.21)</td>
<td>1366 (258)</td>
</tr>
<tr>
<td></td>
<td>Non-confident</td>
<td>.30 (.16)</td>
<td>1480 (264)</td>
</tr>
<tr>
<td></td>
<td>Total False alarms</td>
<td>.23 (.10)</td>
<td>1366 (186)</td>
</tr>
<tr>
<td></td>
<td>Confident</td>
<td>.10 (.05)</td>
<td>1223 (229)</td>
</tr>
<tr>
<td></td>
<td>Non-confident</td>
<td>.13 (.08)</td>
<td>1538 (327)</td>
</tr>
</tbody>
</table>

| No response       | .02 (.04)         |              |          |

Table 5.1 Mean proportion of responses (standard deviations) and mean reaction times (standard deviations) for each response category at test.

RTs associated with preexposed and non-preexposed hits, correct rejections and false alarms were analysed according to whether they were made confidently or non-confidently by a repeated measures 3 x 2 x 2 ANOVA (preexposure x confidence x response category). A significant interaction was observed between response category and confidence \( F (1.6,25.8) = 10.85, p < 0.001 \). Bonferroni t-tests (adjusted alpha-level = .0166) indicated that all confident responses were associated with significantly faster RTs than non-confident responses (hits: \( t (16) = 6.97, p < 0.001 \), correct rejections: \( t (16) = 4.32, p < 0.001 \), false alarms: \( t (16) = 5.87, p < 0.001 \)). This advantage was greater for hits and false alarms (340 ms and 313 msec respectively) than for correct rejections (131 msec).
ERP Analysis Strategy

ERP waveforms were obtained for 5 response categories: preexposed and non-preexposed hits, preexposed and non-preexposed correct rejections, and preexposed false alarms. Each response category was collapsed across confidence in order to achieve sufficient numbers of trials to generate ERP waveforms of adequate signal-to-noise ratio. After collapsing across confidence, there were still insufficient numbers of trials to form an ERP waveform for non-preexposed false alarms. The mean number of trials (range) in each of the 5 response categories are presented in table 5.2.

<table>
<thead>
<tr>
<th>Response category</th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preexposed hits</td>
<td>58</td>
<td>38-74</td>
</tr>
<tr>
<td>Preexposed correct rejections</td>
<td>41</td>
<td>16-57</td>
</tr>
<tr>
<td>Non-preexposed hits</td>
<td>52</td>
<td>37-69</td>
</tr>
<tr>
<td>Non-preexposed correct rejections</td>
<td>53</td>
<td>40-72</td>
</tr>
<tr>
<td>Preexposed false alarms</td>
<td>24</td>
<td>16-65</td>
</tr>
</tbody>
</table>

Table 5.2. Average number and range of trials contributing to the ERP waveforms associated with each response category.

Waveforms associated with preexposed hits, preexposed correct rejections and preexposed false alarms are shown at lateral and midline sites in figure 5.2. Visual inspection of the waveforms indicated that both false alarms and hits elicited ERPs that were more positive going than correct rejections between 150-300 msec. The effect elicited by hits was maximal at right parietal and lateral frontal sites, whereas the effect elicited by false alarms was maximal at frontal sites only. A second phase of positivity was observed at frontal sites for both response categories between 300 - 500 msec. This effect appeared to be greatest in magnitude over the left pre-frontal site, where the effect was also more prolonged. Hits showed greater positivity than both false alarms and correct rejections over all sites from approximately 500 msec until the end of the recording epoch. This effect appeared to be largest in magnitude at mid-parietal sites between 500 and 800 msec, with a right fronto-temporal maximum from 800 msec until the end of the recording epoch. False alarms elicited a more negative-going waveform than either hits or correct rejections over mid-parietal sites from 800 msec until the end of the recording epoch. Hits were also more negative going than correct rejections at the mid-parietal site within this latency region. Waveforms associated with non-preexposed hits and correct rejections from all 25 sites are shown at lateral and midline sites in figure 5.3. Non-preexposed hits were slightly more positive going than non-preexposed correct rejections at left frontal sites between 150-300 msec. Non-preexposed hits elicited a second phase of positivity at left frontal sites between 300-500 msec. These
early effects appeared to be smaller in magnitude than the comparable effects observed for preexposed items. Between 500 and 800 msec, non-preexposed hits elicited a more positive-going waveform than non-preexposed correct rejections, maximal over left parietal sites. Non-preexposed hits showed greater positivity than non-preexposed correct rejections over right temporal sites from approximately 800 msec until the end of the recording epoch. The polarity of this effect was reversed over sites in the left hemisphere.

Figure 5.2. ERP waveforms (N=17) associated with preexposed hits, preexposed false alarms and preexposed correct rejections in Experiment 1 at midline (Fz, Cz, Pz), lateral prefrontal (Fp1, Fp2), lateral frontal (LF, RF), lateral temporal (LT, RT) and lateral posterior (LP, RP) sites.
Two sets of ANOVAs incorporating lateral frontal, temporal and parietal sites (for details, see Chapter 4) were conducted on the mean amplitudes associated with each response category within the 150-300 msec, 300-500 msec, 500-800 msec and 800-1400 msec latency regions. The first set of analyses were conducted on preexposed hits, correct rejections and false alarms in order to compare ERP correlates of familiarity and recollection, and employed the factors of response category, hemisphere, frontal/temporal /parietal location and inferior/mid-lateral/superior site. The second set of analyses were performed on preexposed and non-
preexposed hits and correct rejections in order to assess the influence of preexposure on ERP old/new effects, and employed the factors of old/new (i.e. studied/unstudied), preexposure, hemisphere, frontal/temporal/parietal location and inferior/mid-lateral/superior site. Results from these analyses are presented in tables 5.3 and 5.4 respectively. Mean amplitudes associated with preexposed and non-preexposed old/new effects (i.e. hits minus correct rejections) and preexposed false alarm/correct rejection effects (i.e. false alarms minus correct rejections) are shown at lateral frontal, lateral temporal and lateral parietal sites across each of the four latency regions in figure 5.4. Additional focused a priori analyses were conducted on data from mid-frontal sites within the 300-500 msec latency region and from lateral parietal sites within the 500-800 msec latency region (the rationale underpinning these analyses is described in Chapter 4). Analyses indicating a significant effect of response category (preexposed hits/preexposed false alarms/preexposed correct rejections) were followed up with subsidiary pairwise comparisons consisting of preexposed hits/preexposed correct rejections, preexposed false alarms/preexposed correct rejections and preexposed hits/preexposed false alarms. Analyses indicating significant interactions between the factors of preexposure and old/new were followed up with four sets of subsidiary pairwise analyses contrasting preexposed hits and preexposed correct rejections, non-preexposed hits and non-preexposed correct rejections, preexposed and non-preexposed hits, and preexposed and non-preexposed correct rejections respectively.

Topographic analyses were carried out in order to test for qualitative differences between ERP effects. These analyses were performed on difference waveforms (i.e. the differences in amplitude between ERPs associated with two response categories), in order to determine whether the scalp distribution of various old/new effects differed significantly. A repeated measures ANOVA was performed upon the preexposed hit minus preexposed correct rejection difference waveform (intended to reflect a combination of recollection and familiarity) and the preexposed false alarm minus preexposed correct rejection difference waveform (intended to reflect familiarity-based recognition) within the 300-500 msec and 500-800 msec latency regions. A second topographic analysis compared the preexposed hit minus preexposed correct rejection difference waveform and the non-preexposed hit minus non-preexposed correct rejection difference waveform within the 300-500 msec and 500-800 msec latency regions. Topographic analyses were carried out on rescaled data from all 25 sites (see Chapter 4).
<table>
<thead>
<tr>
<th></th>
<th>150-300 msec</th>
<th>300-500 msec</th>
<th>500-800 msec</th>
<th>800-1400 msec</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>-</td>
<td>F (1.8, 28.9) = 2.83, p &lt; 0.1*</td>
<td>F (1.7, 27.8) = 11.31, p &lt; 0.001</td>
<td>-</td>
</tr>
<tr>
<td>CC/AP</td>
<td>-</td>
<td>-</td>
<td>F (2.6, 42.3) = 3.55, p &lt; 0.05</td>
<td>F (2.7, 43.3) = 3.038, p &lt; 0.05</td>
</tr>
<tr>
<td>CC/HM</td>
<td>F (1.9, 28.0) = 4.68, p &lt; 0.05</td>
<td>-</td>
<td>-</td>
<td>F (1.3, 20.4) = 4.14, p &lt; 0.05</td>
</tr>
<tr>
<td>CC/ST</td>
<td>-</td>
<td>-</td>
<td>F (2.3, 36.2) = 4.09, p &lt; 0.05</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 5.3. Preexposed hits, preexposed correct rejections and preexposed false alarms at lateral frontal, temporal and posterior sites. Key: CC = response category, AP = anterior/temporal/posterior location, HM = left/right hemisphere, ST = inferior/mid-lateral/superior site. NB. Only effects involving response category are reported. * = indicates trend.

<table>
<thead>
<tr>
<th></th>
<th>150-300 msec</th>
<th>300-500 msec</th>
<th>500-800 msec</th>
<th>800-1400 msec</th>
</tr>
</thead>
<tbody>
<tr>
<td>ON</td>
<td>F (1, 15) = 8.32, p &lt; 0.05</td>
<td>F (1, 16) = 25.16, p &lt; 0.001</td>
<td>F (1, 16) = 24.78, p &lt; 0.001</td>
<td>-</td>
</tr>
<tr>
<td>ON/AP</td>
<td>-</td>
<td>-</td>
<td>F (1.3, 21.4) = 5.37, p &lt; 0.05</td>
<td>-</td>
</tr>
<tr>
<td>ON/HM</td>
<td>F (1.15) = 6.42, p &lt; 0.05</td>
<td>-</td>
<td>-</td>
<td>F (1, 16) = 5.47, p &lt; 0.05</td>
</tr>
<tr>
<td>ON/ST</td>
<td>-</td>
<td>-</td>
<td>F (1.1, 18.4) = 11.26, p &lt; 0.005</td>
<td>-</td>
</tr>
<tr>
<td>ON/AP/HM</td>
<td>F (1.4, 20.6) = 12.23, p &lt; 0.001</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PN/ON/HM</td>
<td>-</td>
<td>F (1, 16) = 8.42, p &lt; 0.01</td>
<td>F (1, 16) = 4.89, p &lt; 0.05</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 5.4. Preexposed and non-preexposed hits and correct rejections at lateral frontal, temporal and posterior sites. Key: PN = preexposed/non-preexposed, ON = old/new, AP = anterior/temporal/posterior location, HM = left/right hemisphere, ST = inferior/mid-lateral/superior site. NB. Only effects involving response category are reported.
Figure 5.4. Mean amplitudes of ERP effects at lateral anterior (LT, RT) temporal (LT, RT) and parietal (LP, RP) sites within each latency region analysed. Amplitude measures are averaged over the electrode site indicated and site immediately adjacent.
Magnitude analyses

150-300 msec:

Preexposed Hits, Correct Rejections and False Alarms

The global analysis revealed a response category x hemisphere interaction (see table 5.3). Pairwise comparison of hits and correct rejections revealed a main effect of response category $F(1, 15) = 4.65, p < 0.05$ and a response category x location x hemisphere interaction $F(1.2, 18.6) = 6.55, p < 0.05$, reflecting greater positivity for hits with a lateral frontal and right parietal maximum. No effect of response category was observed in the pairwise comparison of false alarms and correct rejections. A response category x hemisphere interaction $F(1, 15) = 9.98, p < 0.01$ observed in the pairwise comparison of hits and false alarms reflected greater positivity for hits in the right hemisphere whereas the reverse was true in the left hemisphere. Subsidiary analyses indicated that neither effect was individually significant.

Preexposure x Old/New

A main effect of old/new and an old/new x location x hemisphere interaction (see table 5.4) observed in the global analysis reflected greater positivity for hits with a right temporo-parietal maximum. This effect did not interact with preexposure.

300-500 msec:

Preexposed Hits, Correct Rejections and False Alarms

The global analysis indicated a trend towards a main effect for response category (see table 5.3). A pairwise comparison of preexposed false alarms and preexposed correct rejections revealed a response category x location interaction $F(1.5, 23.3) = 5.43, p < 0.05$, reflecting greater positivity for preexposed false alarms maximal at anterior sites (see figure 5.4). A main effect of response category $F(1, 16 = 8.29, p < 0.05$ was observed in the pairwise comparison of preexposed hits and preexposed correct rejections, indicating greater general positivity for preexposed hits. A response category x hemisphere interaction $F(1, 16) = 7.87, p < 0.05$ observed in the pairwise comparison between preexposed hits and preexposed false alarms indicated greater positivity for hits, maximal over the right hemisphere. The simple effects analysis performed on all three response categories at mid-frontal sites gave rise to a response category x site interaction $F(3.5, 55.9) = 3.87, p < 0.01$. A response category x site
interaction $F (1.9, 31) = 7.21, p < 0.005$ was also observed in the pairwise comparison of preexposed false alarms and preexposed correct rejections, indicating a left-lateralised greater positivity for preexposed false alarms. A main effect of response category $F (1, 16) = 5.41, p < 0.05$ was observed in a subsidiary analysis carried out at the left frontal site. A second pairwise comparison carried out on preexposed hits and preexposed correct rejections revealed a main effect of response category $F (1, 16) = 4.49, p < 0.05$, reflecting greater positivity for preexposed hits. No significant differences were observed between preexposed hits and preexposed false alarms at frontal sites.

Preexposure x Old/New

The global analysis gave rise to a preexposure x old/new x hemisphere interaction (see table 5.4). An old/new x hemisphere interaction $F (1, 16) = 13.11, p < 0.005$ was observed in the pairwise comparison of non-preexposed hits and non-preexposed correct rejections, indicating greater positivity for non-preexposed hits, maximal in the left hemisphere. A preexposure x hemisphere interaction $F (1, 16) = 5.93, p < 0.05$ observed in the pairwise comparison of preexposed and non-preexposed hits indicated greater positivity for preexposed hits, also maximal in the left hemisphere. No effect of preexposure was observed for correct rejections. The simple effects analysis performed on preexposed and non-preexposed hits and correct rejections at mid-frontal sites revealed a main effect of old/new $F (1, 16) = 7.10, p < 0.05$ and an interaction between old/new and site $F (1.8, 28.7) = 4.315, p < 0.05$, indicating left-lateralised positivity for hits. This effect did not interact with preexposure.

500-800 msec:

Preexposed Hits, Correct Rejections and False Alarms

The global analysis revealed both a main effect and a number of interactions involving response category (see table 5.3). A pairwise comparison of preexposed hits and preexposed correct rejections gave rise to a response category x site interaction $F (1.2, 18.8) = 5.76, p < 0.05$, reflecting greater positivity for preexposed hits maximal at superior sites. No effect of response category was observed in the analysis conducted on preexposed false alarms and preexposed correct rejections within this latency region. A response category x location interaction was observed in the comparison between preexposed hits and preexposed false alarms $F (1.4, 21.9) = 5.72, p < 0.05$, indicating greater positivity for hits maximal at
posterior sites. A main effect of response category $F(1.8, 28.6) = 8.38, p < 0.001$ and a response category x site interaction $F(2.2, 35.5) = 3.80, p < 0.05$ were observed in the simple effects analysis conducted on all three response categories at lateral parietal sites. The pairwise comparison of preexposed hits and preexposed correct rejections revealed a main effect of response category $F(1, 16) = 26.87, p < 0.001$, indicating greater positivity for hits. No effect was evident at these sites in the pairwise comparison of preexposed false alarms and preexposed correct rejections. A main effect of response category $F(1, 16) = 21.69, p < 0.001$ and a response category x site interaction $F(1.3, 21.1) = 7.89, p < 0.01$ observed in the contrast between preexposed hits and preexposed false alarms indicated greater positivity for hits with a superior maximum.

**Preexposure x Old/New**

The global analysis revealed a preexposure x old/new x hemisphere interaction, as well as a main effect and a number of other interactions involving the factor of old/new (see table 5.4). An old/new x location interaction $F(1.5, 23.5) = 8.07, p < 0.005$ observed in the pairwise comparison of non-preexposed hits and non-preexposed correct rejections reflected greater positivity for non-preexposed hits maximal at parietal sites. No effect of preexposure was observed either in the paired comparison of preexposed and non-preexposed hits, or in the paired comparison of preexposed and non-preexposed correct rejections. The simple effects analysis performed on data from lateral parietal sites gave rise to a preexposure x old/new x hemisphere interaction $F(1.4, 22.3) = 7.68, p < 0.05$. Pairwise comparison of non-preexposed hits and non-preexposed correct rejections revealed an old/new x hemisphere interaction $F(1, 16) = 9.89, p < 0.01$, reflecting greater positivity for non-preexposed hits maximal at left parietal sites. A main effect of old/new $F(1, 16) = 29.22, p < 0.001$ and an old/new x site interaction $F(1.5, 24.6) = 7.23, p < 0.01$ were observed in a subsidiary analysis performed on non-preexposed hits and correct rejections at left parietal sites, reflecting greater positivity for non-preexposed hits maximal at the superior left parietal site (P3). No effect of preexposure was observed for either hits or correct rejections.

800-1400ms:

**Preexposed Hits, Correct Rejections and False Alarms**

Response category x location and response category x hemisphere interactions were evident in the global analysis (see table 5.3). Pairwise comparison of preexposed hits and preexposed hits and preexposed correct rejections.
correct rejections revealed a response category x hemisphere interaction $F (1, 16) = 6.57, p < 0.05$, reflecting greater positivity for preexposed hits over right hemisphere sites. Main effects of hemisphere was observed in subsidiary analyses conducted on preexposed hits $F (1, 16) = 38.67, p < 0.001$ and correct rejections $F (1, 16) = 10.79, p < 0.005$, reflecting greater positivity for both response categories in the right hemisphere than in the left, although the magnitude of this hemispheric asymmetry was greater for hits than for correct rejections (2.43 μν and 1.38 μν respectively). The old/new effect was not significant in either hemisphere. A response category x location interaction observed in the pairwise comparison of preexposed false alarms and preexposed correct rejections $F (1.8, 28.4) = 4.97, p < 0.05$ reflected greater negativity for preexposed false alarms over parietal sites and greater positivity for preexposed false alarms over anterior sites, although subsidiary analyses revealed that neither the effect over frontal sites nor the effect over parietal sites were individually significant. A response category x hemisphere interaction $F (1, 16) = 16.55, p < 0.001$ was observed in the contrast between preexposed hits and preexposed false alarms. A main effect of hemisphere observed in a subsidiary analysis conducted on preexposed false alarms $F (1, 16) = 12.00, p < 0.005$ indicated that this response category elicited significantly greater positivity in the right hemisphere than in the left hemisphere, although again this asymmetry was smaller in magnitude than that associated with hits (1.50 μν and 2.43 μν respectively).

Preexposure x Old/New

An old/new x hemisphere interaction observed in the global analysis (see table 5.4) reflected greater positivity for hits than correct rejections over the right hemisphere, whereas the reverse was true over the left hemisphere. Subsidiary analyses indicated that neither the old/new effect over the left hemisphere nor that over the right hemisphere were individually significant.

Topographic analyses

The topographic analyses performed on preexposed false alarms minus preexposed correct rejections and preexposed hits minus preexposed correct rejections revealed no significant effect of response category within the 300-500 msec latency region. The same analysis conducted within the 500-800 msec latency region gave rise to a response category x site
interaction $E(2.9, 46.2) = 3.46, p < 0.05$. This interaction reflected the finding that while the hit/correct rejection effect was maximal at mid-temporo-parietal sites, the false alarm/correct rejection effect was maximal over frontopolar sites (see figure 5.5). No significant differences were observed between preexposed and non-preexposed old/new effects either within the 300-500 msec latency region or within the 500-800 msec latency region.

Figure 5.5 Voltage maps showing the scalp distributions of: Figure 5.5.1 Preexposed hits minus preexposed CRs between 300-500 msec. Figure 5.5.2 Preexposed FAs minus preexposed CRs between 300-500 msec. Figure 5.5.3 Preexposed hits minus preexposed CRs between 500-800 msec. Figure 5.5.4 Preexposed FAs minus preexposed CRs between 500-800 msec.
Discussion

Behavioural data

Recognition accuracy was significantly higher for non-preexposed items (.57) than for preexposed items (.42). This was due to the fact that preexposure significantly increased the proportions of both confident and non-confident false alarms (or ‘exclusion errors’). The fact that recollection of source information from study phase 1 could not be used to exclude preexposed unstudied items (as studied items had also been presented in study phase 1) may have led to a greater reliance on familiarity at test. It is therefore argued that false alarms in Experiment 1 resulted primarily from a misattribution of familiarity-based recognition to study phase 2, and that the higher false alarm rate observed for preexposed unstudied items relative to non-preexposed unstudied items reflects enhanced familiarity engendered by the preexposure manipulation. Familiarity may have occurred in the absence of recollection, or may have been accompanied by ‘noncriterial recollection’ (Yonelinas & Jacoby, 1996). Preexposure also significantly decreased the proportion of confident correct rejections, possibly by enhancing the familiarity associated with these items to a level close to the response criterion. Item familiarity exceeding that specified by the response criterion appears to have been attributed to study phase 2 (i.e. false alarms).

Functional interpretation of ERP data

Very early effects

Hits elicited greater positivity than correct rejections between 150-300 msec. This effect was maximal at lateral frontal and right temporo-parietal sites and did not interact with preexposure, although the effect elicited by non-preexposed hits appeared to be considerably smaller than that elicited by preexposed hits (see figures 5.2 and 5.3). Although preexposed false alarms also appeared to elicit greater positivity than preexposed correct rejections at frontal sites within this latency region, this effect did not reach significance. It is unclear what the functional significance of this effect may be, or whether or not two effects (i.e. one with a frontopolar maximum and one with a right temporo-parietal maximum) occurred within the same latency region. Few recognition memory studies have reported ERP effects that onset so early in time. One previous study investigating the effects of context of ERP correlates of recognition memory reported positivity at frontopolar sites for all types of old response relative to correct rejections, and hypothesised that this may either be some kind of priming effect or an effect reflecting processing that contributes to familiarity-based
recognition (Tsivilis, Otten, & Rugg, 2001). The present findings are more consistent with
the latter interpretation, as a priming effect would arguably have also been observed for
preexposed correct rejections. The fact that this effect was only observed for items that were
explicitly recognised (i.e. that attracted a ‘studied’ response) suggests that it may indeed
reflect the operation of processing contributing to familiarity-based recognition, as familiarity
is conceptualised as an explicit form of memory.

**Early frontal positivity**

Preexposed false alarms elicited greater positivity than correct rejections between 300-500
msec. It is argued above that false alarms were made largely on the basis of familiarity-based
recognition as described by signal detection models (Yonelinas, Dobbins, Szymanski, &
King, 1996). Accordingly, it is argued that the frontal positivity associated with false alarms
between 300-500 msec reflects item familiarity. The temporal characteristics of this effect
support arguments that familiarity-based recognition occurs prior to recollection-based
recognition (Yonelinas & Jacoby, 1994), as it preceded the parietal positivity associated with
recollection. However, on the basis of results from both this and previous studies, it cannot
be ruled out that this effect merely reflects a positive recognition response. Although early
frontal positivity has previously been reported as a correlate of item familiarity (Rugg et al.,
1998; Curran, 1999; Curran, 2000), the effect observed in the present study appeared to be
maximal at the left frontopolar site (see figure 5.5) as opposed to the mid-frontal maximum
reported in some of these earlier studies. It is unclear why this should be the case. One
possibility is that the effect observed in the present study and the effect reported previously
do not reflect the same cognitive process, but rather reflect different processes associated
with familiarity. Alternatively, the effect observed for false alarms in the present study may
reflect the true distribution of the ERP correlate of item familiarity, but this may have been
distorted in previous studies when eliciting items also elicited parietal positivity, as these two
effects overlap temporally. This appeared to occur for preexposed hits in the present study
(see below). Indeed, items eliciting mid-frontal positivity also elicited left parietal positivity
in two of these previous studies (Rugg et al., 1998; Curran, 1999), and the one study
observing early frontal positivity for items that elicited minimal parietal positivity reported a
more prolonged frontal effect with a left lateralised distribution, similar (but less anterior) to
that seen in the present study (Curran, 2000).
Positivity was also observed for hits relative to correct rejections at frontal sites during the 300-500 latency region, although this effect was not maximal at frontal sites. The more diffuse distribution of positivity observed for preexposed hits may have resulted from the onset of a parietal positivity at approximately 400 msec, an effect that was not present for preexposed false alarms. The fact that preexposed hits showed a left frontopolar distribution between 300-400 msec similar to that observed for false alarms between 300-500 msec (see figure 5.6) supports this argument. The effect observed for hits at mid-frontal sites between 300-500 msec did not significantly interact with preexposure. However, visual inspection of the waveforms suggested that this effect was larger in magnitude for preexposed than for non-preexposed items, possibly because preexposed items were associated with a higher level of familiarity than non-preexposed items. These data are consistent with independent dual-process models of recognition that state that familiarity is a signal-detection as opposed to a threshold process (Yonelinas, Dobbins, Szymanski, & King, 1996), and that a proportion of recollected items are also familiar (Jacoby, 1991).

Figure 5.6. Voltage map showing the distribution of the preexposed hit minus preexposed correct rejection effect between 300-400 msec

It is interesting to note that preexposed correct rejections did not show early frontal positivity when compared with non-preexposed correct rejections, despite the fact that these items had been presented under identical study and test conditions as preexposed false alarms. If early frontal positivity is a correlate of item familiarity, this finding suggests that the familiarity associated with preexposed correct rejections was too low either to manifest itself in the
associated ERPs or to produce false positive responses (being below the response criterion adopted for ‘old’ responses made on the basis of familiarity). A proportion of preexposed correct rejections are also likely to have been rejected in the absence of recognition (i.e. forgotten), thus weakening any familiarity signal present in the ERPs to this response category.

Parietal old/new effect

Both preexposed and non-preexposed hits elicited parietal old/new effects relative to preexposed and non-preexposed correct rejections respectively, which onset at around 400 msec and had a duration of approximately 400 msec. Parietal positivity within this latency region is currently thought to reflect recollection (see for reviews Rugg & Allan, 2000; Friedman & Johnson, 2000). Although it is possible that subjects responded accurately to studied items purely on the basis of familiarity, it is likely that source information was recovered from study phase 2 for the majority of hits, as these items were studied in a conceptual encoding task which typically result in high levels of recollection (Gardiner, 1988). Therefore, the presence of a parietal old/new effect for both types of hits is consistent with the notion that this effect reflects recollection-based recognition memory. The fact that the parietal old/new effect was not detected for false alarms is also consistent with the view that this effect is a correlate of recollection as opposed to familiarity, as these items are argued to have been recognised in the absence of recollection. It was interesting to note that preexposed correct rejections did not elicit a parietal old/new effect relative to non-preexposed correct rejections, as it has been argued that correctly excluded old items are generally excluded on the basis of recollection (Jacoby, 1991). However, as the encoding task employed in study phase 1 was shallow in nature, it is likely that a large proportion of these items were not actually recollected, and were instead rejected in the absence of either recollection or sufficient familiarity.

Significantly, a qualitative difference was demonstrated between the effect observed between preexposed false alarms minus preexposed correct rejections and the effect observed between preexposed hits minus preexposed correct rejections during the 500-800 msec latency, as false alarms elicited no parietal old/new effect relative to preexposed correct rejections within this latency region. This finding supports dual-process models of recognition memory that assert that familiarity and recollection are independent processes (Jacoby, 1991), as opposed to single-process models that argue that familiarity and recollection reflect different points.
along a single continuum of trace strength (Donaldson, 1996; Inoue & Bellezza, 1998). However, as argued in Chapter 3, the absence of a parietal old/new effect for preexposed false alarms could also theoretically be accounted for by single process models if it is assumed that retrieved information associated with preexposed false alarms was simply too weak to elicit an observable parietal old/new effect. Such an interpretation would draw from the fact that a null effect does not necessarily indicate that the response category of interest is not eliciting neural activity, as this activity may simply be too weak to be detected at the scalp. However, the finding that the amplitudes of the early frontal effects associated with preexposed hits and preexposed false alarms did not differ can be cited as evidence against this interpretation, as a single-process account of data pertaining to the parietal old/new effect would arguably imply that the early frontal effect should also be smaller for preexposed false alarms than for preexposed hits.

A significant interaction between old/new and preexposure in the magnitude analysis between 500-800 msec indicated that the preexposed and non-preexposed old/new effects differed significantly within this latency region. The old/new effect seen for preexposed items appeared to be larger in amplitude than that seen for non-preexposed items, and had a central-temporal maximum whereas the latter had a left parietal maximum (see figure 5.3). However, the two old/new effects did not differ significantly in the topographical analysis, suggesting that the differences indicated in the magnitude analysis were quantitative rather than qualitative. The larger parietal effect observed for preexposed items may reflect recollection of noncriterial information in addition to criterial recollection, as previous studies have suggested that the amplitude of the left parietal effect is positively correlated with the amount or quality of recollected information (Allan, Wilding, & Rugg, 1998; Wilding, 2000). However, this is inconsistent with the argument that study phase 1 led to an increase in familiarity rather than recollection, and with the finding that no parietal effect was observed for preexposed false alarms. It is also possible that the scalp distributions associated with the two old/new effects were influenced by the confidence with which participants made their responses. A greater proportion of preexposed correct rejections were made non-confidently than non-preexposed correct rejections (.60 and .50 respectively). Subsequent analysis of confident and non-confident correct rejections (collapsed over preexposure in order to obtain sufficient trials) indicated via an interaction between confidence, location and hemisphere $F$ (1.5, 26.1) = 4.07, $p < 0.05$ that non-confident correct rejections were more negative going than confident correct rejections over all regions except at left parietal sites (see figure 5.7).
Therefore, the larger and more lateralised parietal distribution observed for the preexposed old/new effect compared with the non-preexposed equivalent may have occurred because the lower levels of confidence associated with preexposed correct rejections resulted in a baseline with a different scalp distribution to that associated with non-preexposed correct rejections. However, this interpretation is arguably inconsistent with the finding that preexposed and non-preexposed correct rejections did not differ significantly within this latency region.

![Figure 5.7](image)

**Figure 5.7** Mean amplitudes of confident correct rejections minus non-confident correct rejections at lateral anterior, lateral temporal and lateral parietal sites within the 500-800 msec latency region.

### Concluding remarks

To summarise, it was found that a preexposure manipulation significantly elevated the number of false alarms made in a recognition memory task, and decreased the proportion of confident correct rejections. It is argued that the increased false alarm rate reflected an elevated level of familiarity for preexposed items. ERP effects associated with familiarity (false alarms minus correct rejections) and recollection *and* familiarity (hits minus correct rejections) were characterised by an early frontal distribution (300-500 msec), while recollection alone was associated with a later parietal distribution (500-800 msec). It was demonstrated that the ERP effects associated with familiarity and recollection differed qualitatively rather than quantitatively between 500-800 msec, in that they reflected distinct patterns of neural activity. This is consistent with dual-process models of recognition memory which state that recollection and familiarity operate as independent processes, rather than as differing points along a continuum of memory trace strength.

Introduction

The aim of Experiment 2 was to investigate in what way preexposure of experimental items in a deep encoding task influences behavioural and ERP measures of recognition memory at test, and how these measures differ from those reported in Experiment 1 when the preexposure task was shallow. Experiment 2 therefore employed the same experimental design as that described for Experiment 1, with the exception that the shallow encoding task used in study phase 1 was replaced with a deep encoding task (i.e. sentence generation). In accordance with the view that deeper processing leads to an increase in both familiarity and recollection-based recognition memory (e.g. Yonelinas & Jacoby, 1995; Toth, 1996; Wagner, Gabrieli, & Verfaellie, 1997), it was predicted that replacing the shallow encoding task employed during study phase 1 in Experiment 1 with a deep encoding task in Experiment 2 would increase overall levels of familiarity as well as increasing noncriterial recollection.

It was therefore predicted that a greater proportion of preexposed unstudied items would be familiar in Experiment 2 than in Experiment 1, and that a greater number of preexposed unstudied items would also be associated with noncriterial recollection. However, noncriterial recollection would not allow subjects to reject these items, as half of all studied items had also been presented in study phase 1. The preexposed false alarm rate should therefore be higher in Experiment 2 than in Experiment 1, as the increase in familiarity thought to occur following deep encoding tasks relative to shallow encoding tasks could not be successfully opposed by using noncriterial recollection. ERPs associated with preexposed false alarms in Experiment 2 should subsequently show both the early frontal effect observed for these items in Experiment 1 and the parietal old/new effect indicative of recollection. Similarly, it was predicted that preexposed correct rejections in Experiment 2 would be associated with a greater degree of noncriterial recollection than in Experiment 1, and that ERPs associated with this response category would therefore also show a parietal old/new effect. It was not clear whether or not preexposed correct rejections would also elicit the early frontal effect hypothesised to reflect item familiarity; although a greater proportion of
preexposed unstudied words should elicit familiarity-based recognition in Experiment 2 than in Experiment 1, those eliciting familiarity exceeding that specified by the response criterion may be misattributed to study phase 1 and manifest themselves instead as false alarms. It may therefore be the case that familiarity associated with preexposed correct rejections will be below that specified by the response criterion, and will consequently be too low to be observed in ERPs to these items. This appeared to be the case in Experiment 1.

Method

Subjects

27 subjects participated. 11 sets of test data were rejected due to failure to provide more than 16 artefact-free trials for one or more of the ERP response categories of interest. The mean age of the 16 subjects contributing data was 22 years (range: 19 – 26). Ten of these subjects were male.

Stimuli and Procedure

The design of Experiment 2 replicated the three-phase design used in Experiment 1 (study phase 1/study phase 2/test). The stimulus lists employed in all three phases were identical to those described for Experiment 1. The method employed during study phase 2 and the test phase was also identical to those described for Experiment 1. During study phase 1, subjects were instructed to generate a sentence in response to each item, and to include the item in the sentence. Subjects responded verbally during this task. The sequence of events during study phase 1 consisted of a fixation point ‘*’ that was presented for 1100 msec, followed by a blanked screen of 122 msec duration, and a stimulus that remained on the screen for 300 msec. Trials were experimenter controlled; a trial was initiated by mouse click once a verbal response had been made to the previous stimulus by the subject. No time constraint was imposed during sentence generation, but subjects were encouraged to keep sentences short and simple, and to respond as quickly as possible. As in Experiment 1, an interval of approximately five minutes separated each experimental phase, during which time subjects were instructed to relax.
Results

**Behaviour**

The proportions of each type of behavioural response to the four classes of test item are displayed in table 6.1, together with the associated RTs.

<table>
<thead>
<tr>
<th>Stimuli type</th>
<th>Response Category</th>
<th>Proportion(SD)</th>
<th>RT (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Old preexposed</strong></td>
<td>Total Hits</td>
<td>.73 (.11)</td>
<td>1376 (217)</td>
</tr>
<tr>
<td></td>
<td>Confident Hits</td>
<td>.52 (.15)</td>
<td>1300 (200)</td>
</tr>
<tr>
<td></td>
<td>Non-confident Hits</td>
<td>.21 (.12)</td>
<td>1624 (288)</td>
</tr>
<tr>
<td></td>
<td>Total Misses</td>
<td>.26 (.11)</td>
<td>1589 (267)</td>
</tr>
<tr>
<td></td>
<td>Confident Misses</td>
<td>.14 (.10)</td>
<td>1575 (366)</td>
</tr>
<tr>
<td></td>
<td>Non-confident Misses</td>
<td>.14 (.07)</td>
<td>1651 (282)</td>
</tr>
<tr>
<td><strong>Old non-preexposed</strong></td>
<td>Total Hit</td>
<td>.62 (.12)</td>
<td>1405 (224)</td>
</tr>
<tr>
<td></td>
<td>Confident Hits</td>
<td>.42 (.12)</td>
<td>1308 (193)</td>
</tr>
<tr>
<td></td>
<td>Non-confident Hits</td>
<td>.20 (.10)</td>
<td>1627 (275)</td>
</tr>
<tr>
<td></td>
<td>Total Misses</td>
<td>.37 (.12)</td>
<td>1439 (309)</td>
</tr>
<tr>
<td></td>
<td>Confident Misses</td>
<td>.24 (.14)</td>
<td>1281 (476)</td>
</tr>
<tr>
<td></td>
<td>Non-confident Misses</td>
<td>.15 (.08)</td>
<td>1638 (270)</td>
</tr>
<tr>
<td><strong>New preexposed</strong></td>
<td>Total Correct Rejections</td>
<td>.60 (.13)</td>
<td>1577 (275)</td>
</tr>
<tr>
<td></td>
<td>Confident Correct Rejections</td>
<td>.30 (.15)</td>
<td>1499 (304)</td>
</tr>
<tr>
<td></td>
<td>Non-confident Correct Rejections</td>
<td>.30 (.15)</td>
<td>1715 (242)</td>
</tr>
<tr>
<td></td>
<td>Total False Alarms</td>
<td>.38 (.12)</td>
<td>1509 (234)</td>
</tr>
<tr>
<td></td>
<td>Confident False Alarms</td>
<td>.22 (.11)</td>
<td>1388 (266)</td>
</tr>
<tr>
<td></td>
<td>Non-confident False Alarms</td>
<td>.16 (.08)</td>
<td>1652 (222)</td>
</tr>
<tr>
<td><strong>New non-preexposed</strong></td>
<td>Total Correct Rejections</td>
<td>.85 (.14)</td>
<td>1309 (259)</td>
</tr>
<tr>
<td></td>
<td>Confident Correct Rejections</td>
<td>.66 (.21)</td>
<td>1263 (268)</td>
</tr>
<tr>
<td></td>
<td>Non-confident Correct Rejections</td>
<td>.20 (.15)</td>
<td>1569 (256)</td>
</tr>
<tr>
<td></td>
<td>Total False Alarms</td>
<td>.14 (.13)</td>
<td>1630 (288)</td>
</tr>
<tr>
<td></td>
<td>Confident False Alarms</td>
<td>.05 (.06)</td>
<td>1445 (270)</td>
</tr>
<tr>
<td></td>
<td>Non-confident False Alarms</td>
<td>.08 (.06)</td>
<td>1680 (355)</td>
</tr>
<tr>
<td><strong>No response</strong></td>
<td></td>
<td>.01 (.01)</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.1. Mean proportion of responses (standard deviations) and mean reaction times (standard deviations) for each response category at test.

A 3 x 2 x 2 (response category x preexposure x confidence) repeated measures analysis of variance was performed on the mean proportions of confident and non-confident hits, correct rejections and false alarms to the four word categories (old preexposed, old non-preexposed, new preexposed, new non-preexposed). A significant 3-way interaction was observed
between response category x preexposure x confidence $F(1.2, 18.6) = 29.97, \ p < 0.001$.
Bonferroni corrected t-tests (adjusted alpha-level = .0083) indicated that preexposure increased the proportions of confident hits $t(15) = 3.97, \ p < 0.001$, confident false alarms $t(15) = 6.55, \ p < 0.001$ and nonconfident false alarms $t(15) = 3.12, \ p < 0.01$, significantly decreased the proportion of confident correct rejections $t(15) = 6.73, \ p < 0.001$, and did not influence either non-confident hits or non-confident correct rejections. Discrimination of preexposed old items from preexposed new items was significantly greater than zero $t(15) = 10.21, \ p < 0.001$, as was discrimination of non-preexposed old items from non-preexposed new items $t(15) = 13.24, \ p < 0.001$. A paired samples t-test indicated that recognition accuracy (i.e. hits minus false alarms) was significantly higher for non-preexposed items (0.48) than for preexposed items (0.33) $t(15) = 5.61, \ p < 0.001$. A 3 x 2 x 2 repeated measures ANOVA (response category x preexposure x confidence) carried out on RTs associated with preexposed and non-preexposed hits, correct rejections and false alarms associated with confident and non-confident responses revealed a significant response category x preexposure interaction $F(2.0,29.6) = 26.67, \ p < 0.001$. Bonferroni corrected t-tests (adjusted alpha = .0167) indicated that whereas preexposure significantly increased RTs associated with correct rejections $t(15) = 7.31, \ p < 0.001$, RTs to hits and false alarms were not influenced by this manipulation.

**ERP analysis strategy**

ERP waveforms were obtained for preexposed and non-preexposed hits, preexposed and non-preexposed correct rejections, and preexposed false alarms. An insufficient number of non-preexposed false alarms meant that an ERP data associated with this response category could not be analysed. All response categories were collapsed across confidence in order to form ERPs with an adequate signal-to-noise ratio. The mean number of trials (range) for each response category are displayed in table 6.2.

<table>
<thead>
<tr>
<th>Response category</th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preexposed hits</td>
<td>58</td>
<td>38-74</td>
</tr>
<tr>
<td>Preexposed correct rejections</td>
<td>41</td>
<td>16-57</td>
</tr>
<tr>
<td>Non-preexposed hits</td>
<td>52</td>
<td>37-69</td>
</tr>
<tr>
<td>Non-preexposed correct rejections</td>
<td>53</td>
<td>40-72</td>
</tr>
<tr>
<td>Preexposed false alarms</td>
<td>24</td>
<td>16-55</td>
</tr>
</tbody>
</table>

Table 6.2. Average number and range of trials contributing to the ERPs associated with each response category.

150
Waveforms (averaged across all 16 subjects) associated with preexposed hits, preexposed false alarms and preexposed correct rejections are shown at lateral and midline sites in figure 6.1.

Preexposed hits became more positive going than either preexposed false alarms or preexposed correct rejections at frontal sites at approximately 150 msec. Both preexposed hits and preexposed false alarms were more positive going than preexposed correct rejections at all sites between 300-500 msec, although this positivity onset earlier (approximately 150 msec) at parietal sites. A second phase of positivity was observed for both preexposed hits
and preexposed false alarms relative to preexposed correct rejections, maximal at mid-
parietal sites and onsetting at approximately 500 msec. The positivity observed for
preexposed false alarms was sustained until 800 msec, whereas the positivity observed for
preexposed hits was sustained until approximately 900 msec. Preexposed hits and
preexposed false alarms appeared to become more negative going than preexposed correct
rejections at left frontal and temporal sites towards the end of the recording epoch.

Figure 6.2. ERP waveforms (N=16) associated with non-preexposed hits and non-preexposed correct rejections in
Experiment 2 at midline (Fz, Cz, Pz), lateral prefrontal (Fp1, Fp2), lateral frontal (LF, RF), lateral temporal (LT, RT)
and lateral posterior (LP, RP) sites.

Waveforms (averaged across all 16 subjects) associated with non-preexposed hits and non-
preexposed correct rejections are shown at lateral and midline sites in figure 6.2. Non-
preexposed hits appeared to be more positive going than non-preexposed correct rejections at sites in the left hemisphere between 300-500 msec, and over left and central temporo-parietal sites from 500 msec until 650 msec. Both these effects were relatively small in amplitude. At 650 msec, non-preexposed hits became more negative going than non-preexposed correct rejections over mid parietal and right parietal sites. This negativity was sustained until the end of the recording epoch. Non-preexposed hits were more positive going than non-preexposed correct rejections over frontal sites from 800 msec. This positivity persisted at mid frontal and right frontal sites until the end of the recording epoch.

Two sets of global ANOVAs were performed on data from lateral frontal, temporal and parietal sites within the 150-300, 300-500, 500-800 and 800-1400 msec latency regions (see Chapter 4 for specific sites). One set of analyses were performed on preexposed hits, preexposed false alarms and preexposed correct rejections, and employed the factors of response category, hemisphere, frontal/temporal /parietal location and inferior/mid-lateral/superior site. The second set of analyses were performed on preexposed and non-preexposed hits and correct rejections, and employed the factors of old/new (i.e. studied/unstudied), preexposure, hemisphere, frontal/temporal/parietal location and inferior/mid-lateral/superior site. Results from these analyses are presented in tables 6.3 and 6.4 respectively. Mean amplitudes associated with preexposed and non-preexposed old/new effects and with preexposed false alarm/preexposed correct rejection effects are shown at lateral frontal, temporal and parietal sites for each of the four latency regions in figure 6.3. A priori analyses were conducted on these two data sets at mid-frontal sites within the 300-500 msec latency region and at lateral parietal sites within the 500-800 msec latency region. An additional analysis was conducted on non-preexposed hits and non-preexposed correct rejections at left parietal sites between 500-650 msec in order to investigate the small positivity observed for hits with maximum sensitivity. Analyses indicating a significant effect of response category (preexposed hits/false alarms/correct rejections) were followed up with three subsidiary pairwise comparisons consisting of false alarms/correct rejections, hits/false alarms and hits/correct rejections. Analyses indicating interactions between the factors of preexposure and old/new were followed up with four subsidiary pairwise comparisons consisting of preexposed hits/preexposed correct rejections, non-preexposed hits/non-preexposed correct rejections, preexposed hits/non-preexposed hits and preexposed correct rejections/non-preexposed correct rejections. Topographic analyses were performed
Table 6.3. Preexposed hits, preexposed correct rejections and preexposed false alarms at lateral frontal, temporal and posterior sites. Key: CC = response category, AP = anterior/temporal/posterior location, HM = left/right hemisphere, ST = inferior/mid-lateral/superior site. NB. Only effects involving response category are reported. * = indicates trend.

Table 6.4. Preexposed and non-preexposed hits and correct rejections at lateral frontal, temporal and posterior sites. Key: PN = preexposed/non-preexposed, ON = old/new, AP = anterior/temporal/posterior location, HM = left/right hemisphere, ST = inferior/mid-lateral/superior site. NB. Only effects involving response category are reported.
Figure 6.3 Mean amplitudes of ERP effects at left and right anterior (LF, RF) temporal (LT, RT) and parietal (LP, RP) sites within each latency region analysed. Amplitude measures are averaged over the electrode site indicated and site immediately adjacent.
on preexposed hit minus preexposed correct rejection data and preexposed false alarm minus preexposed correct rejection data within the 300-500 msec and 500-800 msec latency regions in order to determine whether the effects associated with these contrasts differed qualitatively or not.

Magnitude analyses
150-300 msec

Preexposed Hits, Correct Rejections and False Alarms

The global analysis within this latency region revealed a main effect of response category (see table 6.3). Pairwise comparison of preexposed hits and correct rejections gave rise to a main effect of old/new $F(1, 15) = 4.03, p < 0.005$ and an old/new x site interaction $F(1.1, 16.5) = 7.76, p < 0.05$, reflecting greater positivity for hits maximal at superior sites. Pairwise comparison of preexposed false alarms and preexposed correct rejections gave rise to a main effect of response category $F(1, 15) = 5.71, p < 0.05$, reflecting greater positivity for false alarms. No effect of response category was observed in the pairwise comparison of preexposed hits and preexposed false alarms.

Preexposure x Old/New

A main effect of old/new and a number of interactions involving the factors of old/new and preexposure were observed in the global analysis (see table 6.4). Pairwise comparison of non-preexposed hits and non-preexposed correct rejections gave rise to an old/new x hemisphere x site interaction $F(1.6, 24.5) = 3.86, p < 0.05$, reflecting a small negativity for hits at all sites except at right inferior sites where the reverse was true. Subsidiary analyses indicated that neither effect was individually significant. Pairwise comparison of preexposed and non-preexposed hits revealed a preexposure x location x hemisphere interaction $F(1.3, 20.0) = 5.54, p < 0.05$, indicating greater positivity for preexposed hits at all sites, maximal at left frontal sites. Pairwise comparison of preexposed and non-preexposed correct rejections revealed a preexposure x hemisphere interaction $F(1, 15) = 10.43, p < 0.01$, reflecting greater positivity for non-preexposed correct rejections, maximal in the right hemisphere. A subsidiary analysis indicated that the preexposure effect at right hemisphere sites was significant $F(1, 15) = 7.46, p < 0.05$. 

156
300-500 msec

**Preexposed Hits, Correct Rejections and False Alarms**

The global analysis revealed a main effect of response category and a response category x site interaction (see table 6.3). A main effect of response category observed in the pairwise comparison of false alarms and correct rejections $F(1, 15) = 11.79, p < 0.005$ indicated greater positivity for false alarms. Pairwise comparison of hits and correct rejections revealed a main effect of response category $F(1, 15) = 22.43, p < 0.001$ and a response category x site interaction $F(1.3, 19.1) = 9.53, p < 0.005$, indicating greater positivity for hits maximal at superior sites. No effect of response category was observed in the comparison of hits and false alarms. The analysis conducted at mid-frontal sites gave rise to a main effect of response category $F(1.9, 28.4) = 6.17, p < 0.01$. A response category x site interaction observed in the pairwise comparison of false alarms and correct rejections $F(1.9, 29.1) = 3.98, p < 0.05$ reflected greater positivity for false alarms maximal at Fz. The effect at this site was significant $F(1, 15) = 4.27, p = 0.05$. A main effect of response category $F(1, 15) = 15.18, p < 0.001$ observed in the pairwise comparison of hits and correct rejections indicated greater positivity for hits. No effect of response category was observed in the comparison of hits and false alarms.

**Preexposure x Old/New**

A main effect of old/new, and old/new x site and preexposure x old/new interactions were observed in the global analysis (see table 6.4). No significant effect of old/new was observed in the pairwise comparison of non-preexposed hits and non-preexposed correct rejections. A main effect of preexposure was observed in the comparison between preexposed and non-preexposed hits $F(1, 15) = 5.93, p < 0.05$, indicating greater positivity for preexposed hits. The pairwise comparison of preexposed and non-preexposed correct rejections gave rise to a preexposure x hemisphere interaction $F(1, 15) = 27.39, p < 0.001$, which reflected greater positivity for preexposed correct rejections in the left hemisphere whereas the reverse was true in the right hemisphere (see figure 6.4). Subsidiary analyses indicated that only the effect over right hemisphere sites was individually significant $F(1, 15) = 11.28, p < 0.005$. The analysis conducted at mid-frontal sites revealed a main effect of old/new $F(1, 15) = 11.87, p < 0.005$, reflecting greater positivity for hits than for correct rejections. This effect did not interact with preexposure $F > 1$. 

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Figure 6.4. ERP waveforms (N=16) associated with preexposed correct rejections and non-preexposed correct rejections in Experiment 2 at midline (Fz, Cz, Pz), lateral prefrontal (Fp1, Fp2), lateral frontal (LF, RF), lateral temporal (LT, RT) and lateral posterior (LP, RP) sites.

Preexposed Hits, Correct Rejections and False Alarms

A main effect of response category and a response category x site interaction were observed in the global analysis (see table 6.3). Pairwise comparison of false alarms and correct rejections revealed a response category x site interaction $F(1.1, 16.6) = 5.16, p < 0.05$, indicating greater positivity for false alarms maximal at superior sites. Similarly, a response
category x site interaction was observed in the pairwise comparison of hits and correct rejections $F(1.4, 21.3) = 18.69, p < 0.001$, reflecting greater positivity for hits with a superior maximum. A main effect of response category was observed in the comparison of hits and false alarms $F(1, 15) = 5.79, p < 0.05$, reflecting greater positivity for hits. The analysis conducted at lateral parietal sites indicated a main effect of response category $F(1.8, 26.9) = 13.73, p < 0.001$ and a response category x site interaction $F(2.7, 41.1) = 7.74, p < 0.001$. A main effect of response category was observed both in the pairwise comparison of false alarms and correct rejections $F(1, 15) = 14.81, p < 0.005$ and in the pairwise comparison of hits and correct rejections $F(1, 15) = 20.00, p < 0.001$, indicating greater positivity for both response categories than correct rejections. An interaction between response category x site was also observed in both the pairwise comparison of false alarms and correct rejections $F(1.7, 26.1) = 5.12, p < 0.05$ and in that performed on hits and correct rejections $F(1.5, 22.0) = 17.95, p < 0.001$. The results from both pairwise analyses indicated that hits and false alarms were more positive going than correct rejections with a superior parietal maximum. No effect of response category was observed in the comparison of hits and false alarms.

Preexposure x Old/New

The global analysis revealed a main effect of old/new, and old/new x site and preexposure x old/new x hemisphere interactions (see table 6.4). Pairwise comparison of non-preexposed hits and non-preexposed correct rejections gave rise to an interaction between old/new x hemisphere $F(1.4, 21.3) = 18.69, p < 0.001$, reflecting greater positivity for non-preexposed hits over the left hemisphere, and greater positivity for non-preexposed correct rejections over the right hemisphere. A preexposure x hemisphere interaction was revealed in the comparison of preexposed and non-preexposed correct rejections $F(1, 15) = 42.59, p < 0.001$, indicating greater negativity for preexposed correct rejections over sites in the right hemisphere (see figure 6.4). A subsidiary analysis confirmed that the effect of preexposure over right hemisphere sites was significant $F(1, 15) = 10.60, p < 0.005$. No effect of preexposure was observed for hits. The analysis conducted at lateral parietal sites revealed interactions between preexposure x old/new x hemisphere $F(1, 15) = 4.98, p < 0.05$ and between preexposure x old/new x site $F(1.2, 18.0) = 6.2, p < 0.05$. An old/new x hemisphere interaction $F(1, 15) = 5.16, p < 0.05$ observed in the pairwise comparison of non-preexposed hits and non-preexposed correct rejections reflected greater positivity for hits at left parietal sites, and greater negativity for hits at right parietal sites. Neither effect was individually
significant. Pairwise comparison of preexposed and non-preexposed correct rejections gave rise to an interaction between preexposure x hemisphere $F(1, 15) = 16.39, p < 0.001$, indicating that preexposed correct rejections were more positive-going at left parietal sites and more negative-going at right parietal sites. Whereas the effect at left parietal sites was not individually significant, a main effect of preexposure $F(1, 15) = 9.79, p < 0.01$ confirmed that the effect at right parietal sites was significant. No effect of preexposure was observed for hits.

500-650 msec

The additional analysis performed on non-preexposed hits and non-preexposed correct rejections at left parietal sites within this latency region gave rise to a main effect of old/new $F(1, 18) = 6.72, p < 0.05$, reflecting greater positivity for hits.

800-1400 msec

**Preexposed Hits, Correct Rejections and False Alarms**

The global analysis revealed an interaction between response category x frontal/temporal/parietal location x hemisphere (see table 6.3). Pairwise comparison of false alarms and correct rejections indicated via a response category x frontal/temporal/parietal location x hemisphere interaction $F(1.5, 22.3) = 4.02, p < 0.05$ that false alarms were more positive going at right frontal sites and more negative going at all other sites with a right parietal maximum. Neither the effect at right frontal sites nor that at right parietal sites were individually significant. Pairwise comparison of hits and correct rejections revealed a response category x frontal/temporal/parietal location x hemisphere interaction $F(1.5, 22.3) = 5.73, p < 0.05$, reflecting the finding that hits were more negative-going in the left hemisphere, but were more positive going in the right hemisphere with a right frontal maximum. The effect at right frontal sites was not significant. No effect of response category was observed in the comparison of hits and false alarms.

**Preexposure x Old/New**

The global analysis revealed a preexposure x old/new x hemisphere interaction $F(1, 15) = 7.62, p < 0.05$. Pairwise comparisons of non-preexposed hits and non-preexposed correct rejections, and of preexposed and non-preexposed hits did not indicate any significant effects of response category or preexposure respectively. Pairwise comparison of preexposed and
non-preexposed correct rejections gave rise to a preexposure x hemisphere interaction \( F(1, 15) = 24.58, p < 0.001 \), indicating greater positivity for preexposed correct rejections over the left hemisphere, and greater negativity for these items over right hemisphere sites (see figure 6.4). Subsidiary analyses indicated that the effect over left hemisphere sites was not significant, whereas a main effect for preexposure at right hemisphere sites confirmed that the effect over this region was significant \( F(1, 15) = 8.49, p < 0.01 \).

**Topographic analyses**

No qualitative differences were observed between preexposed hits minus preexposed correct rejections and preexposed false alarms minus preexposed correct rejections, either within the 300-500 msec latency region or within the 500-800 msec latency region (see figure 6.5).

Figure 6.5. Voltage maps showing the scalp distributions of: Figure 6.5.1 Preexposed hits minus preexposed CRs between 300-500 msec. Figure 6.5.2 Preexposed FAs minus preexposed CRs between 300-500 msec. Figure 6.5.3 Preexposed hits minus preexposed CRs between 500-800 msec. Figure 6.5.4 Preexposed FAs minus preexposed CRs between 500-800 msec.
Discussion

Behavioural data

The preexposure manipulation employed in Experiment 2 significantly modified the proportions of confident false alarms, non-confident false alarms, and confident hits. Preexposure increased the proportion of these responses to a greater degree in Experiment 2 (.17, .08 and .11 respectively) than in Experiment 1 (.14, .05 and .04 respectively). The increase in 'old' responses observed for preexposed items was accompanied by a decrease in recognition accuracy, despite the fact that preexposed items attracting an 'old' response were associated with significantly more confident responses than non-preexposed items attracting an 'old' response. Therefore, the mechanism by which preexposure increased the proportion of 'old' responses appears to have been relatively unreliable and indiscriminatory. As in Experiment 1, it is argued here that preexposure increased the proportions of hits and false alarms at least partially by enhancing item familiarity. However, a proportion of preexposed unstudied items may also have elicited noncriterial recollection (Yonelinas & Jacoby, 1996). This proportion is likely to have been greater in Experiment 2 than in Experiment 1, as these items were studied more deeply during study phase 1 in Experiment 2 (Gardiner, 1988). Recollection of noncriterial source information could not be used to exclude nontargets and did not therefore aid discrimination. It is therefore likely that familiarity and noncriterial recollection both contributed to the exclusion error rate. The large proportion of preexposed unstudied items intruding as exclusion errors in Experiment 2 is consistent with the finding that retrieval of conceptual episodic information can contribute to familiarity estimates if retrieval of this information does not allow one to exclude the item (Gruppuso, Lindsay, & Colleen, 1997), suggesting that estimates of familiarity as measured by the process dissociation procedure (Jacoby, 1991) can be contaminated by recollection.

The fact that recognition accuracy for both preexposed and non-preexposed items (.34 and .46 respectively) was somewhat lower than in Experiment 1 (.42 and .57 respectively) suggests that discrimination of studied from unstudied items was more difficult in Experiment 2 than in Experiment 1 (although these differences did not reach significance in independent samples t-tests). This must have been due to the fact that preexposed items were encoded more deeply in Experiment 2. One possible explanation is that subjects were able to rely on the experience of recollection when identifying studied items in Experiment 1, as it is unlikely that many of the preexposed unstudied items in this experiment were recollected as
they were studied in a shallow encoding task. However, subjects would arguably not have been able to employ this strategy in Experiment 2; the fact that all items were encoded deeply is likely to have resulted in the recollection of a high proportion of both studied items and preexposed unstudied items, and may not therefore have allowed subjects to rely on the phenomenological experience of recollection when judging the study status of an item. It is therefore likely that a greater degree of source discrimination was required in order to make this decision in Experiment 2 than in Experiment 1.

The data associated with correct rejections suggests that subjects rejected these items with greater difficulty when they had been preexposed than when they had not. As well as significantly decreasing the proportion of confident correct rejections, preexposure significantly increased the RTs associated with correct rejections. These findings suggest that a greater amount of evaluation had to be performed in order to respond accurately to preexposed than to non-preexposed unstudied lures. This may either have been an evaluation of trace strength (or familiarity), or an evaluation of recollected source information. It was interesting to note that preexposure increased RTs associated with correct rejections but did not influence those associated with false alarms, despite the fact that both types of response had identical experimental histories. It therefore appears that this monitoring was not performed on preexposed unstudied items that were incorrectly endorsed. In accordance with signal detection models of familiarity-based recognition (Yonelinas, Dobbins, Szymanski, & King, 1996), it is possible that only preexposed unstudied items associated with lower levels of familiarity close to the response criterion elicited these monitoring processes, whereas those associated with higher levels of familiarity were quickly misattributed to study phase 2. This interpretation is reminiscent of the argument that items eliciting familiarity close to response criterion will initiate a search process resulting in longer RTs (Juola, Fischler, Wood, & Atkinson, 1971), and is also consistent with attributional theories (Jacoby, Kelley, & Dywan, 1989) which state that items eliciting an enhanced feeling of fluency will be attributed to the focus of the task demands (i.e. study phase 2).

**Functional interpretation of ERP data**

**Very early effects**

As in Experiment 1, preexposed hits and preexposed false alarms elicited greater positivity than preexposed correct rejections from approximately 150 msec post-stimulus. Visual
inspection of the waveforms suggested that the effect elicited by hits was maximal at both frontal and parietal sites whereas the effect elicited by false alarms was evident at parietal sites only (see figure 6.1), although this observation was not confirmed by statistical analysis. Non-preexposed hits did not elicit greater positivity than non-preexposed correct rejections within this early latency region. The possibility that this effect reflects priming-related processing therefore appears to be unlikely, and it remains unclear what kind of processing this effect actually reflects. The fact that very early positivity was elicited by items associated with relatively high levels of familiarity is consistent with the argument expressed in Chapter 5 that this effect may reflect the operation of processes contributing to familiarity-based recognition (Tsivilis, Otten, & Rugg, 2001). However, this explanation does not account for why the very early effect observed for non-preexposed hits in Experiment 1 was not detected in Experiment 2.

Early frontal positivity
As in Experiment 1, preexposed false alarms, preexposed hits and non-preexposed hits were significantly more positive going than preexposed correct rejections at frontal sites between 300-500 msec. It is somewhat surprising that the main effect of old/new observed at mid-frontal sites within this latency region did not interact with preexposure, as the effect associated with non-preexposed hits appears to be considerably smaller and left-lateralised than that associated with preexposed hits (see figures 6.1 and 6.2). Statistical confirmation of this observation would have been consistent with the hypothesis that preexposure results in an increase in familiarity.

Although positivity was significant at mid-frontal sites, no frontal-maximum was indicated in the global analyses conducted within this latency region. Indeed, the ERP effects elicited by preexposed hits and preexposed false alarms within this latency region now appeared to be maximal at mid-parietal sites (see figure 6.5). These effects may have had a more parietal distribution because these response categories also elicited old/new effects at parietal sites both within the 150-300 msec latency region and within the 500-800 msec latency region, effects that were not elicited by false alarms in Experiment 1. It may therefore be the case that these additional effects overlapped with the putative familiarity effect observed at mid-frontal sites in Experiment 1, resulting in a more posterior distribution for this effect. Alternatively, this effect may genuinely have had qualitatively distinct generators in Experiments 1 and 2. If this is the case, this topographic difference may have resulted from
the greater degree of conceptual processing performed on eliciting items during study phase 1 in Experiment 2. The fact that the distribution of the very early effect elicited by preexposed false alarms also appeared to shift from a frontal to a parietal maximum between Experiments 1 and 2 suggests that both effects may differ qualitatively according to the nature of the information contributing to familiarity (i.e. perceptual vs conceptual). This interpretation would arguably be consistent with the view that familiarity is multi-componential, consisting of distinct contributing processes such as perceptual fluency, conceptual fluency and novelty detection (e.g. Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998), although the fact that early familiarity effects with a frontal distribution have previously been reported for semantically-related lures (Curran, Schacter, Johnson, & Spinks, 2001) and deeply processed items (Rugg et al., 1998) is inconsistent with this interpretation.

As in Experiment 1, the early frontal ERP effect was not observed for preexposed correct rejections relative to non-preexposed correct rejections. If frontal positivity within this latency region serves as a correlate of familiarity-driven recognition memory, this finding again suggests that this response category was associated with a lower level of familiarity than that associated with either preexposed false alarms or hits. This is unsurprising given the argument that preexposed unstudied items associated with a high level of familiarity were misattributed to study phase 2 (i.e. false alarms). It is also likely that a proportion of preexposed correct rejections were not recognised at all. However, as in Experiment 1, the argument that early frontal positivity is merely elicited by items attracting an 'old' response can not be rejected on the basis of these data.

Parietal old/new effect
ERPs associated with preexposed hits and preexposed false alarms were significantly more positive going than preexposed correct rejections at parietal sites between 500-800 msec, with a superior parietal maximum. Parietal positivity within this latency region is generally considered to reflect recollection, but is often left-lateralised when elicited by verbal material (Smith & Halgren, 1989; Smith, 1993; Paller, Kutas, & Mclsaac, 1995; Wilding & Rugg, 1996; Wilding & Rugg, 1997; Rugg et al., 1998). The parietal old/new effect observed in Experiment 1 was also maximal at superior parietal sites, and it was suggested that this effect was not left-lateralised because the lower confidence with which preexposed correct rejections were made resulted in a more negative going baseline over all sites with the exception of left parietal sites. Confidence may also have influenced the distribution of the
preexposed old/new effect in Experiment 2, as preexposed correct rejections were again associated with a decrease in confident responses. Indeed, when preexposed hits and preexposed false alarms were instead compared with non-preexposed correct rejections, the old/new effects observed were left-lateralised (see figure 6.6). In the topographical analysis conducted within the 500-800 msec latency region, no qualitative difference was detected between preexposed hits minus preexposed correct rejections and preexposed false alarms minus preexposed correct rejection. This was because a parietal old/new effect was also observed for preexposed false alarms in Experiment 2, an effect that had been absent for this contrast in Experiment 1. This finding suggests that, as predicted, a greater proportion of study phase 1 items were recollected in Experiment 2 than in Experiment 1, and also indicates that the ERP correlate of noncriterial recollection is qualitatively similar to that associated with criterial recollection.

![ERP waveforms](image)

Figure 6.6. ERP waveforms (N=16) associated with preexposed hits, preexposed false alarms and non-preexposed correct rejections in Experiment 2 at midline (Fz, Cz, Pz), lateral prefrontal (Fp1, Fp2), lateral frontal (LF, RF), lateral temporal (LT, RT) and lateral posterior (LP, RP) sites.
No parietal old/new effect was initially detected for non-preexposed hits compared to non-preexposed correct rejections within the 500-800 msec latency region. Visual inspection of the waveforms suggested that non-preexposed hits did become more positive going at left parietal sites at approximately 500 msec, but then became more negative going than non-preexposed correct rejections over mid and right temporal and parietal sites from approximately 650 msec until the end of the recording epoch (see figure 6.2). Therefore, whereas preexposed hits elicited positivity over all parietal sites within 500-800 msec, non-preexposed hits elicited positivity over left parietal sites and negativity over right parietal sites within the same latency region (see figure 6.7). This negativity may have overlapped with and attenuated the positivity that is otherwise elicited by recollected items over left parietal sites. An analysis conducted on non-preexposed hits and non-preexposed correct rejections between 500-650 msec (i.e. prior to the onset of observed negativity) confirmed that the small positivity observed at left parietal sites within this latency region was significant, suggesting that these items did elicit recollection of study phase 2 information.

![Figure 6.7.1](image1)  
![Figure 6.7.2](image2)

Figure 6.7 Voltage maps show the scalp distributions of the preexposed hit minus preexposed correct rejection effect (figure 6.7.1) and of the non-preexposed hit minus non-preexposed correct rejection effect between 500-800 msec (figure 6.7.2).

As in Experiment 1, no parietal old/new effect was observed for preexposed correct rejections, despite the fact that correctly excluded items are thought to be excluded on the basis of recollection (Jacoby, 1991). Whereas it was previously argued that these items may not actually have been recollected due to the shallow nature of the study phase 1 task during Experiment 1, Experiment 2 employed a deep encoding task during this phase that typically results in high levels of recollection. As right parietal negativity was also elicited by
preexposed correct rejections, the possibility was considered that these items may also have elicited positivity at left parietal sites that was subsequently attenuated by the onset of this negativity. However an analysis conducted on left parietal sites within the 500-650 msec latency region indicated no effect of preexposure. This finding suggests either that correctly excluded items are not necessarily excluded on the basis of recollection, or that the parietal old/new effect is elicited by some additional process consequential on recollection. Either possibility is intriguing, and shall be investigated further in the experiments remaining in this thesis.

Late negative wave
Non-preexposed hits and preexposed correct rejections elicited greater negativity over mid and right parietal sites than non-preexposed correct rejections, an effect that had not been observed in Experiment 1 (although this effect only reached significance for preexposed correct rejections). A late negative wave was also observed over mid and right parietal sites for preexposed hits and preexposed false alarms relative to non-preexposed correct rejections (see figure 6.6), suggesting that all items previously presented in the experiment elicited this effect relative to truly new words. This negativity is not commonly observed in old/new contrasts, although a minority of experiments have previously reported a late negative wave over parietal sites for old items relative to new (Wilding & Rugg, 1997; Rugg & Doyle, 1992; Nessler, Mecklinger, & Penney, 2001; Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997), some of which also required source memory judgements. It has been suggested that this effect is response-related, and that negativity is greater for items associated with longer RTs (Wilding & Rugg, 1997). This interpretation is consistent with the data in the present study, as non-preexposed correct rejections were associated with faster RTs than any other kind of response (see table 6.1). However, the finding that a late negative wave was elicited by old relative to new items in an exclusion task in which RT to the two classes of item did not differ was cited as evidence against this hypothesis (Cycowicz, Friedman, & Snodgrass, 2001). It was instead argued that the late negative wave reflected the evaluation of retrieved contextual information, and was therefore related to recollection (Cycowicz, Friedman, & Snodgrass, 2001). Evidence against Cycowicz et al.'s (2001) hypothesis came from a study reporting a late negative wave for old items in a task that did not require retrieval of source, while failing to detect a late negative wave for correctly classified old items in a second task which did require the retrieval of contextual information (Donaldson & Rugg, 1998).
It is unclear either from the present findings or from the findings discussed above whether the late negative wave over right temporal and parietal sites results from enhanced positivity associated with new items, or from increased negativity associated with old items. If the effect is accounted for by increased negativity elicited by old items, it may arguably reflect the response conflict that is experienced when recognition of an item can lead to more than one response. This hypothesis is consistent with Mecklinger's (2000) argument that the late negative wave reflects response conflict under conditions in which error is likely. If the late negative wave does in actuality take the form of enhanced positivity associated with new items, it may be better characterised as an effect indicative of processes related to novelty detection. It appears that the late negative wave is only observed when the discrimination of old items from different sources is relatively difficult, as it was not detected in Experiment 1. Experiment 3 therefore employed a between subjects design which varied the ease of discrimination of study phase 1 items from study phase 2 items to determine whether this effect does indeed occur only when the discrimination between old items of different sources was difficult. The design of Experiment 3 also permitted an evaluation of whether this effect is carried by new items or by old items.

Summary

A preexposure manipulation (in which words were studied deeply) increased the proportion of hits and false alarms made during a recognition memory test. It is argued that false alarms (i.e. exclusion errors) were made on the basis of a combination of familiarity and noncriterial recollection. Consistent with this argument, false alarms elicited an early frontal effect and a parietal old/new effect. Early frontal positivity was again significant for preexposed hits, non-preexposed hits and preexposed false alarms, although the distribution of this effect was more parietal in Experiment 2 than in Experiment 1. The early frontal effects were preceded by a very early positivity elicited by preexposed hits and false alarms between 150-300 msec. It was suggested that this positivity may also be familiarity-related, as it discriminated preexposed from non-preexposed items. ERPs associated with all types of old item became more negative going over mid and right parietal sites relative to truly new items at approximately 650 msec. This negativity was sustained until the end of the recording epoch. It was suggested that this late negative wave may reflect the response conflict experienced when recognised items require different responses on the basis of their source. However, it was also considered that this effect may be carried by enhanced positivity associated with
non-preexposed correct rejections and may therefore instead reflect novelty detection.
Comparison of the effect over mid and right parietal sites between Experiments 1 and 2 suggested that this effect is only elicited when discrimination between old items from various sources is relatively difficult. Experiment 3 was designed both to test this hypothesis, and to determine whether this effect is carried by new items or by old items.
Chapter 7. Experiment 3: Functional characteristics of the late negative wave.

Introduction

Experiment 3 investigated the conditions under which ERPs associated with old items in an exclusion task exhibit greater negativity than those associated with truly new items over mid and right parietal sites from 800 msec until the end of the recording epoch. The fact that this effect was not detected in Experiment 1, but was observed in Experiment 2 for preexposed correct rejections relative to non-preexposed correct rejections suggests that some kind of additional process was recruited during test performance in Experiment 2 that was not recruited in Experiment 1. It is important to establish what the nature of this process may be in order to understand the dynamics of recognition memory more fully. Behavioural data indicated that discrimination of studied items from unstudied lures was poorer in Experiment 2 than in Experiment 1. It was therefore hypothesised that the late negative wave over mid and right parietal sites may be elicited when discrimination of source information is relatively difficult. However, it was not possible to determine whether this effect occurred because greater positivity was elicited by new items in Experiment 2 than in Experiment 1 (i.e. a novelty effect) or because greater negativity was elicited by old items in Experiment 2 than in Experiment 1.

Negativity over mid and right parietal sites has been observed previously if infrequently. Wilding and Rugg (1996) recorded ERPs during an exclusion recognition memory task, and reported greater negativity associated with both included and excluded old items relative to new items over mid and right parietal sites, onsetting at approximately 800 msec. This effect was larger in amplitude for correctly excluded old items (‘nontargets’) than for included items (‘targets’). It was proposed that this effect may be response-related as opposed to mnemonic, as the amplitude of the late negative wave was positively correlated with RT (Wilding & Rugg, 1996). Comparable findings from other studies requiring the retrieval of source information (Rugg, Schloerscheidt, Doyle, Cox, & Patching, 1996; Nessler, Mecklinger, & Penney, 2001) supported this hypothesis (see Chapter 3). However, a further study reported right parieto-occipital negativity for correctly identified old items relative to new items in an exclusion task, despite the fact that RTs to these two classes of item did not differ significantly (Cycowicz, Friedman, & Snodgrass, 2001). The finding that this
negativity was not elicited by old items in an inclusion task led to the argument that this effect is related to the requirement to differentially respond to old items depending on their source, a task that usually requires additional monitoring and evaluation processes, and that the late negative wave therefore reflects search or evaluation processes associated with the recollection of contextual details (Cycowicz, Friedman, & Snodgrass, 2001). Such an account may explain why items eliciting this negativity are often associated with longer RTs. However, late parietal negativity is not always elicited by items for which source information is retrieved, whereas it is occasionally elicited when subjects are not required to retrieve source information at all (Donaldson & Rugg, 1998). It therefore appears that the late negative wave is not a direct correlate either of long RTs, or of the retrieval of source information, although it may reflect processes indirectly related to both of these factors.

Two other possible explanations present themselves. It may be the case that the late negative wave reflects some form of response conflict that occurs when items are recognised either on the basis of familiarity or noncriterial recollection, but when this non-diagnostic retrieval does not allow subjects to respond until diagnostic information is recollected. This effect may therefore be elicited when an item is recognised as being old, but when an ‘old’ response must be suppressed until contextual details from the prior presentation have been retrieved. According to this hypothesis, although the process reflected by the late negative wave may be highly correlated both with RT and with the successful retrieval of contextual details, it is not causally linked with either of these factors. This hypothesis is consistent with the finding that the late negative wave is associated with activations in the anterior cingulate cortex, a finding which led to the argument that both effects may reflect response competition in situations in which the likelihood of response error is high (Mecklinger, 2000). Similarly, the finding that this effect was only elicited in Experiment 2, when discrimination was poorer than in Experiment 1, is consistent with this interpretation. This hypothesis does, however, rest on the assumption that the effect observed over parietal sites is in fact a negative wave elicited by old items, rather than a positive wave elicited by new items. If the effect is in fact a positive wave elicited by new items, it may be the case that this effect is actually an enhanced response to the subjective novelty of an item. According to this hypothesis, as discrimination of old items from various sources becomes increasingly difficult, truly new items are perceived to ‘pop out’ on the basis of their novelty. If this is the case, one would predict that these items would be associated with faster RTs, a finding that has been reported by a number of the studies described above.
Experiment 3 attempted to delineate the functional significance of the late negative wave in order to understand the contribution of the process/es reflected by this effect to performance during an exclusion task. The hypothesis that this effect is elicited only when discrimination of source is relatively difficult was directly tested in a between subjects design. ERPs were recorded while each group completed an exclusion task similar in design to that employed in Experiments 1 and 2. One group performed a shallow encoding task in study phase 1 ('shallow' group), while the second group performed a deep encoding task ('deep' group). Half of these words were repeated in study phase 2. At test, both groups were required to respond 'old' to items from study phase 2 ('targets'), and to exclude all other items. The between group manipulation of levels-of-processing during study phase 1 was intended to vary the ease with which targets could be discriminated from nontargets, as it was anticipated on the basis of the findings from Experiments 1 and 2 that study phase 1 items should cause more interference when deeply encoded than when shallowly encoded. Therefore, it was predicted that a late negative wave would be observed for old items in the deep group, but not for old items in the shallow group. This design also permitted an evaluation of whether this effect is elicited by new words or by old words, as these items could be directly contrasted between the two groups.

Also of interest was whether the parietal old/new effect would be elicited by all correctly classified old items or not. According to Jacoby (1991), both correctly identified targets and correctly identified nontargets should be recollected, as correctly excluded nontargets are assumed to be excluded on the basis of recollection. Consistent with this assumption, a number of ERP studies employing exclusion tasks have reported significant parietal old/new effects both for correctly endorsed targets and for correctly excluded nontargets (Rugg, Brovedani, & Doyle, 1992; Wilding & Rugg, 1997; Cycowicz, Friedman, & Snodgrass, 2001). In some cases these effects have been smaller for nontargets (Rugg, Brovedani, & Doyle, 1992; Wilding & Rugg, 1997), whereas in others the parietal effect elicited by targets and nontargets have been equivalent in amplitude (Cycowicz, Friedman, & Snodgrass, 2001). In the light of these studies, it was somewhat surprising to observe that deeply studied preexposed correct rejections did not elicit a parietal old/new effect in Experiment 2, as one would have predicted that these items would only be correctly classified if their source was correctly recollected. This finding was not without precedent; a previous study had reported that correctly excluded nontargets in a continuous recognition memory paradigm did not
elicit a parietal old/new effect when discrimination was good (Dywan, Segalowitz, & Webster, 1998). It was therefore of great interest as to whether correctly excluded nontargets in Experiment 3 would elicit a parietal old/new effect or not.

Similarly, it was of interest which responses would elicit the putative correlate of familiarity; the early frontal effect. As familiarity is thought to be an automatic and acontextual form of recognition, one may predict that the ERP correlate of familiarity should be elicited by old items regardless of their source or response requirement, and that this effect should therefore be observed for both targets and nontargets. However, no early frontal effect was detected for preexposed correct rejections in Experiments 1 and 2, although an early frontal effect was observed for preexposed false alarms. It was argued in Chapters 5 and 6 that only those preexposed unstudied items whose familiarity level was above response criterion (and which were therefore misattributed to the target study phase) elicited an early frontal effect, and that correctly identified preexposed unstudied items were associated with lower levels of familiarity. If subjects were to adopt the same strategy in Experiment 3, an early frontal effect may not be elicited by nontargets.

Method

Subjects
Each group consisted of 18 subjects, resulting in a total of 36 subjects. 44 subjects participated, and 8 sets of data were discarded prior to analysis as they failed to provide more than 16 artefact-free trials for one or more of the critical ERP conditions. The 18 subjects who contributed data to the ‘deep’ group consisted of 11 females and 9 males, as did the 18 subjects contributing data to the ‘shallow’ group. Subjects were alternately allocated to each group. The average age of the deep group was 20 years and ranged from 18 – 25 years, whereas the average age of the shallow group was 21 years and ranged from 18 – 27 years. These two groups did not differ significantly in age.

Stimuli and Design
Experiment 3 employed a mixed 3 x 2 design, in which the factor of group was crossed with the within subjects factor of item type (i.e. target/nontarget/new), and consisted of three phases; study phase 1, study phase 2 and test. Figure 7.1 shows the design of Experiment 3.
The term 'targets' refers to old items from study phase 2, 'nontargets' refers to old items from study phase 1 alone, and 'new' refers to unstudied items. This nomenclature is adopted throughout the remainder of this thesis, and replaces the terminology employed in Chapters 5 and 6 because the factor of preexposure was no longer fully crossed with the factor of studied/unstudied. Non-preexposed studied items were not employed in Experiment 3 because these were not required for the principal aim of this experiment (i.e. delineation of the functional significance of the late negative wave).

Critical stimuli consisted of 240 visually presented concrete nouns along with 12 filler words. Each study phase 1 list contained 160 randomly ordered words (two filler words were added at the beginning and midpoint of each list). Each study phase 2 list consisted of 80 randomly ordered words, all of which had been previously presented in study phase 1 (two filler words were added to the beginning of each list). Each test list contained all 240 critical items. Eighty test items had been presented in study phase 1 alone, 80 had been presented in both study phases, and 80 were new words. Two filler words were added to the beginning of each test list. Another 2 filler words were added after 80 and 160 items in each test list. All items were fully counterbalanced so that they appeared with equal probability in each phase. The 240 critical items were split into 3 lists of 80 stimuli each; A, B and C. Three study phase 1 lists were created which consisted of lists A + B, B + C and A + C respectively. Three of the 6 subjects in each group presented with study phase 1 list A + B were presented with list A during study phase 2, and three were presented with list B. Three of the 6 subjects in each
group presented with study phase 1 list B + C were presented with list B during study phase 2, and three were presented with list C. Three of the 6 subjects in each group presented with study phase 1 list A + C were presented with list A during study phase 2, and three were presented with list C. Three test lists were created, each of which consisted of lists A, B and C, but which were created in differently randomised orders. Counterbalancing resulted in 6 different combinations of study phase 1, study phase 2 and test lists. Three subjects in each group were presented with one of these six combinations.

Procedure

Subjects were informed that the experiment consisted of three phases, and that each phase focused on different aspects of word processing. They were not informed that the experiment would involve a memory test. Trials were initiated by an experimenter-controlled mouse click for both study phases. Each trial consisted of a fixation character (‘*’) which was presented for 100msec, followed by a 600 msec period during which the stimulus was presented. Stimulus presentation was replaced by a blank screen while the subject made a verbal response. During study phase 1, subjects in the deep group were asked to perform a sentence generation task on each word presented and to include each word in the sentence, and subjects in the shallow group were instructed to judge whether the first and last letters were in alphabetical order or not. Both tasks required a verbal response. During study phase 2, all subjects were asked to verbally rate each item for pleasantness on a five-point scale (-2, -1, 0, +1, +2). Subjects were told that they may recognise some words from the previous task, but to ignore this and concentrate on the present task. During the test phase, subjects were required to respond with one hand to items that had been presented in study phase 2 and with the other hand to all other items. Each trial consisted of a fixation character ‘*’ which was presented for 100msec, followed by a 122msec period in which the screen was blanked. The stimulus was then presented for a duration of 600msec after which the screen was blanked for 4400msec, during which time the subject was required to make a response. Responses faster than 300ms and slower than 2700 ms after stimulus presentation were discounted as errors. The mapping of keys to response type was counterbalanced across subjects, ensuring that there was no correlation between hand use and response type. An interval of around 5 minutes separated each phase of the experiment. Subjects were instructed to relax during this time.
**ERP recording**

EEG was recorded from 31 silver/silver chloride electrodes, 29 of which were embedded in an elastic cap, and 2 of which were placed on right and left mastoid processes (see Chapter 4). All channels were referenced to channel Fz during recording and were subsequently re-referenced off-line to linked mastoids. All other recording and data processing parameters were identical to those employed Experiments 1 and 2, and are detailed in Chapter 4.

**Results**

**Behaviour**

Accuracy and RT data from each of the two groups are displayed in table 7.1, together with the relevant standard deviations.

<table>
<thead>
<tr>
<th>Group</th>
<th>Stimuli type</th>
<th>Response Category</th>
<th>Proportion (SD)</th>
<th>RT (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHALLOW</td>
<td>Target old</td>
<td>Hits</td>
<td>.87 (.08)</td>
<td>1064 (118)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Misses</td>
<td>.11 (.08)</td>
<td>1250 (240)</td>
</tr>
<tr>
<td></td>
<td>Nontarget old</td>
<td>Correct rejections</td>
<td>.84 (.10)</td>
<td>1166 (176)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>False alarms</td>
<td>.12 (.08)</td>
<td>1372 (228)</td>
</tr>
<tr>
<td></td>
<td>New</td>
<td>Correct rejections</td>
<td>.91 (.07)</td>
<td>1114 (175)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>False alarms</td>
<td>.07 (.07)</td>
<td>1332 (295)</td>
</tr>
<tr>
<td>DEEP</td>
<td>Target old</td>
<td>Hits</td>
<td>.78 (.11)</td>
<td>1237 (188)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Misses</td>
<td>.19 (.09)</td>
<td>1402 (303)</td>
</tr>
<tr>
<td></td>
<td>Nontarget old</td>
<td>Correct rejections</td>
<td>.77 (.16)</td>
<td>1314 (211)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>False alarms</td>
<td>.23 (.16)</td>
<td>1344 (305)</td>
</tr>
<tr>
<td></td>
<td>New</td>
<td>Correct rejections</td>
<td>.98 (.07)</td>
<td>1033 (165)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>False alarms</td>
<td>.02 (.02)</td>
<td>1269 (532)</td>
</tr>
</tbody>
</table>

Table 7.1. Mean proportion of responses (standard deviations) and mean reaction times (standard deviations) for each response category in the deep group and the shallow group in Experiment 3.

A 2 x 3 mixed design ANOVA performed on accuracy data incorporating the factors of group and response category (i.e. target/nontarget/new) revealed a main effect of group $F(1, 34) = 4.68, p < .05$, a main effect of response category $F(1.5, 50.7) = 16.98, p < .001$, and an interaction between these two factors $F(1.5, 50.7) = 5.39, p < .005$. Bonferroni t-tests (adjusted alpha value = 0.0166) indicated that whereas target accuracy was lower in the deep group than in the shallow group $t(34) = 3.10, p < 0.005$, accuracy associated with nontargets
and new items did not differ significantly between the two groups. An independent samples t-test comparing the discrimination of targets from nontargets (i.e. target hits minus nontarget false alarms) between the two groups revealed that this index was significantly lower in the deep (.59) than in the shallow (.75) group \( t (34) = 3.43, p < 0.005 \). A 2 x 3 mixed design ANOVA performed on the RT data revealed a main effect of response category \( F (1.7, 58.2) = 25.52, p < 0.001 \) and an interaction between group and response category \( F (1.7, 58.2) = 4.99, p < 0.001 \). Bonferroni t-tests (corrected alpha level = 0.006) indicated that both deep targets \( t (34) = 3.32, p < 0.005 \) and deep nontargets \( t (34) = 3.39, p < 0.005 \) were associated with significantly longer RTs than their equivalents in the shallow task, whereas no effect of group was observed for new items. RTs to shallow targets and to new items did not differ significantly, whereas shallow nontargets were associated with significantly longer RTs than shallow new words \( t (17) = 3.40, p < 0.005 \). Shallow nontargets were also associated with significantly longer RTs than shallow targets \( t (17) = 3.19, p < 0.005 \). Both deep targets \( t (17) = 4.18, p < 0.001 \) and deep nontargets \( t (17) = 8.15, p < 0.001 \) were associated with significantly longer RTs than deep new items. RTs to deep targets and nontargets did not differ significantly.

**ERP analysis strategy**

Test data ERPs were formed for 3 response categories; correctly identified items presented in study phase 1 only (nontargets), correctly identified items presented in study phases 1 and 2 (targets), and correctly identified new items. High numbers of subjects showing insufficient numbers of trials (i.e. less than 16) for misses and false alarms meant that ERPs associated with these response categories could not be analysed. The mean number of trials (range in brackets) contributing to averaged ERPs associated with targets, nontargets and new items were 52 (29-65), 52 (27-73) and 61 (47-78) in the deep group respectively, and 62 (35-72), 58 (36-76) and 62 (43-76) in the shallow group respectively. Grand average waveforms associated with these three conditions at selected midline and lateral sites are shown for the deep group in figure 7.2, and for the shallow group in figure 7.3. ERP differences between targets and new items will be referred to as ‘target old/new effects’, and ERP differences between nontargets and new items will be referred to as ‘nontarget old/new effects’. In the shallow group, ERPs associated with targets became more positive going than either nontargets or new items at approximately 300 msec. This positivity was present over all sites, and appeared to be maximal over mid-frontal and left parietal sites. This effect was
sustained until approximately 1200 msec over sites in the left hemisphere, and until the end of the recording epoch over sites in the right hemisphere. No differences were observed between nontargets and new items in the shallow group. In the deep group, ERPs to targets began to diverge from ERPs to new items at approximately 400 msec post-stimulus. A large sustained positivity was evident over frontal and left parietal sites between 400 and 1200 msec with a mid-frontal maximum. With the exception of frontopolar sites, this positivity was not observed in the ERPs to nontargets. Both targets and nontargets became more negative going than new items from around 600 msec post-stimulus over mid and right parietal and occipital sites. Targets showed enhanced positivity relative to new items over right frontal and frontopolar sites from 400 msec until the end of the recording epoch. Nontargets showed this positivity at right frontopolar sites only, onsetting at approximately 800 msec.

Figure 7.2. Grand average ERPs (N=18) associated with targets, nontargets and new items at lateral frontopolar (50, 36), lateral and midline frontal (33, 8, 22), lateral and midline parietal (30, 14, 25) and lateral occipital sites (44, 42) in the deep group.
Figure 7.3. Grand average ERPs (N=18) associated with targets, nontargets and new items at lateral frontopolar (50, 36), lateral and midline frontal (33, 8, 22), lateral and midline parietal (30, 14, 25) and lateral occipital sites (44, 42) in the shallow group.

Data associated with targets, nontargets and new items in each group were quantified by measuring the mean amplitude of the waveforms associated with each response category relative to the pre-stimulus baseline in the following 3 latency regions; 400-600 msec, 500-800 msec, 800-1400 msec. The 400-600 latency region analysis replaced the 300-500 region analysed in the Experiments 1-2 as visual inspection of the waveforms suggested that the early frontal effect of interest onset a little later in the deep group in Experiment 3. Repeated measures ANOVAs conducted within each latency region initially contrasted ERPs to all three response categories within each group. These ANOVAs were conducted on data from lateral frontopolar (49, 50, 37, 36), lateral frontal (33, 19, 22,9), lateral parietal (30, 29, 25,
(45, 44, 41, 42) electrode sites, employing the factors of response category, hemisphere, location (frontopolar/ frontal/parietal/occipital) and site (inferior/ superior). The results of these analyses are shown in tables 7.2 and 7.3.

<table>
<thead>
<tr>
<th></th>
<th>400-600 msec</th>
<th>500-800 msec</th>
<th>800-1400 msec</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>F(1.6, 26.8) = 18.70, p &lt; 0.001</td>
<td>F(1.5,25.6) = 29.152, p &lt; 0.001</td>
<td>F(1.6,26.8) = 6.41, p &lt; 0.01</td>
</tr>
<tr>
<td>CC/AP</td>
<td>-</td>
<td>F(3.0,50.8) = 7.53, p &lt; 0.001</td>
<td>-</td>
</tr>
<tr>
<td>CC/ST</td>
<td>-</td>
<td>F(1.4,23.9) = 6.28, p &lt; 0.05</td>
<td>-</td>
</tr>
<tr>
<td>CC/AP/ST</td>
<td>F(3.6, 60.5) = 5.026, p &lt; 0.002</td>
<td>F(3.3,56.9) = 11.28, p &lt; 0.001</td>
<td>F(3.5,59.1) = 7.37, p &lt; 0.001</td>
</tr>
</tbody>
</table>

Table 7.2 Results of subsidiary ANOVAs performed on ERP data associated with targets, nontargets and new items in the shallow group at lateral frontopolar, frontal, parietal and occipital sites. Key: CC = response category, AP = frontopolar/frontal/parietal/occipital location, HM = left/right hemisphere, ST = inferior/superior site. NB. Only effects involving response category are reported.

<table>
<thead>
<tr>
<th></th>
<th>400-600 msec</th>
<th>500-800 msec</th>
<th>800-1400 msec</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>F(1.9, 32.7) = 9.35, p &lt; 0.001</td>
<td>F(2.0,33.4) = 15.16, p &lt; 0.001</td>
<td>F(1.8,30.4) = 4.70, p &lt; 0.05</td>
</tr>
<tr>
<td>CC/HM</td>
<td>-</td>
<td>F(1.7,28.6) = 5.89, p &lt; 0.01</td>
<td>-</td>
</tr>
<tr>
<td>CC/AP</td>
<td>-</td>
<td>F(2.7,46.1) = 7.26, p &lt; 0.001</td>
<td>F(2.2,36.9) = 6.67, p &lt; 0.005</td>
</tr>
<tr>
<td>CC/HM/AP</td>
<td>F(3.9, 66.9) = 4.12, p &lt; 0.005</td>
<td>F(1.9,31.9) = 4.23, p &lt; 0.001</td>
<td>F(2.5,41.8) = 10.65, p &lt; 0.001</td>
</tr>
<tr>
<td>CC/AP/ST</td>
<td>F(3.1, 53.3) = 3.13, p &lt; 0.05</td>
<td>F(4.1,70.2) = 9.41, p &lt; 0.001</td>
<td>F(3.6,61.5) = 10.14, p &lt; 0.001</td>
</tr>
</tbody>
</table>

Table 7.3 Results of subsidiary ANOVAs performed on ERP data associated with targets, nontargets and new items in the deep group (table 7.3) at lateral frontopolar, frontal, parietal and occipital sites. Key: CC = response category, AP = frontopolar/frontal/parietal/occipital location, HM = left/right hemisphere, ST = inferior/superior site. NB. Only effects involving response category are reported.

Mean amplitude differences between targets and new items and between nontargets and new items are shown at lateral frontopolar, frontal, parietal and occipital electrode sites in figure 7.4 for both groups. Analyses resulting in an effect of response category were followed up with three sets of pairwise comparisons between targets and new items, nontargets and new items, and targets and nontargets. A priori analyses were also conducted on data from midfrontal sites (19, 8, 9) within the 400-600 msec latency region and on data from lateral parietal sites (46, 30, 29, 40, 25, 26) within the 500-800 msec latency region in order to investigate the putative ERP correlates of familiarity and recollection with maximum sensitivity.
Figure 7.4. Mean amplitudes and standard errors of target and nontarget old minus new effects for each of the two groups (shallow/deep) at left and right prefrontal (LPf, RPf), left and right frontal (LF, RF), left and right parietal (LP, RP) and left and right occipital (LO, RO) sites within each of the latency regions analysed. Each value is an average of the mean amplitudes observed at the inferior and the superior site at each scalp location.
A pair of mixed-design global ANOVAs were also conducted within each latency region on the same sites described above; the first of these compared target and nontarget old/new effects between groups, and employed the factors of group, target/nontarget, hemisphere, location (frontopolar/ frontal/parietal/occipital) and site (inferior/superior). These analyses were intended to demonstrate if and how the old/new effects of interest were influenced by item status (i.e. target/nontarget) and by group (i.e. shallow/deep). Figure 7.5 shows ERPs associated with target and nontarget old/new effects (i.e. correctly classified old items minus correctly classified new items) in the deep and shallow groups at lateral frontopolar, frontal, parietal and occipital sites.

![Figure 7.5](image)

Figure 7.5. Grand average ERPs associated with target and nontarget old/new effects (i.e. correctly classified old items minus correctly classified new items) in the shallow group (n=18) and in the deep group (n=18) at lateral frontopolar (50, 36), lateral and midline frontal (33, 8, 22), lateral and midline parietal (30, 14, 25) and lateral occipital sites (44, 42).
A second mixed design ANOVA compared ERPs associated with correct rejections between groups in order to determine whether correct rejections in the deep group elicited greater positivity than correct rejections in the shallow group. This ANOVA employed the factors of group, hemisphere, location (frontopolar/frontal/parietal/occipital) and site (inferior/superior). Figure 7.6 shows ERPs associated with correct rejections in the deep and shallow groups at lateral frontopolar, frontal, parietal and occipital sites. _A priori_ analyses of target and nontarget old/new effects across group, and of correct rejections across group were also conducted on data from mid-frontal sites (19, 8, 9) within the 400-600 msec latency region, and on data from lateral parietal sites (46, 30, 29, 40, 25, 26) within the 500-800 msec latency region.

![ERPs](image)

Figure 7.6. Grand average ERPs associated with shallow (n=18) and deep (n=18) correct rejections at lateral frontopolar (50, 36), lateral and midline frontal (33, 8, 22), lateral and midline parietal (30, 14, 25) and lateral occipital sites (44, 42).
Topographic analyses were also conducted where appropriate in order to determine whether target and nontarget old/new effects were associated with qualitatively distinct patterns of neural activity, and whether these patterns differed qualitatively between group or not. These analyses were only performed on pairs of old/new effects which had both reached significance, and which had differed significantly in the magnitude analyses. All topographic analyses were conducted on data rescaled to satisfy the additivity assumption of the ANOVA (see Chapter 4).

**Magnitude analyses**

400-600 msec:

**Within subjects analyses**

Global analysis of targets, nontargets and new items in the shallow group revealed a main effect of response category and a response category x location x site interaction (see table 7.2). Pairwise comparison of shallow targets and new items revealed a main effect of response category $F(1, 17) = 27.95, p < 0.001$ and a response category x location x site interaction $F(2.1, 35.5) = 7.56, p < 0.005$, reflecting greater positivity for targets with a mid-frontal maximum (see figure 7.7.1). No effect of response category was observed in the pairwise comparisons of nontargets and new items. Pairwise comparison of targets and nontargets showed a main effect of response category $F(1, 17) = 18.18, p < 0.001$ and a response category x location x site interaction $F(2.0, 33.6) = 9.01, p < 0.001$, indicating greater positivity for targets maximal at mid-frontal sites (see figure 7.3). A main effect of response category $F(1.7, 28.9) = 23.07, p < 0.001$ was observed in the *a priori* analysis of these three response categories at mid-frontal sites. A main effect of response category was observed in pairwise comparison of targets and new items at mid-frontal sites $F(1, 17) = 31.70, p < 0.001$. No effect of response category was observed in the pairwise comparison of nontargets and new items. Pairwise comparison of targets and nontargets revealed a main effect of response category $F(1, 17) = 26.26, p < 0.001$.

Global analysis of targets, nontargets and new items in the deep group showed a main effect of response category, a response category x location x site interaction and a response category x hemisphere x location interaction (see table 7.3). A main effect of response category $F(1, 17) = 13.78, p < 0.005$, a response category x location x site interaction $F(2.2, 38.0) = 4.44, p$
< 0.05 and a response category x hemisphere x location interaction $F(1.8, 30.4) = 4.90$, $p < 0.05$ were observed in the pairwise comparison of deep targets and new items, reflecting greater positivity for targets maximal at mid-frontal and left parietal sites (see figure 7.7.2). No effect of response category was observed in the pairwise comparison of deep nontargets and new items. Pairwise comparison of deep targets and nontargets revealed a main effect of response category $F(1, 17) = 13.85$, $p < 0.005$ and a response category x location x site interaction $F(2.2, 38.20) = 6.23$, $p < 0.005$, reflecting greater positivity for targets maximal at mid-frontal sites (see figure 7.2). A main effect of response category $F(1.9, 32.7) = 9.63$, $p < 0.001$ was observed in the a priori analysis of the three response categories at mid frontal sites. A main effect of response category was observed both in the pairwise comparison of targets and new items $F(1, 17) = 14.02$, $p < 0.005$ and in the pairwise comparison of targets and nontargets $F(1, 17) = 16.52$, $p < 0.001$. No effect of response category was observed in the pairwise comparison of nontargets and new items.

Figure 7.7 Voltage maps showing the scalp distributions of the old/new effects associated with targets minus correct rejections between 400-600 msec in the shallow group (figure 7.7.1) and in the deep group (figure 7.7.2).

Between-subjects analyses

Between-subjects analysis of target and nontarget old/new effects revealed a main effect of target/nontarget $F(1, 34) = 32.03$, $p < 0.001$ and a target/nontarget x location x site interaction $F(2.2, 76.3) = 15.55$, $p < 0.001$, indicating a larger old/new effect for targets than for nontargets, maximal at mid-frontal sites within this latency region (see figure 7.5). A priori analysis of target and nontarget old/new effects across group at mid-frontal sites showed a main effect of target/nontarget $F(1, 34) = 42.58$, $p < 0.001$. No effect of group was observed either in the global analysis or in the a priori analysis of new items.
500-800 msec:

**Within-subjects analyses**

The global analysis of targets, nontargets and new items in the shallow group revealed a main effect of response category and a response category x location x site interaction (see table 7.2). Pairwise comparison of targets and new items showed a main effect of response category $F(1, 17) = 35.30, p < 0.001$ and a response category x location x site interaction $F(2.2, 37.1) = 15.34, p < 0.001$, reflecting greater positivity for targets maximal at mid-frontal and left fronto-temporal sites (see figure 7.8.1). Subsidiary analysis of targets and new items at mid-frontal sites revealed a main effect of response category $F(1, 17) = 32.34, p < 0.001$. No effect of response category was observed either in the pairwise comparison of nontargets and new items. Pairwise comparison of targets and nontargets revealed a main effect of response category $F(1, 17) = 23.92, p < 0.001$ and a response category x location x site interaction $F(2.2, 36.6) = 22.00, p < 0.001$, reflecting greater positivity for targets with a mid-frontal and parietal maximum. Subsidiary analysis of shallow targets and nontargets at mid-frontal sites showed a main effect of response category $F(1, 17) = 34.48, p < 0.001$. *A priori* analysis of targets, nontargets and new items at lateral parietal sites indicated a main effect of response category $F(1.7, 28.8) = 32.74, p < 0.001$ and a response category x site interaction $F(2.0, 34.2) = 12.05, p < 0.001$. Pairwise comparison of targets and new items revealed a main effect of response category $F(1, 17) = 45.54, p < 0.001$ and a response category x site interaction $F(1.2, 20.6) = 16.93, p < 0.001$, reflecting greater positivity for targets with a mid-parietal maximum. No effect of response category was observed either in the pairwise comparison of nontargets and new items. Pairwise comparison of targets and nontargets at parietal sites revealed a main effect of response category $F(1, 17) = 37.28, p < 0.001$ and a response category x site interaction $F(1.1, 18.8) = 14.80, p < 0.001$, reflecting greater positivity for targets with a mid-parietal maximum.

Global analysis of targets, nontargets and new items in the deep group revealed a main effect of response category, a response category x location x site interaction and a response category x hemisphere x location interaction (see table 7.3). Pairwise comparison of targets and new items showed a main effect of response category $F(1, 17) = 9.18, p < 0.01$, a response category x location x site interaction $F(2.3, 38.8) = 9.94, p < 0.001$ and a response category x hemisphere x location interaction $F(1.4, 23.8) = 4.86, p < 0.05$, reflecting greater positivity for targets maximal at mid-frontal sites (see figure 7.8.2). Subsidiary analyses showed that the effect at mid-frontal sites was significant $F(1, 17) = 10.30, p < 0.005$. Pairwise
comparison of nontargets and new items revealed a main effect of response category $F(1, 17) = 6.18, p < 0.05$, a response category x location x site interaction $F(2.4, 40.0) = 5.26, p < 0.01$ and a response category x hemisphere x site interaction $F(1, 17) = 4.98, p < 0.05$, reflecting greater negativity for nontargets maximal at mid parietal and right parietal sites (see figure 7.8.3).

Figure 7.8.1. Figure 7.8.2

Figure 7.8.3

Figure 7.8. Voltage maps showing the scalp distributions of the old/new effects associated with targets minus correct rejections between 500-800 msec in the shallow group (figure 7.8.1), targets minus correct rejections between 500-800 msec in the deep group (figure 7.8.2), and nontargets minus correct rejections between 500-800 msec within the deep group (figure 7.8.3).

Pairwise comparison of targets and nontargets revealed a main effect of response category $F(1, 17) = 31.01, p < 0.001$, a response category x hemisphere x location interaction $F(1.5,$.
indicating greater positivity for targets maximal at the superior right frontal site (see figure 7.2). Subsidiary analysis showed that the effect at this site was significant \( F(1,17) = 11.84, p < 0.005 \). *A priori* analysis of the three response categories at lateral parietal sites indicated a main effect of response category \( F(1.9, 31.7) = 16.64, p < 0.001 \). Pairwise comparison of targets and new items revealed a response category x hemisphere interaction \( F(1, 17) = 8.96, p < 0.01 \). Subsidiary analyses indicated that targets elicited greater positivity than new items at left parietal sites only \( F(1, 17) = 4.88, p < 0.05 \). Pairwise comparison of nontargets and new items revealed a main effect of response category \( F(1, 17) = 16.04, p < 0.001 \) and a response category x hemisphere interaction \( F(1, 17) = 13.25, p < 0.005 \), reflecting greater negativity for nontargets maximal at right parietal sites. Pairwise comparison of targets and nontargets revealed a main effect of response category \( F(1, 17) = 40.33, p < 0.001 \) and a response category x site interaction \( F(1.2, 20.6) = 7.27, p < 0.01 \), reflecting greater negativity for nontargets maximal at mid-parietal sites.

*Between-subjects analyses*

The global analysis of target and nontarget old/new effects across group revealed a group x target/nontarget x hemisphere x site interaction \( F(1, 34) = 5.90, p < 0.05 \). Subsidiary analysis of target old/new effects across group revealed a main effect of group \( F(1, 34) = 7.30, p < 0.05 \) and a group x location x site interaction \( F(2.3, 78.5) = 3.20, p < 0.05 \), indicating a more negative-going target old/new effect in the deep group than in the shallow group, maximal at mid-parietal sites (see figure 7.5). Simple effects analysis showed a main effect of group at mid-parietal sites \( F(1, 34) = 16.30, p < 0.001 \). Subsidiary analysis of nontarget old/new effects across group showed a group x hemisphere interaction \( F(1, 34) = 4.97, p < 0.05 \) and a group x location interaction \( F(1.6, 55.7) = 7.57, p < 0.005 \), reflecting a more negative-going nontarget old/new effect in the deep group than in the shallow group, maximal at right parietal sites (see figure 7.5). Simple effects analysis indicated a main effect of group at right parietal sites \( F(1, 34) = 13.06, p < 0.001 \). The *a priori* analysis of target and nontarget old/new effects across group at lateral parietal sites revealed main effects of group \( F(1, 34) = 18.36, p < 0.001 \) and target/nontarget \( F(1, 34) = 75.04, p < 0.001 \) and interactions between group x site \( F(1.5, 52.0) = 6.43, p < 0.01 \) and target/nontarget x site \( F(1.2, 39.6) = 21.69, p < 0.001 \). This pattern of results reflected a more positive going old/new effect in the
shallow group than in the deep group, maximal at mid-parietal sites, and a more positive going target than nontarget old/new effect, maximal at mid-parietal sites. No interaction was observed between the factors of target/nontarget and group. No effect of group was detected either in the global or in the a priori analysis of new items across group.

800-1400 msec:

Within-subjects analyses

The global analysis of targets, nontargets and new items in the shallow group revealed a main effect of response category and a response category x location x site interaction (see table 7.2). Pairwise comparison of targets and new items showed a main effect of response category $F(1, 17) = 8.36, p < 0.001$ and a response category x hemisphere x location x site interaction $F(2.3, 39.0) = 4.20, p < 0.05$, reflecting greater positivity for targets, maximal at the superior right frontal site (see figure 7.9.1). Subsidiary analysis revealed a main effect of response category at this site $F(1, 17) = 8.22, p < 0.05$. No effect of response category was observed in the pairwise comparison of nontargets and new items. Pairwise comparison of targets and nontargets showed a main effect of response category $F(1, 17) = 6.73, p < 0.05$ and a response category x location x site interaction $F(2.3, 43.3) = 14.74, p < 0.001$, reflecting greater positivity for targets maximal at superior frontal sites (see figure 7.3). Subsidiary analysis revealed a main effect of response category at these sites $F(1, 17) = 9.37, p < 0.01$.

The global analysis of targets, nontargets and new items in the deep group revealed a main effect of response category, a response category x hemisphere x location interaction and a response category x location x site interaction (see table 7.3). A response category x hemisphere x location $F(1.6, 27.2) = 14.16, p < 0.001$ and a response category x location x site interaction $F(2.1, 35.4) = 16.58, p < 0.001$ were observed in the pairwise comparison of targets and new items, reflecting greater positivity for targets at frontal and frontopolar sites (maximal at superior right frontopolar sites) and greater negativity for targets at parietal and occipital sites (maximal at superior right occipital sites, see 7. 9.2). Subsidiary analyses indicated a main effect of response category both at the superior right frontopolar site $F(1, 17) = 18.72, p < 0.001$ and at the superior right occipital site $F(1, 17) = 9.19, p < 0.01$. Pairwise comparison of nontargets and new items revealed a response category x hemisphere x location x site interaction $F(2.0, 34.3) = 5.21, p < 0.01$, reflecting greater positivity for nontargets at frontopolar sites (maximal at the superior right frontopolar site) and greater
negativity for nontargets at all other sites (maximal at the superior right parietal site, see figure 7.9.3). Subsidiary analyses indicated a main effect of response category both at the superior right frontopolar site $F(1, 17) = 12.31, \ p < 0.005$ and at the superior right parietal site $F(1, 17) = 18.01, \ p < 0.001$. A main effect of response category $F(1, 17) = 13.09, \ p < 0.005$, a response category x hemisphere x location interaction $F(1.5, 25.1) = 2.30, \ p < 0.05$ and a response category x location site interaction $F(2.4, 40.0) = 5.75, \ p < 0.005$ were observed in the pairwise comparison of targets and nontargets, reflecting greater positivity for targets maximal at superior frontal sites (see figure 7.2). Subsidiary analysis indicated that the effect at these sites was significant $F(1, 17) = 19.89, \ p < 0.001$.

**Figure 7.9.1**

**Figure 7.9.2**

**Figure 7.9.3**

**Figure 7.9** Voltage maps showing the scalp distributions of the old/new effects associated with targets minus correct rejections between 800-1400 msec in the shallow group (figure 7.9.1), targets minus correct rejections between 800-1400 msec in the deep group (figure 7.9.2), and nontargets minus correct rejections between 800-1400 msec in the deep group (figure 7.9.3).
**Between-subjects analyses**

Global analysis of target and nontarget old/new effects between groups revealed interactions between target/nontarget x hemisphere x site $F (1, 34) = 5.32, p < 0.05$ and between target/nontarget x location x site $F (2.5, 86.3) = 17.43, p < 0.001$, reflecting a more positive-going target old/new effect than nontarget old/new effect, maximal over mid frontal and right frontal sites (see figure 7.5). A subsidiary analysis indicated a main effect of target/nontarget at these sites $F (1, 34) = 24.73, p < 0.001$. A third interaction was observed between group x hemisphere x location x site $F (2.4, 81.1) = 4.10, p < 0.05$. This interaction reflected a larger old/new effect in the deep group than in the shallow group at frontopolar sites (maximal at the superior right frontopolar site), and a more negative going old/new effect in the deep group than in the shallow group over all other sites (maximal at the superior right parietal site). Subsidiary analyses indicated that these between-group differences reached significance both at the superior right frontopolar site $F (1, 34) = 7.03, p < 0.05$ and at the superior right parietal site $F (1, 34) = 24.43, p < 0.001$. No effect of group was observed in the global analysis of new items between group.

**Topographic analyses**

No topographic analyses were conducted within the 400-600 msec latency region, as significant old/new effects had only been observed for targets in the magnitude analyses, and target old/new effects had not differed statistically between groups. Two sets of topographic analyses were performed within the 500-800 msec latency region; a target/nontarget x site interaction was observed in the analysis performed on target and nontarget old/new effects within the deep group $F (3.4, 57.3) = 9.32, p < 0.001$, reflecting a positive going old/new effect with a mid-frontal focus elicited by deep targets but not by deep nontargets (see figure 7.8). The second topographic analysis conducted within the 500-800 msec latency region was performed on target old/new effects between groups, and showed a group x site interaction $F (4.3, 146.3) = 4.43, p < 0.005$. This interaction reflected a scalp distribution associated with the deep target old/new effect in which targets were more positive-going over frontal sites and became more negative going over right parieto-occipital sites, whereas shallow targets were more positive-going than new items over all sites (see figure 7.8). The same two sets of topographic analyses were also performed within the 800-1400 msec latency region; a target/nontarget x site interaction was observed in that performed on target and
nontarget old/new effects within the deep group $F(3.4, 58.0) = 2.98, p < 0.05$, reflecting greater positivity for targets over right frontal regions and greater negativity for targets over right occipital sites, while nontargets elicited greater positivity over right frontopolar sites only and greater negativity over all other sites with a right parietal focus (see figure 7.9). The topographic analysis performed on target old/new effects between groups showed a group x site interaction $F(3.7, 126.5) = 3.76, p < 0.01$, reflecting a right frontal effect elicited by both deep and shallow targets, and a negative right parieto-occipital wave elicited by deep targets only (see figure 7.9).

Discussion

Behavioural data

The between-subjects levels-of-processing manipulation employed in study phase 1 successfully influenced subjects' ability to discriminate targets from nontargets, as discrimination was significantly lower in the deep group than in the shallow group. This decrease was largely accounted for by the finding that target accuracy was significantly lower in the deep group than in shallow group, whereas nontarget accuracy remained unaffected by the between-group manipulation. As argued in Chapter 6, a likely explanation of this finding is that whereas targets eliciting a recollective experience could be correctly classified on the basis of this information in the shallow group, recollection was a less reliable basis for responding in the deep group as both studied items and preexposed lures had been deeply encoded and were therefore likely to have elicited recollection-based recognition memory.

Both deep targets and deep nontargets were associated with significantly longer RTs than their shallow equivalents. It is likely that all old items in the deep group required a greater degree of monitoring prior to responding than their shallow counterparts, as discrimination of targets from nontargets was more difficult in the deep group than in the shallow group. The behavioural data suggests that this monitoring was not performed on new items in the deep group, as both accuracy and RTs associated with new items remained unaffected by group, and new items were associated with significantly shorter RTs than either class of old item in the deep group. This finding indicates that information that allowed new items to be rejected was available at an earlier time than information that allowed a source discrimination to be made. These characteristics suggest that these correctly classified new items may have been responded to on the basis of novelty/familiarity information, both because Jacoby (1991)
argues familiarity is elicited by targets and nontargets in exclusion tasks, and because evidence from response deadline tasks suggests that familiarity has an earlier time course than recollection of source information (Yonelinas & Jacoby, 1994). However, an equally plausible account of this data is that contextual information was retrieved incrementally, but that subjects had to postpone their response until sufficiently diagnostic source information had been retrieved. This interpretation does not require the operation of two distinct processes to account for the data, and is consistent with the source monitoring framework (Johnson, Hashtroudi, & Lindsay, 1993) which states that information retrieved at short delays may be associated with poorer accuracy and/or specificity than information retrieved at longer delays (Mitchell & Johnson, 2000; Johnson, Kounios, & Reede, 1994).

In comparison with the findings of Experiments 1 and 2, the nontarget false alarm rates (exclusion errors) of both groups in Experiment 3 were surprisingly low. It is unclear why items presented in the same study phase I tasks as those employed in Experiments 1 and 2 should have attracted so few exclusion errors in Experiment 3. The four key differences between Experiments 1-2 and Experiment 3 were i) the degree of overlap between items presented in the two study phases (50% in Experiments 1-2, and 100% in Experiment 3), ii) the number of items presented during study phase 2 (164 in Experiments 1-2, and 82 in Experiment 3), iii) the proportion of targets requiring a positive response to nontargets (50/50 in Experiment 1 and 2, and 33/66 in Experiment 3), and iv) the fact that both study phases were self-paced in Experiment 3 whereas only study phase 1 was self-paced in Experiment 2.

One possibility is that the lower proportion of target to nontarget items in Experiment 3 caused subjects to set a stricter response criterion. Alternatively, it may be that the additional time required to present 164 items as opposed to 82 items during study phase 2 (effectively increasing the delay between study phase 1 and test) was sufficient to increase the rate of exclusion errors from study phase 1 at test. In principle, this interpretation is consistent with the finding that the number of both Know and Remember responses to lures increase with study-test delay (Gardiner & Java, 1991), although the retention interval examined in that experiment was in the order of days as opposed to minutes.
Functional interpretation of ERP data

Late negative wave

A sustained late parieto-occipital negativity was observed both for deep targets and for deep nontargets relative to new items. This effect had an earlier onset latency for nontargets than for targets, as had been reported previously (Wilding & Rugg, 1997). As predicted, a late negative wave was observed only for old items in the deep group and was not elicited by old items in the shallow group. This effect appeared to occur as a consequence of old items eliciting greater negativity over right parietal and occipital sites as opposed to new items eliciting greater positivity over these regions, as this effect was also evident both between deep and shallow nontargets and between deep and shallow targets whereas no effect of group was observed for new items. The late negative wave does not therefore appear to be an enhanced response to subjective novelty, but rather appears to be related to the additional processing required to accurately respond to old items in exclusion tasks when discrimination between old items is relatively difficult. This finding is consistent with previous studies that have reported late negative waves in source memory tasks (Wilding & Rugg, 1997; Cycowicz, Friedman, & Snodgrass, 2001). The finding that deep targets and nontargets were associated with significantly longer RTs than their shallow equivalents initially appears to be consistent with the argument that right parietal negativity is a response-related effect (Wilding and Rugg 1996), as is the finding that deep targets and deep nontargets were associated with significantly longer RTs than deep new items. However, this hypothesis does not account for the finding that late negative wave was earlier onsetting for nontargets than for targets, as RTs to the two classes of old items did not differ. Also problematic for this account is the fact that shallow nontargets did not elicit greater negativity than either shallow targets or new items despite being associated with significantly longer RTs.

The fact that late negative waves were elicited by the two classes of old item only in the group in which the greatest degree of source monitoring was required is consistent with Cycowicz et al.'s (2001) hypothesis that this effect reflects processes related to the evaluation of source information. However, the finding that the late negative wave elicited by nontargets was earlier onsetting than that associated with targets is not consistent with this hypothesis, as it is difficult to explain why source information associated with nontargets should have been evaluated earlier than that associated with targets. Indeed, the fact that the
onset latency of this negativity predicted responses to old items suggests that some kind of signal in the brain discriminated targets from nontargets prior to the onset of late parietal negativity. The finding that the onset latency of the late negative wave discriminated nontargets from targets is arguably consistent with the hypothesis that this effect reflects the response conflict that occurs (and/or its attentional modulation) when familiar items require a ‘new’ response (Mecklinger, 2000). This interpretation does not account for the fact that a late negative wave was also elicited by deep targets, although it is possible that this effect is elicited by the recognition of any old item when recognition does not determine the response. The fact that the late negative wave was elicited by old items only when the discrimination of targets from nontargets was poor is also consistent with the assertion that this effect reflects response conflict under demanding conditions in which the likelihood of error is high (Mecklinger, 2000).

**Parietal old/new effect**

Targets elicited greater positivity than new items at parietal sites in both groups between 500-800 msec, although these sites did not form the focus of positivity during this latency region due to the unusually large positive wave elicited by targets at frontal sites. As targets are likely to have attracted a correct response on the basis of a combination of familiarity and recollection of source information from study phase 2, this finding is consistent with the view that the parietal old/new effect reflects recollection-based recognition memory. Shallow targets were significantly more positive going than deep targets within this latency region. This finding was in direct contrast to the findings of Rugg et al. (1998), who reported that deeply studied items elicited greater positivity than shallowly studied items, and does not therefore support the view that the amplitude of parietal positivity increases with depth of processing. However, the positivity elicited by deep targets may well have been attenuated by the right parietal negativity also elicited by deep targets which onset within the same latency region, an effect that was not elicited by shallow targets.

Nontargets did not elicit greater positivity than new items at parietal sites between 500-800 msec in either group. Although this finding is consistent with Experiments 1 and 2 (in which preexposed correct rejections did not elicit parietal positivity), it is somewhat surprising. This is because a core assumption underlying the use of the exclusion task in the process dissociation procedure is that nontarget old items in an exclusion task are correctly excluded on the basis of recollection (Jacoby, 1991). One key difference between the paradigms
employed in Experiments 1–3 and the process dissociation procedure is the fact that a proportion of study phase 2 (target) items were also presented in study phase 1 in the present studies, whereas target and nontarget items are non-overlapping in the process dissociation procedure. In Experiments 1 and 2 this proportion was 50%, whereas in Experiment 3 it rose to 100%. Subjects in Experiments 1-3 could not therefore reject nontargets on the basis of recollecting source information from study task 1, as either half or all of the targets had also been presented in this study phase. Indeed, it was arguably advantageous for subjects either to suppress or to discount retrieval of source information from study phase 1 for this reason. This may explain why no parietal old/new effect was observed for preexposed correct rejections or nontargets in Experiments 1–3. This in itself would be an important finding, as it would suggest either that the parietal old/new effect is sensitive to additional factors contingent on recollection, or that recollection itself can be subjected to conscious control. This issue is explored further in Chapters 8 and 9.

**Right frontal old/new effect**

Shallow targets, deep targets and deep nontargets all elicited greater positivity than new items over right frontal/frontopolar regions within the 800-1400 msec latency region, an effect that has been observed in a number of ERP studies of recognition memory (e.g. Donaldson & Rugg, 1998; Wilding & Rugg, 1996; Johnson, Kreiter, Russo, & Zhu, 1998; Wilding & Rugg, 1997). It was initially argued that this effect reflects monitoring and evaluation operations contingent on recollection (Wilding & Rugg, 1996), but it was subsequently demonstrated that right frontal positivity can be elicited in the absence of correct source judgements (Trott, Friedman, Ritter.D., Fabiani, & Snodgrass, 1999). It has since been hypothesised that right frontal positivity may instead reflect monitoring processes that probe and evaluate recognised items, and that this effect is larger for items associated with relatively weak memory as these items require a greater degree of monitoring prior to responding (Rugg, Allan, & Birch, 2001; Ullsperger, Mecklinger, & Muller, 2001). The finding that the majority of old items in the present experiment elicited a right frontal old/new effect is consistent with this hypothesis, as any contextual information associated with recognised items must be evaluated for source in order to respond to these items correctly. Interestingly, a right frontal effect was observed for deep but not for shallow nontargets. As shallow nontargets were processed very superficially in study phase 1, it is possible that these items were excluded because they were forgotten. The fact that no parietal old/new effect (the ERP correlate of recollection) or mid-frontal effect (the putative ERP correlate of
familiarity) was observed for these items is consistent with this interpretation. If the argument that shallow nontargets were not recognised is correct, the absence of a right frontal old/new effect for this response category is consistent with the view that the monitoring operations reflected by the right frontal effect are only engaged once items have been identified as being old.

The finding that shallow nontargets did not elicit a right frontal effect initially appears to be consistent with another ERP study that employed an exclusion task and reported right frontal positivity for targets but not for nontargets (Wilding & Rugg, 1997). However, as this earlier study also reported a late negative wave greater in magnitude for nontargets than for targets, it is possible that this negativity overlapped with and attenuated any right frontal positivity elicited by nontargets within the same latency region. This appears to have occurred for items in the deep group in the present study. The right frontal effect derives its name from the fact that it is typically maximal at right frontal sites (Friedman & Johnson, 2000; Rugg & Allan, 2000). Indeed the right frontal old/new effect observed for shallow targets (which did not elicit a late negative wave) was maximal over right frontal sites in Experiment 3. However, the right frontal effect elicited by deep targets and deep nontargets (which did elicit late negative waves) was instead maximal at right frontopolar sites, the sites furthest from the focus of negativity. As these frontopolar sites were not employed in the Wilding and Rugg (1997) study, it is possible that a right frontal old/new effect was in fact elicited by nontargets in this study, but was not detected in the presence of the late negative wave. It is unclear why no significant right frontal old/new effect was detected for old items in Experiments 1 and 2. This issue is discussed more fully in Chapter 10.

Early frontal positivity
Targets in both the shallow and the deep group elicited greater positivity than new items. This effect was maximal at mid-frontal sites, and did not interact with group. However, when compared with the equivalent effects elicited in Experiments 1 and 2, early frontal positivity in Experiment 3 was particularly large in amplitude, and was sustained until the end of the recording epoch. It is possible that this occurred because targets in Experiment 3 elicited a high degree of familiarity as a result of a combination of having been presented most recently and having been presented twice, but this account is not supported by the fact that preexposed hits in the previous two experiments received a comparable amount of processing yet did not elicit as large or as sustained a positivity at mid-frontal sites as that elicited by targets in
Experiment 3. It therefore remains unclear why the amplitude of this effect was so large in Experiment 3, nor why it was so prolonged.

Nontargets in Experiment 3 did not elicit positivity at mid-frontal sites in either the deep or the shallow group. If familiarity serves as an automatic basis for recognition memory, this finding is apparently inconsistent with the argument that the early frontal effect reflects item familiarity, as both target and nontarget items should arguably elicit a degree of familiarity irrespective of their source (Jacoby 1991). However, the absence of a nontarget early frontal effect is consistent with the finding that preexposed correct rejections in Experiments 1 and 2 did not elicit this effect. As argued in Chapters 5 and 6, this pattern of results may be explained in terms of the level of overall familiarity associated with accurate responses to targets and nontargets. Whereas all correctly endorsed targets must have been recognised in order to attract a positive response, it remains unknown what proportion of nontargets were truly recognised. It is unlikely that 100% of correctly excluded nontargets were recognised, therefore the proportion of recognised items is likely to have been greater for targets than for nontargets. Additionally, nontargets recognised in the absence of recollection and associated with relatively high levels of familiarity exceeding that specified by the response criterion are likely to have been attributed to study phase 2 as exclusion errors. Unfortunately an insufficient number of nontarget false alarms in Experiment 3 prevented an investigation of whether mid-frontal positivity was elicited by these items or not, but findings from the comparable contrasts in Experiments 1 and 2 between false alarms and correct rejections is consistent with this interpretation. Therefore, the overall familiarity level associated with correctly endorsed targets is likely to have been higher than that associated with correctly excluded targets, and this may explain why an early frontal effect was detected for targets and not for nontargets.

The fact that RTs to new items and nontargets in the shallow group did not differ suggests that a large proportion of shallow nontargets may indeed not have been recognised. However, it appears likely that a significant proportion of correctly classified deep nontargets were recognised on some basis, as RTs to these items were significantly longer than those to new items. The question therefore remains, why was no early frontal effect observed for deep nontargets? One possibility is that the vast majority of recognised and correctly excluded deep nontargets were recollected but not familiar in accordance with independence models (Jones, 1987). Such an argument would be consistent with the theory that correctly
excluded items are largely recognised on the basis of recollection (Jacoby, 1991). However, the fact that no parietal old/new effect was elicited by these items is inconsistent with this interpretation. Alternatively, it may be the case that the early frontal effect is not a direct correlate of familiarity-based recognition, but rather reflects processing 'downstream' from this process. Such an argument has already been proposed following the finding that not all correctly recognised classes of item elicit an early frontal effect (Tsivilis, Otten, & Rugg, 2001). As the explicit recognition of nontargets was not required to fulfil the task demands (and, as has already been argued, may have been discounted in some way), the fact that no early frontal effect was elicited by these items suggests that this correlate of recognition may be sensitive to the retrieval strategy employed. This interpretation would imply that the familiarity signal itself must precede the onset of the early frontal effect (i.e. 400 msec), as indicated by response deadline studies (Yonelinas & Jacoby, 1994; Hintzman, Caulton, & Levitin, 1998) and single unit recordings (e.g. Xiang & Brown, 1998). A final possibility is that considered in Experiments 1 and 2; the fact that early frontal positivity was only elicited by those old items attracting a positive recognition response (i.e. targets) adds weight to the suggestion that this effect may indeed be response-related rather than a direct correlate of familiarity-based recognition. Although the fact that the onset latency of this effect precedes its associated response by several hundred milliseconds suggests that this explanation is unlikely, no study has as yet reported early frontal positivity in the absence of a positive recognition response.

Summary

Experiment 3 employed a between-subjects design and a paradigm based on the logic underlying the exclusion task in the process dissociation procedure in which all target items presented in study phase 2 had previously been presented in study phase 1 together with nontargets. A between-subjects manipulation of levels-of-processing implemented during study phase 1 meant that all items in this phase were studied deeply in one group ('deep') and shallowly in another group ('shallow'). Behavioural data indicated that study phase 1 items caused greater interference during the retrieval of source information from study phase 2 in the deep group than in the shallow group. A late negative wave was elicited over right parietal and occipital sites between 800-1400 msec in the deep group but not in the shallow group, supporting the hypothesis that this effect is only elicited when discrimination of source is relatively difficult. Between-group comparisons confirmed that this effect occurred as a
result of deep targets and nontargets eliciting greater negativity than their shallow counterparts, as opposed to new items eliciting greater positivity. It was suggested that this effect is related to the response conflict experienced when simple recognition does not allow subjects to make a response, and when discrimination of items from different sources is difficult. The late negative wave appeared to interact with the right frontal old/new effect elicited by old items within the same latency region, an effect thought to reflect retrieval-related monitoring and evaluation processes. Although both deep and shallow targets elicited parietal old/new effects between 500-800 msec, this effect was conspicuously absent for nontargets from either group. As the retrieval of source information from study phase 1 was arguably disruptive to performance, it was hypothesised that no parietal old/new effect was observed for nontargets because recollection of nontarget information was either suppressed or discounted.
Chapter 8. Experiment 4: Does the parietal old/new effect reflect recollection of task-relevant information?

Introduction

Jacoby (1991) argued that nontargets presented during an exclusion task are correctly excluded on the basis of recollection, as source information associated with these items is retrieved and identified as being associated with the to-be-excluded study list. It was therefore somewhat surprising that Experiments 1-3 did not detect a parietal old/new effect (the putative ERP correlate of recollection) for nontargets. Although it could be argued that nontargets (i.e. preexposed correct rejections) in Experiment 1 and shallow nontargets in Experiment 3 did not elicit parietal old/new effects because the shallow task in which they were encoded typically results in low levels of recollection, this explanation does not account for the absence of parietal old/new effects for nontargets in Experiment 2 and deep nontargets in Experiment 3, as these items were deeply encoded in a sentence generation task which generally gives rise to high levels of recollection (Gardiner, 1988). Why, therefore, was no parietal old/new effect observed for these items? One possible explanation lies in the design employed in Experiments 1-3; the fact that targets presented in study phase 2 had also been previously presented in study phase 1 meant that recollection of nontarget source information could not be employed to reject these items as nontargets. It is therefore hypothesised that parietal old/new effects were not elicited by nontargets in Experiments 1-3 because subjects discounted source information from study phase 1, as recollection of this information could not be used to aid performance. Experiment 4 tested this hypothesis by presenting new words in study phase 2 rather than repetitions from study phase 1, so that recollection of nontarget source information could now be used to exclude nontargets. It was predicted that a parietal old/new effect would be elicited by nontargets in Experiment 4.

Previous findings pertaining to ERP correlates of correctly excluded nontargets have proved inconclusive. Early findings indicated that both targets and nontargets elicited parietal old/new effects. Rugg et al. (1992) reported parietal old/new effects both for correctly classified within-block repetitions (i.e. targets) and for correctly classified across-block repetitions (i.e. nontargets) in their continuous recognition memory experiment (see Chapter 3), although the nontarget parietal old/new effect had a later onset (approximately 600 msec) and appeared to be far smaller in amplitude than the parietal old/new effect observed for
targets. However, the fact that target and nontarget old/new effects were inherently confounded with lag rendered these findings ambiguous. Parietal old/new effects have also been reported both for targets and for nontargets in exclusion tasks which specify voice gender (Wilding & Rugg, 1997) and picture colour (Cycowicz, Friedman, & Snodgrass, 2001) as the exclusion criteria, although the former study reported a smaller parietal old/new effect for nontargets than for targets whereas the latter study reported target and nontarget parietal old/new effects of equal size. However, findings from a more recent exclusion-based ERP study suggests that nontargets may not always elicit parietal positivity (Dywan, Segalowitz, & Webster, 1998), as it was reported that young subjects did not show a parietal old/new effect for repeating foils which were to be rejected (see Chapter 3). The fact that a parietal old/new effect was observed for repeating foils both in older subjects, and in young subjects under conditions of divided attention was cited in the argument that younger subjects were normally able to exercise greater control during retrieval than older subjects, and that the attenuated amplitude of ERPs to repeating foils reflected this control (Dywan, Segalowitz, & Webster, 1998). Although it was not specified at what level this control may operate, this study provided additional evidence that nontargets in an exclusion task do not necessarily elicit a parietal old/new effect.

Experiment 4 explored the relationship between excluded nontargets and the parietal old/new effect further. Specifically, it tested the hypothesis that nontargets did not elicit a parietal old/new effect in Experiments 1-3 because subjects did not retrieve source information from study phase 1. It is argued that subjects adopted this retrieval strategy because recollection of source information from study phase 1 could not be used to identify and exclude nontargets, as targets had also been presented in study phase 1. The design employed in Experiment 4 was identical to that described for the deep group in Experiment 3, with the exception that new words were presented in study phase 2 as opposed to repetitions from study phase 1. This alteration was designed to ensure that targets and nontargets would no longer share an encoding task. Consequently, recollecting at test that an item had appeared in study phase 1 would now allow subjects to reject the item as a nontarget. As the encoding tasks were blocked, this design resembled the classical exclusion paradigm as described by Jacoby (1991) more closely that the design employed by Wilding and Rugg (1997). However, two key differences remained; the target encoding phase occurred in study phase 2 as opposed to study phase 1, and the two study phases employed different encoding tasks. These discrepancies were maintained in order to ensure comparability of results with Experiment 3.
Method.

Subjects
Twenty right-handed subjects participated. Four sets of data were discarded prior to analysis as they failed to provide more than 16 artefact-free trials for one or more of the critical ERP conditions. The average age of the 16 subjects who contributed data was 22 years, and ranged from 18 – 26 years. The 16 subjects consisted of 9 females and 7 males.

Experimental design and procedures
The design, stimuli and procedures employed in Experiment 4 were identical to those described for the deep group component of Experiment 3, with the exception that a list of 80 new items (plus 2 fillers) were presented during study phase 2. At test, it was emphasised to subjects that they could reject any item recollected from study phase 1 as a nontarget. The same sequence of events was employed in Experiment 4 as that described for Experiment 3, with the exception that responses slower than 2700 msec were no longer rejected. This alteration was made because a larger proportion of responses than expected exceeded this cut-off in Experiment 3. ERP recording, trial rejection and blink correction procedures were identical to those described for Experiment 3.

Results

Behaviour
Accuracy and RT data associated with targets, nontargets and new items are displayed in table 8.1. A one-way ANOVA performed on accuracy responses to targets, nontargets and new words indicated that the three means differed significantly $F (1.3, 20.2) = 18.37, p < 0.001$. Bonferroni t-tests (adjusted alpha-level = 0.0166) indicated that both target $t (15) = 5.27, p < 0.001$ and nontarget $t (15) = 6.93, p < 0.001$ accuracy was significantly lower than accuracy associated with new words, and that target and nontarget accuracy did not differ. A one-way ANOVA performed on RTs associated with accurate responses to targets, nontargets and new words revealed a main effect of response category $F (1.8, 26.3) = 13.91, p < 0.001$. Bonferroni t-tests (corrected alpha level = 0.0166) indicated that new words were associated with significantly faster RTs than either targets $t (15) = 3.98, p < 0.001$ or nontargets $t (15) = 4.39, p < 0.001$. RTs to targets and nontargets did not differ.
<table>
<thead>
<tr>
<th>Stimuli type</th>
<th>Response Category</th>
<th>Proportion(SD)</th>
<th>RT (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target old</td>
<td>Hits</td>
<td>.76 (.16)</td>
<td>1578 (349)</td>
</tr>
<tr>
<td></td>
<td>Misses</td>
<td>.24 (.16)</td>
<td>1759 (525)</td>
</tr>
<tr>
<td>Non-target old</td>
<td>Correct rejections</td>
<td>.83 (.06)</td>
<td>1673 (325)</td>
</tr>
<tr>
<td></td>
<td>False alarms</td>
<td>.17 (.06)</td>
<td>1894 (585)</td>
</tr>
<tr>
<td>New</td>
<td>Correct rejections</td>
<td>.96 (.05)</td>
<td>1366 (368)</td>
</tr>
<tr>
<td></td>
<td>False alarms</td>
<td>.04 (.05)</td>
<td>2096 (696)</td>
</tr>
</tbody>
</table>

Table 8.1. Mean proportion of responses (standard deviations) and mean reaction times (standard deviations) for each response category at test in Experiment 4.

**ERP analysis strategy**

Test data ERPs were formed for 3 response conditions; correctly classified target items (targets), correctly classified non-target items (non-targets) and correctly classified new items (new correct rejections). The mean number of trials (range in brackets) contributing to averaged ERPs associated with targets, non-targets and new items were 51 (17-71), 53 (33-66) and 65 (36-75) respectively. Grand average waveforms associated with these three response categories are shown at selected lateral and midline sites in figure 8.1.

ERPs associated with targets began to diverge from those associated with new items from approximately 200 msec post-stimulus, showing greater positivity at occipital sites. Both targets and non-targets showed greater positivity than new items between 400 and 600 msec (see figure 8.1). This effect appeared to be maximal at left and mid-frontal sites for non-targets, and at midline and left parietal sites for targets, and also appeared to be greater in magnitude for targets than for non-targets. Targets also elicited greater positivity than new items at left parietal sites between 400 and 800 msec (see figure 8.1). Nontargets appeared to elicit a small degree of positivity at left parietal sites between 400-600 msec. Both targets and non-targets became more negative going than new items at mid and right parieto-occipital sites from 800 msec post-stimulus until the end of the recording epoch. Both targets and non-targets showed enhanced positivity relative to new items over frontal and frontopolar sites from 400 msec until the end of the recording epoch. This effect was maximal in amplitude at the right frontopolar site.
Magnitude analyses were performed to quantify the ERP data associated with target and nontarget old/new effects. Global analyses were performed on targets, nontargets and new items at the same lateral frontopolar, frontal, parietal and occipital sites as those analysed in Experiment 3. These analyses were conducted within the latency regions of 400-600 msec, 500-800 msec and 800-1400 msec, and employed the factors of response category, hemisphere, location (frontopolar/frontal/parietal/occipital) and site (inferior/superior). The 400-600 msec latency region employed in Experiment 3 was again analysed in Experiment 4, as this latency region again appeared to capture the early frontal effect of interest (see figure 8.1). Mean amplitude differences between targets and new items, and between nontargets...
and new items are shown at lateral frontopolar, frontal, parietal and occipital sites for each of the three latency regions in figure 8.2.

Figure 8.2. Mean amplitudes and standard errors of target and nontarget old minus new effects at left and right prefrontal (LPf, RPf), left and right frontal (LF, RF), left and right parietal (LP, RP) and left and right occipital (LO, RO) sites within each of the latency regions analysed. Each value is an average of the mean amplitudes observed at the inferior and the superior site at each scalp location.
A priori analyses were performed on the three response categories at the three mid-frontal sites (19, 8, 9) within the 400-600 msec latency region, and on lateral parietal sites (46, 30, 29, 40, 25, 26) within the 500-800 msec latency region. A simple effects analysis was also performed on nontargets and new items at left parietal sites within the 400-600 msec latency region in order to investigate the small positivity observed for nontargets at these sites with maximum sensitivity. Analyses giving rise to a main effect or interaction involving the factor of response category were followed up with three sets of pairwise comparisons between targets and new items, between nontargets and new items, and between targets and nontargets respectively.

A series of pairwise comparisons (i.e. serial t-tests) between targets and new items and between nontargets and new items were also conducted on successive latency regions of 50 msec duration in order to determine the onset latencies of the late negative waves associated with targets and nontargets. These analyses were prompted by previous reports that the nontarget late negative wave onsets earlier than the target late negative wave (e.g. Wilding & Rugg, 1997), and were performed on data from right occipital sites in order to minimise the attenuating influence of any associated right frontal old/new effects.

**Magnitude analyses**

400-600 msec

The global analysis of all three response categories revealed a main effect of response category $F (1.8, 27.6) = 7.97, p < 0.005$. A main effect of response category $F (1, 15) = 12.07, p < 0.005$ and a response category x site interaction $F (1, 15) = 4.91, p < 0.05$ were observed in the pairwise comparison of targets and new items, reflecting greater positivity for targets, maximal towards the midline (see figure 8.1). No effect of response category was observed in the analysis of nontargets and new items. Pairwise comparison of targets and nontargets revealed a main effect of response category $F (1, 15) = 6.90, p < 0.05$ and a response category x location x hemisphere x site interaction $F (2.2, 32.5) = 3.78, p < 0.05$, indicating greater positivity for targets maximal at the left parietal sites (see figure 8.1). Subsidiary analysis of targets and nontargets at this site revealed a main effect of response category $F (1, 15) = 9.60, p < 0.01$. The *a priori* analysis conducted on the three response categories at mid-frontal sites gave rise to a main effect of response category $F (1.8, 26.6) = 5.03, p < 0.05$. A main effect of response category $F (1, 15) = 9.34, p < 0.01$ observed in the
pairwise comparison of targets and new items reflected greater positivity for targets. A trend towards a main effect of response category was observed in the pairwise comparison of nontargets and new items $F (1, 15) = 3.96, p < 0.1$. No effect of response category was observed either in the pairwise comparison of targets and nontargets at mid-frontal sites, or in the simple effects analysis conducted on nontargets and new items at left parietal sites within this latency region.

500-800 msec
A main effect of response category $F (1.5, 22.1) = 7.30, p < 0.01$ and a response category x hemisphere x location interaction $F (2.5, 37.8) = 3.39, p < 0.05$ were observed in the global analysis. Pairwise comparison of targets and new items revealed a response category x hemisphere x location interaction $F (1.8, 27.6) = 9.40, p < 0.001$, indicating greater positivity for targets at all sites with a left parietal maximum (see figure 8.3.1). A response category x location interaction $F (1.8, 26.5) = 3.96, p < 0.05$ observed in the pairwise comparison of nontargets and new items reflected greater positivity for nontargets maximal at frontopolar sites, and greater negativity for nontargets at occipital sites (see figure 8.3.3), although neither effect was individually significant. Pairwise comparison of targets and nontargets revealed a main effect of response category $F (1, 15) = 17.33, p < 0.001$ and a response category x location x hemisphere x site interaction $F (2.3, 34.8) = 3.18, p < 0.05$, indicating greater positivity for targets with a left parietal maximum (see figure 8.1). The a priori analysis of targets, nontargets and new items at lateral parietal sites revealed a main effect of response category $F (2, 30) = 5.06, p < 0.05$ and a response category x hemisphere interaction $F (2.0, 29.9) = 5.41, p < 0.01$. Pairwise comparison of targets and new items revealed a response category x hemisphere interaction $F (1, 15) = 9.45, p < 0.01$, reflecting greater positivity for targets with a left parietal maximum. A main effect of response category $F (1, 15) = 6.83, p < 0.05$ observed in a subsidiary analysis conducted at left parietal sites confirmed that the target old/new effect was significant at these sites. A response category x hemisphere interaction $F (1, 15) = 5.96, p < 0.05$ observed in the pairwise comparison of nontargets and new items indicated a small positivity for nontargets over left parietal sites and greater negativity for nontargets over right parietal sites, although subsidiary analyses revealed that neither effect was individually significant. Pairwise comparison of targets and nontargets indicated a main effect of response category $F (1, 15) = 14.46, p < 0.005$ and a response category x hemisphere x site interaction $F (1.7, 24.8) = 3.84, p < 0.05$, reflecting greater positivity for targets with a left parietal maximum. Subsidiary analyses indicated that targets
were significantly more positive going both over left parietal sites $F(1, 15) = 15.63, p < 0.001$ and over right parietal sites $F(1, 15) = 13.26, p < 0.005$.

Figure 8.3.1

Figure 8.3.2

Figure 8.3.3

Figure 8.3.4

Figure 8.3 Voltage maps show the scalp distributions of the target minus new effect between 500-800 msec (figure 8.3.1) and between 800-1400 msec (see figure 8.3.2), and of the nontarget minus new effect between 500-800 msec (figure 8.3.3) and between 800-1400 msec (figure 8.3.4).

800-1400 msec

A response category x hemisphere x location interaction $F(3.1, 46.6) = 4.95, p < 0.005$ was revealed by the global analysis, together with a response category x hemisphere x site interaction $F(1.9, 29.0) = 6.07, p < 0.01$ and a response category x location x site $F(2.8, 42.3) = 5.95, p < 0.005$ interaction. Pairwise comparison of targets and new items gave rise
to a response category x hemisphere x location interaction $F(1.9, 28.3) = 6.90, p < 0.005$, reflecting greater positivity for targets over frontal sites (maximal at the right frontopolar site) and greater negativity for targets over right parietal and occipital sites (maximal at right occipital sites, see figure 8.3.2). A main effect of response category $F(1, 15) = 11.37, p < 0.005$ was observed in a subsidiary analysis conducted on targets and new items at right frontopolar sites. A second subsidiary analysis conducted on targets and new items at right occipital sites revealed a response category x site interaction $F(1, 15) = 8.18, p < 0.05$, indicating greater negativity for targets at the superior right occipital site. The effect at this site was significant $F(1, 15) = 6.29, p < 0.05$. Pairwise comparison of nontargets and new items revealed a response category x hemisphere x location interaction $F(1.5, 23.1) = 6.26, p < 0.05$, in which nontargets elicited greater positivity at frontopolar and frontal sites (maximal at right frontopolar sites), and greater negativity over right parietal and occipital sites (maximal at right occipital sites, see figure 8.3.4). Main effects of response category were observed both in a subsidiary analysis conducted at right frontopolar sites $F(1, 15) = 6.72, p < 0.05$, and in a subsidiary analysis conducted at right occipital sites $F(1, 15) = 1.67, p < 0.05$. Pairwise comparison of targets and nontargets gave rise to a response category x hemisphere interaction $F(1, 15) = 5.02, p < 0.05$, in which targets were more positive going than nontargets, maximal over right hemisphere sites. A main effect of response category $F(1, 15) = 6.73, p < 0.05$ was observed in a subsidiary analysis conducted at right hemisphere sites. Subsidiary analyses also revealed that targets were significantly more positive going than nontargets at right occipital sites $F(1, 15) = 9.16, p < 0.01$, but that there was no effect of response category at right frontopolar sites.

**Serial t-tests**

A main effect of response category $F(1, 15) = 4.80, p < 0.05$ was first observed in the pairwise comparison of nontargets and new items performed within the 650-700 msec latency region. A main effect of response category was not observed in any pairwise comparison of targets and new items until that performed within the 950-1000 latency region $F(1, 15) = 4.79, p < 0.05$.  

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**Topographic analyses**

A topographic analysis was conducted on target minus correct rejection data and nontarget minus correct rejection data across the 500-800 msec and the 800-1400 msec latency regions, in order to determine whether or not these response categories were associated with dissociable patterns of neural activity, and whether or not these patterns changed qualitatively over time. This analysis employed the factors of epoch (i.e. 500-800 msec and 800-1400 msec latency regions), target/nontarget and site, and gave rise to an epoch x site interaction $F(2.8, 41.9) = 3.85, p < 0.05$. This interaction reflected the onset both of a right frontal old/new effect and of a late negative wave over right parieto-occipital sites both for targets and for nontargets in the 800-1400 latency region (see figure 8.3), confirming that these effects were qualitatively distinct from parietal old/new effect elicited in the earlier latency region.

**Discussion**

**Behavioural data**

Correctly classified new items were associated with greater accuracy and faster RTs than either class of correctly classified old item. The finding that new items were quickly and accurately rejected suggests that subjects were able to discriminate old from new items before they were able to discriminate targets from nontargets. It therefore appears that many old items were again initially recognised as being old prior to an attribution of source being made. This discrimination of old from new items may either have been made on the basis of early familiarity information which is thought to be available prior to recollection (Mandler, 1980; Yonelinas & Jacoby, 1994), or may have been made on the basis of accruing undifferentiated recollection of non-diagnostic contextual details (Johnson, Hashtroudi, & Lindsay, 1993; Johnson, Kounios, & Reede, 1994). The hypothesis that these items were initially recognised on the basis of familiarity is consistent with the view that both targets and nontargets elicit familiarity-based recognition in exclusion tasks (Jacoby, 1991). Accuracy and RTs associated with targets and nontargets did not differ significantly. Therefore any differences in the ERPs associated with these two response categories could not be attributed to differences in response time.

Little can be concluded from the nontarget performance data, as these items were responded to on the same key as new items. It is therefore impossible to establish what proportion of
these items were recognised, although the fact that these items were deeply encoded suggests that they should have been available to episodic retrieval (Gardiner, 1988). Fewer exclusion errors were made in Experiment 4 (0.17) than in the deep group component of Experiment 3 (0.23), suggesting either that fewer nontargets were recognised in Experiment 4, or that subjects adopted a stricter response criterion in Experiment 4 when responding ‘old’ on the basis of familiarity. It could be argued that the deep nature of the encoding task employed in study phase 2 may have resulted in sufficient retroactive interference so as to render study phase 1 items irretrievable. A small behavioural experiment employing 6 subjects was conducted in order to investigate this possibility (see appendix a). The design, stimuli and procedures of this study were identical to those employed in Experiment 4, with the exception that subjects were required to respond positively to study phase 1 items, and to exclude all other items. A less ambiguous measure of retrieval of study phase 1 items could now be obtained. Target (i.e. study phase 1) accuracy in this experiment was .86, and the false alarm rates to new items and nontargets were .03 and .13 respectively. These findings indicate that subjects were able to accurately retrieve items from study phase 1 when directed, and that nontarget source information should therefore have been available to retrieval in Experiment 4. It therefore appears that subjects adopted a stricter response criterion when responding on the basis of familiarity in Experiment 4 than in earlier experiments. Possible explanations of why this response criterion shift may have occurred are discussed in Chapter 10 as part of a wider discussion of other experimental findings reported within this thesis.

**Functional interpretation of ERP data**

**Parietal old/new effect**

The empirical question of interest was whether or not a parietal old/new effect would be observed for nontargets relative to new items. It was argued that no parietal old/new effect was observed for correctly excluded old items in Experiments 1-3 because subjects discounted source information from study phase 1. It was also argued that this information was discounted because it could not be used to exclude nontargets, as targets had also been presented in study phase 1. This retrieval strategy may either have suppressed recollection of nontarget source information, or may have prevented subjects from attending to this information. As Experiment 4 removed the encoding overlap shared by targets and nontargets in the previous three experiments, it was predicted that a parietal old/new effect would be observed for nontargets now that recollection of source information from study
phase 1 could be used to exclude these items. The fact that nontargets had been presented in a deep encoding task during study phase 1 maximised the likelihood that these items would be recollected. However, although a parietal old/new effect was observed for targets relative to new items, no such effect was evident for nontargets (see figure 8.3). It therefore appears that the encoding overlap between targets and nontargets in Experiments 1-3 was not solely responsible for the absence of a nontarget parietal old/new effect in these studies. This finding prompted further consideration of two alternative hypotheses which need not be mutually exclusive; the absence of a nontarget parietal old/new effect may either indicate that this effect is not an obligatory correlate of recollection, or it may reflect the possibility that nontargets were not actually recollected despite the fact that source information from study phase 1 was available to episodic retrieval and could be used to aid performance.

The first of these two hypotheses states that the parietal old/new effect, rather than being an obligatory correlate of recollection, reflects additional processing contingent on recollection that occurred for targets but not for nontargets. For example, a parietal effect may only be observed for recollected items that require a positive recognition response, a characteristic that would suggest that this effect may be a correlate of intentional recollection. However, the fact that previous studies have reported parietal old/new effects for nontargets in exclusion tasks (Rugg, Brovedani, & Doyle, 1992; Allen, Iacono, & Danielson, 1992; Van Hooff, Brunia, & Allen, 1996; Wilding & Rugg, 1997; Cycowicz, Friedman, & Snodgrass, 2001) can be cited as evidence against this interpretation. A more plausible hypothesis is that the parietal old/new effect may reflect recollected information that is attended to and employed in a task-relevant manner. Although some researchers who conceptualise recollection solely as the retrieval of any contextual aspect (e.g. Gardiner & Java, 1993b) may argue that this characteristic would indicate that the parietal old/new effect is not a direct correlate of recollection, others who conceptualise recollection as the ability to control and manipulate retrieved contextual information (e.g. Jacoby & Kelley, 1992) would still view the parietal old/new effect as a correlate of recollection.

The hypothesis that subjects did not actually recollect nontarget source information was supported by subject debriefing (although it is acknowledged that information obtained through debriefing is not necessarily reliable). The response assignment employed in exclusion tasks required subjects to press one key for targets, and a second key for both nontargets and new words. Therefore, although recollection of source information from
study phase 1 could be used to facilitate performance, recollection of this information was not explicitly required. Indeed, it was possible to perform at ceiling without recollecting a single nontarget. All targets had been studied in a conceptual encoding task, and the fact that these items were subsequently associated with a relatively high degree of accuracy (.76) suggests that memory for these items was reliable. The combination of these two factors potentially encouraged subjects to adopt a retrieval strategy in which all test items were specifically probed for source information from study task 2 at the expense of source information from study task 1. The task would then require a simple yes/no response (i.e. “Did I see this item in study phase 2 or not?”). Adoption of such a retrieval strategy may result in poor recollection of nontargets, as subjects do not attempt to retrieve this type of source information although it is available to episodic retrieval. When asked how they had completed the exclusion task, 11 of the 16 subjects claimed to have attempted to retrieve source information from study phase 2 for all test items, and 6 of these also claimed that they had done this by reinstating the study phase 2 encoding task at test. This raises the possibility that nontargets may not have been consistently recollected in the present study.

As two of the core assumptions underlying the process dissociation procedure (Jacoby 1991) state that nontargets are correctly excluded on the basis of recollection, and that recollection is equivalent for both inclusion and exclusion, such a finding would imply that the boundary conditions (i.e. the experimental conditions under which the assumptions underlying the process dissociation procedure remain valid) of the process dissociation procedure had been violated in Experiment 4. As stated at the beginning of this chapter, the paradigm employed in Experiment 4 differed from the classical exclusion task as described by the process dissociation procedure in two ways; targets were studied in the second study phase as opposed to the first study phase, and different encoding tasks were employed in the two encoding tasks. It appears that these deviations differentiated memory associated with targets and nontargets to such an extent that the assumptions underlying the process dissociation procedure were violated.

The possibility must also be considered that nontargets did elicit a parietal old/new effect, but that the negativity also elicited by these items over right parietal sites within the 500-800 msec latency region (see figure 8.3) had such an attenuating effect that the parietal old/new effect could no longer be detected. Although targets also elicited a late negative wave, the negativity elicited by nontargets over right parietal sites was significantly larger that that elicited by targets between 500-800 msec, and so may arguably have had more of an
attenuating effect. However, it should be noted that the late negative wave elicited by nontargets within the 500-800 msec latency region did not reach significance. It is therefore unlikely that this negativity would have been large enough to eradicate the parietal old/new effect. This issue is discussed further in Chapter 9.

Early frontal effect

Visual inspection of the waveforms revealed greater positivity at mid-frontal sites for both targets and nontargets relative to new items between 400-600 msec, an effect that was larger in magnitude for targets than for nontargets (see figure 8.1). The mid-frontal effect elicited by targets was statistically significant, whereas that observed for nontargets showed a trend but failed to reach significance. Jacoby (1991) argued that both targets and nontargets in an exclusion task elicit familiarity-based recognition, and that the familiarity elicited by nontargets must be opposed by recollection in order for these items to be excluded. One would therefore expect both targets and nontargets to elicit familiarity-based recognition, and that these items would be associated with early frontal old/new effects if this effect is a correlate of familiarity. Indeed the behavioural data indicates that information pertaining to an item's old/new status was available before a source attribution was made, suggesting that subjects may have recognised items on the basis of early familiarity/novelty information before sufficient source information was available to permit accurate responding to old items. Therefore, the finding that targets and nontargets elicited greater positivity than new items at mid-frontal sites between 400-600 msec is consistent with the view that this effect reflects item familiarity.

It is possible that the nontarget early frontal effect did not reach statistical significance because of a lack of power, as this effect was small in amplitude relative to that observed for targets. Assuming this proposal is correct, this finding is inconsistent with Experiments 1-3, as no early frontal effect was observed for nontargets (or 'preexposed correct rejections') in any of these experiments. As the only difference between the deep group component of Experiment 3 and Experiment 4 was the removal of the encoding overlap between targets and nontargets, the emergence of a nontarget early frontal effect must be related to this manipulation. As discussed above, this manipulation also reduced the nontarget false alarm rate from .23 in Experiment 3 to .17 in Experiment 4 and therefore appeared to encourage subjects to adopt a stricter response criterion. It was argued in Chapters 5-7 that no early frontal effect was observed for correctly excluded nontargets because this response category
was associated with a relatively low level of familiarity, both because a proportion of these items were not recognised at all (thus diluting any familiarity signal present in the ERPs), and because a high proportion of familiar nontargets were misattributed to study phase 2. Assuming that the proportion of unrecognised correctly excluded nontargets remained constant between Experiments 3 and 4, the familiarity signal in the ERPs to nontargets may have increased in Experiment 4 because fewer familiar nontargets were misclassified as targets.

Alternatively, it may be the case that the early frontal old/new effect is not a correlate of item familiarity, and is in fact sensitive to task demands. The removal of the encoding overlap between Experiments 3 and 4 was implemented because it was hypothesised that a parietal old/new effect was not elicited by nontargets because subjects did not retrieve source information from study phase 1. Although this manipulation did not have the predicted effect on the parietal old/new effect, it did influence the mid-frontal effect. It is therefore possible that this effect is sensitive to task demands and reflects the retrieval and/or manipulation of task-relevant information. As discussed in Chapter 3, evidence already exists to suggest that the early frontal effect may reflect responses ‘downstream’ from familiarity (Tsivilis, Otten, & Rugg, 2001). However, it is unclear how this interpretation would account for the finding that false alarms elicited an early frontal effect in Experiments 1 and 2. Finally, if replicated, the observation of a nontarget mid-frontal effect can be cited to reject the argument that this effect is merely a correlate of positive recognition responses, as was speculated in Experiment 1-3.

Late negative wave and right frontal old/new effect
As in Experiment 3, both targets and nontargets elicited greater negativity over right parietal and occipital sites than new items, providing further evidence that the late negative wave is elicited in exclusion tasks by old items requiring an evaluation of source information. The late negative wave elicited by nontargets was significantly larger in amplitude than that elicited by targets. It also onset approximately 300 msec earlier for nontargets. Both targets and nontargets were associated with significantly longer RTs than new items, but the fact that RTs to targets and nontargets did not differ despite the fact that the late negative wave was both earlier onsetting and significantly larger in amplitude for nontargets than for targets suggests that that this effect is not a direct correlate of longer RTs. Similarly, this pattern of results is arguably problematic for the view that this effect reflects the evaluation of source
information (Cycowicz, Friedman, & Snodgrass, 2001), as it is difficult to explain why this kind of processing should have occurred earlier (or to a greater extent) for nontargets than for targets. As argued in Chapter 7, this pattern of results is arguably consistent with the view that the late negative wave reflects the response conflict experienced when response selection places high demands on attentional resources and when the likelihood of error is high, as this view also states that response conflict is particularly high when a recognised item requires a 'new' response because the competing response has to be suppressed (Mecklinger, 2000). It was again apparent that the late negative wave had an attenuating influence on the right frontal old/new effects elicited by old items, as the right frontal old/new effects observed for targets and nontargets in Experiment 4 were maximal at right frontopolar sites rather than at right frontal sites.

Although the finding that targets and nontargets both elicited a right frontal old/new effect is consistent with the idea that this effect reflects some aspect of source monitoring, the fact that a right frontal effect was elicited by nontargets suggests that the right frontal old/new effect is not contingent on recollection, as no parietal old/new effect was elicited by these items. This pattern of results supports the view that the right frontal old/new effect is not tied to recollection, but rather reflects monitoring and evaluation processes required to respond accurately to recognised items (Rugg, Allan, & Birch, 2001; Ullsperger, Mecklinger, & Muller, 2001). As it is argued above that subjects adopted a retrieval strategy in which they specifically probed each test item for source information from study phase 2, the fact that targets and nontargets elicited qualitatively similar right frontal old/new effects is consistent with this conclusion. The finding that the right frontal old/new effect observed for targets was larger than that observed for nontargets may be explained by the fact that the late negative wave associated with nontargets at right parietal sites was larger than that associated with targets, as it may have had more of an attenuating effect on the associated right frontal old/new effect. The behavioural data suggests that new items would not have elicited monitoring and evaluation processes, as they were quickly and confidently rejected.

**Summary**

Experiment 4 examined the hypothesis that the absence of a nontarget parietal old/new effect in Experiment 3 was because an encoding overlap between targets and nontargets at encoding rendered the recollection of nontarget source information unhelpful, and that recollection of
this information was either suppressed or discounted as a result. This encoding overlap was removed in Experiment 4, so that source information from study phase 1 could now be employed to exclude nontargets. However, a parietal old/new effect was not detected for nontargets in Experiment 4. Debriefing revealed that a high proportion of subjects employed a retrieval strategy in which each test item was probed specifically for source information from study phase 2, a strategy which appeared to be reflected in the finding that right frontal old/new effects were observed for both targets and nontargets despite the absence of a nontarget parietal old/new effect. Subjects were encouraged to adopt this retrieval strategy because the retrieval of source information from study phase 1 was not explicitly required by the response assignment implemented (i.e. an overt recognition judgement was only required for targets), and was facilitated by the fact that memory for targets was reliable. It is therefore hypothesised that no parietal old/new effect was elicited by nontargets because source information associated with these items was not actually recollected. Possible mechanisms which may allow subjects to adopt such a retrieval strategy are discussed in Chapter 10.
Chapter 9. Experiment 5: Does the parietal old/new effect reflect recollection susceptible to retrieval strategy?

Introduction

It was reported in Experiment 4 that targets in an exclusion task elicited a parietal old/new effect, whereas no such effect was observed for nontargets. This finding was somewhat surprising in the light of earlier studies which had demonstrated both target and nontarget parietal old/new effects in exclusion tasks (Allen, Lacons, & Danielson, 1992; Van Hooff, Brunia, & Allen, 1996; Rugg, Brovedani, & Doyle, 1992; Wilding & Rugg, 1996; Cycowicz, Friedman, & Snodgrass, 2001), particularly as Experiment 4 had been designed both to maximise the memorability of nontargets and to allow recollection of these items to be used to exclude them. However, subject debriefing suggested that all test items in Experiment 4 were probed for source information from study phase 2 at the expense of source information from study phase 1, indicating that the absence of a nontarget parietal old/new effect in this study may reflect poor recollection of source information associated with nontargets. It is hypothesised that subjects adopted this retrieval strategy both because the response assignment only explicitly required the recollection of targets, and because the deep encoding of targets produced relatively high levels of recollection-based memory that could be used to support this retrieval strategy. If correct, this hypothesis may have implications for the boundary conditions of the process dissociation procedure, as a key assumption underlying the use of the exclusion task is that subjects employ recollection to reject nontarget items (Jacoby, 1991). It is not obvious, however, that this is always necessary for successful performance in exclusion tasks. Subjects may instead endorse an item as a target only if recognition is accompanied by the appropriate source-specifying information, rejecting any item for which such information is unavailable. Under these circumstances, recollection of the source of a nontarget would not be necessary for it to be successfully excluded, even if its familiarity were high; the item could be excluded on the basis of its failure to elicit information diagnostic of the target source. It is therefore in principle possible for subjects to perform well in an exclusion task by selectively retrieving source information diagnostic of a target, as long as memory for targets is reliable.

Experiment 5 tested the hypothesis that the parietal old/new effect was not elicited by nontargets in Experiment 4 because few of these items were actually recollected (or nontarget
information was recollected but not employed). It is argued that few nontargets were recollected because memory for targets was sufficiently reliable to allow subjects to selectively probe each test cue for target source information at the expense of nontarget source information. Subjects were presented with the same exclusion task as that described in Experiment 4, with the exception that the deep encoding task employed during study phase 2 (i.e. the target study phase) was replaced with a shallower encoding task in which subjects were required merely to read each word aloud. A behavioural pilot study indicated that the shallower encoding task reduced recognition accuracy for targets without significantly increasing either the new or nontarget false alarm rate, and without producing a discrepancy in RT between targets and nontargets (see appendix b). The purpose of replacing the deep encoding task in study phase 2 with a shallower task was to encourage subjects in Experiment 5 to adopt a different retrieval strategy in which they would employ source information from both study phases, as memory for targets would now be insufficiently reliable to support selective responding on the basis of this information alone. It was anticipated that source information associated with nontargets would become more salient as memory for targets became less reliable, and that a parietal old/new effect would subsequently be observed for both targets and nontargets at test.

Method

Subjects

17 subjects participated. One data set was discarded prior to analysis due to technical failure. The 16 subjects contributing data consisted of 8 females and 8 males, and had a mean age of 22 years.

Stimuli, design and procedures

The experimental design, stimuli and procedures employed in Experiment 5 were identical to those described for Experiment 4, with the exception that subjects were now required to read words presented in study phase 2 aloud instead of rating them for pleasantness. ERP recording parameters, trial exclusion criteria and blink correction algorithms were the same as those employed in Experiments 3 and 4.
Results

Behaviour

Accuracy and RT data associated with targets, nontargets and new items are presented in table 9.1. A one-way ANOVA performed on accurate responses to these three response categories revealed a main effect of response category $F(1.6, 24.0) = 26.84, p < 0.001$.

Bonferroni t-tests (adjusted alpha level = 0.0166) indicated that targets were associated with significantly fewer accurate responses than either new items $t(15) = 5.76, p < 0.001$ or nontargets $t(15) = 5.55, p < 0.001$, while accuracy did not differ significantly between the latter two conditions. A one-way ANOVA carried out on RT data associated with accurate responses to targets, nontargets and new items revealed a main effect of response category $F(1.7, 25.2) = 13.25, p < 0.001$. Bonferroni t-tests (adjusted alpha level = 0.0166) indicated that new items were associated with significantly faster RTs than either targets $t(15) = 4.10, p < 0.001$ or nontargets $t(15) = 4.94, p < 0.001$. RTs to targets and nontargets did not differ significantly.

<table>
<thead>
<tr>
<th>Stimuli type</th>
<th>Response Category</th>
<th>Proportion(SD)</th>
<th>RT (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target old</td>
<td>Hits</td>
<td>.63 (.13)</td>
<td>1619 (344)</td>
</tr>
<tr>
<td></td>
<td>Misses</td>
<td>.37 (.14)</td>
<td>1548 (394)</td>
</tr>
<tr>
<td>Non-target old</td>
<td>Correct rejections</td>
<td>.84 (.08)</td>
<td>1571 (253)</td>
</tr>
<tr>
<td></td>
<td>False alarms</td>
<td>.16 (.08)</td>
<td>1883 (442)</td>
</tr>
<tr>
<td>New</td>
<td>Correct rejections</td>
<td>.88 (.11)</td>
<td>1356 (290)</td>
</tr>
<tr>
<td></td>
<td>False alarms</td>
<td>.12 (.11)</td>
<td>1891 (440)</td>
</tr>
</tbody>
</table>

Table 9.1. Mean proportion of responses (standard deviations) and mean reaction times (standard deviations) for each response category at test in Experiment 5.

Accuracy and RT associated with each response category were also compared between Experiment 4 and Experiment 5, in order to determine whether the levels-of-processing manipulation in study phase 2 influenced any of these measures. Planned pairwise comparisons indicated that target accuracy was lower in Experiment 4 than in Experiment 5, $F(1, 30) = 6.37, p < .05$, as was accuracy for new items, $F(1, 30) = 6.45, p < .05$. Accuracy for nontargets did not differ significantly between experiments. No effect of experiment was observed for RTs to any of the three response categories. A planned comparison comparing
discrimination of targets from new items across group indicated that this discrimination was significantly poorer in Experiment 5 than in Experiment 4 $F(1, 30) = 3.25, p < 0.005$.

**ERP analysis strategy**

ERPs were formed at test for correctly identified target items ('targets'), correctly identified non-target items ('nontargets') and correctly identified new items (‘new’). The mean number of trials (range in brackets) contributing to the ERPs associated with targets, nontargets and new items were 41 (26-60), 49 (34-71) and 53 (33-77) respectively. Figure 9.1 shows the averaged waveforms associated with these three response categories overlaid at selected lateral and midline sites.

![Grand average ERPs](image)

Figure 9.1. Grand average ERPs (N=16) associated with targets, nontargets and new items at lateral prefrontal (50, 36), lateral and midline frontal (33, 8, 22), lateral and midline parietal (30, 14, 25) and lateral occipital sites (44, 42) in Experiment 5.
Both targets and nontargets elicited greater positivity than new items, onsetting at around 200 msec post-stimulus at mid and left parieto-occipital sites. This positivity became maximal at mid-frontal and left parietal sites between 400 and 600 msec, and was sustained at left parietal sites until approximately 800 msec. Targets also showed enhanced positivity relative to both nontargets and new items over right frontopolar sites from 800 msec until the end of the recording epoch. This effect was not observed for nontargets. Both targets and nontargets elicited greater negativity than new items at mid and right parietal and at lateral occipital sites. This negativity onset at approximately 600 msec (the negativity elicited by nontargets onset a little later), and was sustained until the end of the recording epoch.

Experiment 5 used the same ERP analysis strategy as that described in Experiment 4. Global repeated measures analyses were conducted on data associated with new items, targets and nontargets from lateral frontopolar, frontal, parietal and occipital sites within the 400-600, 500-800 and 800-1400 msec latency regions. As in Experiments 3 and 4, the 400-600 msec latency region replaced the 300-500 msec latency region analysed in Experiments 1 and 2, as the early frontal effect of interest again appeared to onset a little later than in these earlier experiments. Mean amplitude differences between targets and new items and between nontargets and new items are shown at lateral frontopolar, frontal, parietal and occipital sites for each latency region in figure 9.2. An a priori analysis was also conducted on the three response categories at mid-frontal sites (19, 8, 9) within the 400-600 msec latency region. Any effect of response category observed in either the global or a priori analyses were followed up with three pairwise comparisons between targets and new items, between nontargets and new items, and between targets and nontargets. As Experiments 4 and 5 employed exactly the same design and were conducted in quick succession on the same subjects from the same population, a set of focused between-subjects analyses were also conducted on data from the two experiments. These analyses were intended to demonstrate which ERP old/new effects were influenced by the between-experiment manipulation of levels-of-processing during study phase 2. Data from mid-frontal sites (19, 8, 9) were analysed within the 400-600 msec latency region. Data from left parietal sites (46, 30, 19) were analysed within the 500-800 msec latency region, as were data from right parietal sites (40, 25, 26). Finally, data from right frontopolar sites (36, 37) and from the mid-parietal site (14) were analysed within the 800-1400 msec. These analyses employed the factors of experiment, response category and site. Any analysis indicating a target/nontarget x
experiment interaction was followed up with two between-experiment pairwise comparisons between targets and new items and between nontargets and new items.

Figure 9.2. Mean amplitudes and standard errors of target and nontarget old minus new effects at left and right prefrontal (LPf, RPf), left and right frontal (LF, RF), left and right parietal (LP, RP) and left and right occipital (LO, RO) sites within each of the latency regions analysed. Each value is an average of the mean amplitudes observed at the inferior and the superior site at each scalp location.
Again, serial t-tests were conducted in order to determine the onset latency of the late negative waves elicited by targets and nontargets. These t-tests took the form of a series of pairwise comparisons between targets and new items and between nontargets and new items over successive 50 msec latency regions, which were again conducted on data from right occipital sites.

**Magnitude analyses**

Repeated measures analyses

400-600 msec

The global analysis conducted on targets, nontargets and new items revealed a main effect of response category $F(1.6, 23.7) = 7.57, p < 0.005$. A main effect of response category observed in the pairwise comparison performed on targets and new items $F(1.15) = 13.90, p < 0.005$ reflected greater general positivity for targets. A response category x hemisphere x location interaction revealed by the pairwise analysis performed on nontargets and new items $F(1.9, 28.9) = 5.87, p < 0.01$ indicated greater positivity for nontargets over all regions with a mid-temporal and left parietal maximum (see figure 9.3).

![Figure 9.3](image)

Figure 9.3: Voltage map show the scalp distribution of the nontarget minus new effect within the 400-600 msec latency region in Experiment 5.

A main effect of response category $F(1.15) = 20.38, p < 0.001$ observed in a subsidiary analysis confirmed that the effect observed at left parietal sites was significant. No effect of
response category was observed in the pairwise comparison of targets and nontargets. The a priori analysis conducted at mid-frontal sites revealed a main effect of response category $F (2.0, 30.0) = 3.83, p < 0.05$. Pairwise comparisons revealed a main effect of response category $F (1, 15) = 7.34, p < 0.05$ for nontargets and new items, and a trend towards a main effect of response category $F (1, 15) = 3.21, p < 0.01$ for targets and new items. Both effects reflected greater positivity for old items than for new items. No effect of response category was observed in the pairwise comparison of targets and nontargets.

500-800 msec

Response category x location x hemisphere $F (3.4, 50.5) = 5.63, p < 0.001$ and response category x location x site $F (4.0, 60.6) = 4.79, p < 0.005$ interactions were observed in the global analysis conducted on targets, nontargets and new items. Pairwise comparison of targets and new items revealed a response category x location x hemisphere interaction $F (2.2, 32.3) = 4.56, p < 0.05$, reflecting greater positivity for targets over all regions, maximal at mid-temporal sites and spreading over left parietal sites (see figure 9.4.1). A main effect of response category $F (1, 15) = 7.17, p < 0.05$ observed in a simple effects analysis conducted on targets and new items at left parietal sites indicated that the effect at these sites was significant. Pairwise comparison of nontargets and new items gave rise to a response category x location x hemisphere interaction $F (2.0, 29.6) = 10.31, p < 0.001$, indicating greater positivity for nontargets over sites in the left hemisphere (maximal at left parietal sites) and greater negativity for nontargets over sites in the right hemisphere (with a right parieto-occipital maximum, see figure 9.4.3). Subsidiary analyses indicated main effects of response category both at right parieto-occipital sites $F (1, 15) = 5.39, p < 0.05$ and at left parietal sites $F (1, 15) = 13.47, p < 0.005$. Pairwise comparison of targets and nontargets gave rise to a response category x hemisphere x site interaction $F (1, 15) = 7.25, p < 0.05$, indicating greater negativity for targets at right hemisphere sites (see figure 9.2). Subsidiary analyses indicated that the effect over right hemisphere sites was significant $F (1, 15) = 4.86, p < 0.05$.

800-1400 msec

The global analysis conducted on the three response categories within this latency region revealed a response category x location x hemisphere interaction $F (3.3, 49.4) = 6.03, p <$
0.001. Pairwise comparison of targets and new items gave rise to a response category x location x site interaction $F(2.4, 36.3) = 9.10, p < 0.001$, reflecting greater positivity for targets at superior prefrontal sites, and greater negativity for targets at all other sites maximal at superior occipital sites (see figure 9.4.2).

Figure 9.4.1 Figure 9.4.2

Figure 9.4.3 Figure 9.4.4

Figure 9 4. Voltage maps show the scalp distributions of the target minus new effect between 500-800 msec (figure 9.4.1) and between 800-1400 msec (figure 9.4.2), and of the nontarget minus new effect between 500-800 msec (figure 9.4.3) and between 800-1400 msec (figure 9.4.4).

A response category x hemisphere x site interaction $F(1, 15) = 5.67, p < 0.05$ observed in a subsidiary analysis performed on targets and new items at superior prefrontal sites indicated
greater positivity for targets with a right superior prefrontal maximum. The effect at this site was significant $F(1, 15) = 6.22, p < 0.05$. A main effect of response category $F(1, 15) = 16.10, p < 0.001$ observed in a second subsidiary analysis conducted at superior occipital sites confirmed that the effect at these sites was also significant. Pairwise comparison of nontargets and new items revealed a response category x location x hemisphere interaction $F(2.5, 38.1) = 13.73, p < 0.001$, reflecting greater negativity for nontargets over most regions with a right parietal maximum and a small degree of positivity at the right superior frontopolar site (see figure 9.4.4). A main effect of response category $F(1, 15) = 17.04, p < 0.001$ was observed in a simple effects analysis conducted on nontargets and new items at right parietal sites. No effect of response category was detected in a subsidiary analysis of nontargets and new items at the right superior frontopolar site. Pairwise comparison of targets and nontargets gave rise to a response category x hemisphere x location interaction $F(2.1, 31.0) = 3.47, p < 0.05$. This interaction reflected greater positivity for targets over all sites with a right prefrontal maximum. A main effect of response category was observed in a subsidiary analysis of targets and nontargets conducted at these sites $F(1, 15) = 11.21, p < 0.005$. No effect of response category was detected in a second subsidiary analysis conducted on targets and nontargets at right occipital sites.

**Between-subjects analyses**

**400-600 msec**

The between-subjects analysis conducted on all three response categories at mid-frontal sites revealed a main effect of response category $F(1.9, 58.4) = 7.23, p < .005$, which did not interact with experiment. Pairwise comparisons showed that both targets $F(1, 30) = 11.64, p < .005$, and nontargets $F(1, 30) = 11.29, p < .005$, were significantly more positive-going than new items. Neither effect interacted with experiment.

**500-800 msec**

The analysis of targets, nontargets and new items at left parietal sites gave rise to a response category x experiment interaction $F(1.6, 49.2) = 4.69, p < .05$, and a response category x site interaction $F(2.4, 71.3) = 5.91, p < .005$. Subsidiary analysis of targets and new items revealed a main effect of response category $F(1, 30) = 13.27, p < .001$ and a response category x site interaction $F(1.5, 44.8) = 4.16, p < .05$. These findings indicate greater positivity for targets at left parietal sites, an effect that did not interact with experiment. Pairwise comparison of nontargets and new items revealed a response category x experiment interaction...
interaction \( F (1, 30) = 5.30, p < .05 \), indicating that the size of the effect at these sites differed between experiments. Subsidiary analyses showed a main effect of response category \( F (1, 15) = 13.47, p < .005 \) in Experiment 5, but no effect of response category in Experiment 4. Analysis of targets, nontargets and new items at right parietal sites revealed a main effect of response category \( F (1.7, 50.3) = 6.86, p < 0.005 \). No effect of response category was observed in the subsidiary analysis of targets and new items. A main effect of response category \( F (1, 30) = 4.89, p < 0.05 \) was observed in the pairwise comparison of nontargets and new items, reflecting greater negativity for nontargets. This effect did not interact with experiment.

800-1400 msec

The analysis of the three response categories at right frontopolar sites revealed a main effect of response category \( F (1.9, 56.4) = 9.24, p < 0.001 \) and a response category x site interaction \( F (1.6, 47.4) = 9.09, p < 0.001 \). Pairwise comparison of targets and new items gave rise to a main effect of response category \( F (1, 30) = 15.48, p < 0.001 \) and a response category x site interaction \( F (1, 30) = 7.97, p < 0.01 \), reflecting greater positivity for targets with a superior right frontopolar maximum. This effect did not interact with experiment. Pairwise comparison of nontargets and new items revealed an experiment x response category interaction \( F (1, 30) = 6.43, p < 0.05 \). Subsidiary analysis revealed a main effect of response category \( F (1, 15) = 6.72, p < 0.05 \) and a response category x site interaction \( F (1, 15) = 8.52, p < 0.05 \) in Experiment 4, but no effect of response category in Experiment 5. A main effect of response category was observed in the analysis of targets, nontargets and new items at the mid-parietal site \( F (1.9, 55.9) = 15.65, p < 0.001 \). Main effects of response category were also observed in the pairwise comparisons of targets and new items \( F (1, 30) = 16.16, p < 0.001 \) and of nontargets and new items \( F (1, 30) = 23.97, p < 0.001 \). Neither effect interacted with experiment.

Serial t-tests

A main effect of response category was observed in the pairwise comparison of nontargets and new items within the 650-700 msec latency region \( F (1, 15) = 11.29, p < 0.005 \). A main effect of response category was not observed in the pairwise comparisons of targets and new items until the 950-1000 msec latency region \( F (1, 15) = 5.07, p < 0.05 \).
**Topographic analyses**

A topographic analysis was conducted on targets minus new items and on nontargets minus new items across the 500-800 msec and 800-1400 msec latency regions. This analysis employed the factors of epoch, target/nontarget and site, and revealed an epoch x target/nontarget x site interaction $F(3.5, 53.0) = 3.44, p < 0.05$. Target/nontarget x site interactions were also observed both in the 500-800 msec latency region $F(4.2, 62.4) = 3.52, p < 0.05$ and in the 800-1400 msec latency region $F(4.8, 71.5) = 3.81, p < 0.005$. This pattern of results indicated that the target old/new effect had a mid-temporal maximum between 500-800 msec shifting to a right frontopolar maximum between 800-1400 msec, whereas the nontarget old/new effect had a left parietal maximum between 500-800 msec and elicited no right frontal effect between 800-1400 msec (see figure 9.4). Both targets and nontargets were also characterised by greater negativity within the 800-1400 msec latency region.

**Discussion**

**Behavioural data**

Accuracy associated with targets was significantly lower than that associated with either nontargets or new items in Experiment 5. Discrimination of targets from new items was also poorer in Experiment 5 (.52) than in Experiment 4 (.72), presumably because targets were encoded more superficially in Experiment 5. As anticipated, memory for targets therefore appeared to be less reliable in Experiment 5 than in Experiment 4. Accuracy associated with nontargets did not differ between Experiments 4 (.83) and 5 (.84). As in Experiments 3 and 4, correctly classified new items were associated with significantly faster RTs than either class of correctly classified old item, indicating that subjects were again able to reject new items at an earlier point than they were able to make a source attribution. Although this discrimination of old from new items could either have been made on the basis of early novelty/familiarity information or on the basis of the retrieval of undifferentiated information (Johnson, Hashtroudi, & Lindsay, 1993; Johnson, Kounios, & Reede, 1994), the hypothesis that items were recognised on the basis of familiarity prior to source information becoming available is consistent both with response deadline studies reporting an earlier time course for familiarity than for recollection (Yonelinas & Jacoby, 1994) and with the observation of early frontal effects for these items in Experiment 4. Few conclusions could be drawn with regard to the nontarget behavioural data, as the ratio of recognised to forgotten items remain
unknown. However, as nontargets were encoded under identical study conditions in both Experiment 4 and Experiment 5, it can be argued on the basis of the behavioural study described in Experiment 4 that the majority of these items were available to episodic retrieval. The finding that RTs to all three response categories did not differ across experiments suggests that any between-experiment differences observed in the ERPs to these response categories cannot be explained in terms of latency jitter.

**Functional interpretation of ERP data**

**Parietal old/new effect**

It was anticipated that by reducing the reliability of memory for targets in Experiment 5, subjects would be encouraged to probe for source information from both study phases as opposed to probing selectively for source information from study phase 2. It was predicted that both targets and nontargets would consequently elicit a parietal old/new effect. The findings from Experiment 5 supported this hypothesis, as ERPs to both targets and nontargets were significantly more positive going than ERPs to new items at left parietal sites between 400-800 msec. Perhaps the most striking feature of these data is the fact that nontargets were encoded and tested under identical experimental conditions in Experiments 4 and 5, and accuracy and RTs associated with nontargets remained constant between the two experiments. Indeed, the only difference between the two experiments was the processing task with which targets were encoded. The differences observed in nontarget ERPs between the two experiments, therefore, were attributable to this manipulation. The finding that nontargets elicited a parietal old/new effect in Experiment 5 but not in Experiment 4 supports the argument that subjects did not attempt to retrieve nontargets in Experiment 4 when memory for targets was good, but did attempt to retrieve source information from study phase 1 in Experiment 5 when memory for targets was poor. This interpretation implies that excluded nontargets are not necessarily recollected in exclusion tasks if source memory for to-be-included items is reliable. The implications of this finding, and its relevance to those of previous studies will be discussed in Chapter 10.

However, an alternative interpretation must also be considered. This interpretation focuses on the functional characteristics of the parietal old/new effect, and rather than assuming that the absence of this effect reflects an absence of recollection, it assumes that the findings from Experiments 4 and 5 suggest that recollection is necessary but not sufficient to elicit the
parietal old/new effect. According to this interpretation, nontargets were in fact recollected in both experiments, but additional processing consequential on the recollection of nontargets was performed in Experiment 5 but not in Experiment 4, and it is this additional processing that elicited the parietal old/new effect. As stated above, this differential processing must be related to the between-experiment manipulation of study phase 2 (i.e. target) encoding task. It may be the case that as nontargets became more salient in Experiment 5, more attentional resources were allocated to these items, and that a parietal old/new effect was observed only in Experiment 5 because source information associated with nontargets was attended to and manipulated in a task-relevant manner. According to one’s definition of recollection, this may amount to the same thing as saying that nontargets were not recollected in Experiment 4, as some theorists would argue that recollection constitutes not only the retrieval of contextual information but also the conscious manipulation of this information (Jacoby & Kelley, 1991) (Gruppuso, Lindsay, & Colleen, 1997). Again, this point shall be discussed in greater detail in Chapter 10.

Although targets and nontargets both elicited significant parietal positivity between 500-800 msec, the two old/new effects were qualitatively distinct. Whereas nontargets elicited an effect maximal at left parietal sites, targets elicited an effect maximal at mid centro-parietal sites. As a qualitative difference in ERPs is indicative of at least partially non-overlapping neural generators, this finding may contravene a further assumption underlying the process dissociation procedure; namely, that retrieval processes during inclusion and exclusion are qualitatively similar (Jacoby, 1991). This difference was also observed between the old/new effects associated with preexposed and non-preexposed items in Experiments 1 and 2, when it was argued that a baseline artefact resulting from differences in response confidence may have been to blame. However, as both targets and nontargets were compared with the same baseline (and these items were quickly and accurately rejected), this interpretation does not appear to account for the data in Experiment 5. A more plausible explanation may be that the earlier onset of the late negative wave elicited by nontargets relative to targets influenced the scalp distributions of the target and nontarget old/new effects observed within this latency region (see figure 9.3). The fact that the late negative wave associated with nontargets again onset earlier than that associated with targets indicates that the absence of a parietal old/new effect in Experiment 4 was not due to the attenuating influence of this effect. The between-subjects analyses conducted within the 500-800 msec latency region supported this argument, as an effect of experiment was observed for the nontarget parietal old/new effect whereas no
effect of experiment was observed for the late negative wave elicited by nontargets at right parietal sites. It therefore appears that the amplitude of the parietal old/new effect does not co-vary with the amplitude of the late negative wave, and that the absence of a nontarget parietal old/new effect in Experiment 4 cannot be accounted for by the larger and earlier onsetting negativity elicited by these items over right parietal sites.

Early frontal effect

Nontargets were significantly more positive going than new items at mid-frontal sites between 400-600 msec. This effect did not reach significance for nontargets in Experiment 4, although a trend was indicated for the positivity observed. Jacoby (1991) argued that both targets and nontargets elicit familiarity-based recognition in exclusion tasks, and that familiarity elicited by nontargets must be opposed by recollection in order to respond to these items accurately. One would therefore expect both targets and nontargets to elicit early frontal effects in both experiments if this effect is a correlate of item familiarity, as familiarity-based recognition is assumed to remain independent of controlled processes such as retrieval strategy (Mandler, 1980; Jacoby, 1991). Although the early frontal effect observed for nontargets did not reach significance in Experiment 5, a trend towards this effect was observed within this latency region, and the early frontal effect associated with targets was significant in Experiment 4. As both nontargets in Experiment 4 and targets in Experiment 5 elicited early frontal effects that showed a trend but failed to reach significance, it was again considered that this may have been due to a lack of power. This argument was supported when the between-experiment analysis conducted at mid-frontal sites within the 400-600 msec latency region revealed significant old/new effects for both targets and nontargets that did not interact with experiment. This pattern of data is consistent with the criteria discussed above for a correlate of familiarity-based recognition, as early frontal effects were observed for both targets and nontargets and remained unaffected by experiment. The fact that no effect of experiment was observed for the early frontal effect elicited by targets is also consistent with previous reports that that this effect does not vary with depth of processing (Rugg et al., 1998), as targets were encoded deeply in Experiment 4 and less deeply in Experiment 5. The finding that both targets and nontargets elicited the putative correlate of familiarity is also consistent with the behavioural finding that new items were rejected prior to old items receiving a source attribution, as it was hypothesised from this finding that targets and nontargets were initially recognised on the basis of familiarity before recollection of diagnostic source information became available.
The late negative wave and right frontal old/new effect
Whereas both targets and nontargets elicited significant positivity at right frontopolar sites in Experiment 4, this effect was not observed for nontargets in the present experiment. This finding was unexpected, and together with findings from Experiment 4 provided a double dissociation between the parietal old/new effect and the right frontal old/new effect. This dissociation weakens the link between recollection and the right frontal effect still further (Wilding & Rugg, 1996; Donaldson & Rugg, 1998; Johnson, Kreiter, Russo, & Zhu, 1998), as it appears that right frontal positivity is neither contingent on recollection nor necessarily elicited by it. The fact that a right frontal old/new effect was elicited by targets which were associated with a relatively low level of accuracy, but not by nontargets which were associated with a higher level of accuracy is consistent with previous studies reporting significant right frontal old/new effects for old items associated with relatively weak levels of memory but not for well-remembered items (Rugg, Allan, & Birch, 2001; Ullsperger, Mecklinger, & Muller, 2001), and supports the view that the functional significance of the right frontal effect observed in these studies is more consistent with a monitoring and evaluative role independent of recollection. It is, however, unclear why a right frontal old/new effect was elicited by nontargets in Experiment 4 but not in Experiment 5, as accuracy associated with these items did not change between experiments. According to the theoretical framework within which this experiment was conducted, the absence of the nontarget right frontal effect in Experiment 5 must be related to the different retrieval strategy that subjects are argued to have adopted in Experiment 5. One possible explanation is that now subjects were encouraged to retrieve source information associated with nontargets, little monitoring was required to retrieve this information as nontargets had been encoded in a very deep processing task that typically results in high levels of recollection, whereas targets are likely to have required a high degree of monitoring now that memory for these items was relatively poor. However, if this was the case, one would arguably expect nontargets to be associated with significantly faster RTs than either targets in Experiment 5 or nontargets in Experiment 4, and no differences in RT were detected between these response categories.

Both targets and nontargets again elicited significantly greater negativity than new items over right parietal and occipital regions. As in Experiment 4, the late negative wave elicited by nontargets onset between 650-700 msec whereas that associated with targets onset between 950-1000 msec, although no differences in amplitude were detected between targets and
nontargets within the 800-1400 msec latency region in this experiment. It was argued in Experiments 3 and 4 that the late negative wave may reflect the response conflict experienced when recognition can lead to more than one response under conditions in which response selection is difficult, and that this conflict is greater for recognised nontargets as they require a 'new' response. This pattern of results is consistent with this argument but does not add to it.

Summary

Experiment 5 investigated the hypothesis that no parietal old/new effect was observed for nontargets in Experiment 4 because subjects probed each test cue judged to be old specifically for source information diagnostic of a target, and that this retrieval strategy was facilitated by the fact that memory for targets was reliable. Experiment 5 examined this hypothesis by replacing the deep encoding task employed during study phase 2 in Experiment 4 with a shallower encoding task in Experiment 5. Memory for targets was subsequently poorer in Experiment 5 than in Experiment 4, and a parietal old/new effect was elicited both by targets and by nontargets. It is argued that this finding reflected the adoption of a different retrieval strategy in Experiment 5 in which subjects attempted to retrieve source information from both study phases, and that they were encouraged to adopt this retrieval strategy because memory for targets was now less reliable. Findings from Experiments 4 and 5 suggest that nontargets are not necessarily excluded on the basis of recollection but that they can instead be excluded in the absence of the retrieval of source information indicative of a target, and that this retrieval strategy is adopted only if memory for targets is reliable. If true, this account may have implications for the boundary conditions of the process dissociation procedure, as the use of the exclusion task assumes that nontargets are excluded on the basis of recollection. An alternative explanation is that nontargets were in fact recollected in both experiments, but that the parietal old/new effect is only elicited if retrieved information is attended to and consciously employed to control responding. Between-experiment analyses demonstrated that both targets and nontargets elicited early frontal effects in both Experiment 4 and Experiment 5, and that these effects did not differ between experiments. These findings suggest the kind of automaticity often associated with familiarity, and are therefore consistent with the view that the early frontal effect is a correlate of item familiarity. Finally, although targets elicited a right frontal old/new effect, surprisingly this effect was not elicited by nontargets. Although this finding supports the view that the parietal old/new effect is
neither necessary nor sufficient to elicit the right frontal effect, it is difficult to explain why no right frontal effect was observed for nontargets. The proposed explanation is that it is plausible that nontargets in the present experiment would require little or no monitoring as they should be retrieved quickly, accurately and confidently due to the deep nature of their encoding. However, the fact that no RT differences were observed between targets and nontargets does not support this explanation.
Chapter 10. General Discussion

The experiments described within this thesis examined models of recognition memory using variations on a design derived from the exclusion component of the PDP (Jacoby, 1991). All studies employed a three-phase design in which nontargets were encoded in study phase 1, targets were encoded in study phase 2, and subjects were at test instructed to respond ‘old’ to targets and ‘new’ both to new items and to nontargets. This design allowed the identification of multiple ERP correlates of recognition memory, insight into the functional significance of each of these correlates, and an examination of various boundary conditions and assumptions underlying the PDP. Findings from each of the five experiments will be briefly summarised before a more detailed discussion of the various issues which arose from these experimental findings. A large part of this discussion focuses on the fractionation and functional significance of ERP correlates of recognition memory. The relevance of these findings to the study of recognition memory is also discussed. It should be noted that a distinction is made throughout this chapter between the phenomenological experience of recognition and an overt recognition response, as the former does not necessarily result in the latter.

Summary of experimental findings

Experiment 1: An investigation of dual-process models of recognition memory employing a shallow preexposure manipulation.

Experiment 1 preexposed half of all studied items and half of all new items in a shallow preexposure task. This manipulation was intended to increase the number of false alarms made to unstudied items by increasing familiarity-based recognition while minimising the contribution of recollection. It was argued that false alarms (i.e. exclusion errors) at test would reflect familiarity-based recognition in the absence of recollection, and that hits (i.e. correctly endorsed studied items) would reflect a combination of familiarity and recollection (Jacoby, 1991). Preexposure significantly increased the proportion of confident and non-confident false alarms, and decreased the proportion of confident correct rejections. Recognition accuracy was therefore greater for non-preexposed items than for preexposed items. Both false alarms and hits were associated with significantly greater positivity than correct rejections at mid-frontal sites between 300-500 msec. It was argued that preexposed false alarms were associated with a higher level of familiarity (i.e. above response criterion) than preexposed correct rejections. It was therefore argued that this early frontal effect
reflected familiarity-based recognition. Hits were also associated with greater positivity than either correct rejections or false alarms at parietal sites between 500-800 msec. This effect was not detected for false alarms, and was therefore associated with recollection. The finding that ERPs associated with familiarity and recollection differed qualitatively supported dual-process models which state that familiarity and recollection are independent processes (e.g. Jacoby, 1991; Yonelinas, 1994).

**Experiment 2: An investigation of dual-process models of recognition memory employing a deep preexposure manipulation.**

Experiment 1 replicated Experiment 2, but presented items in study phase 1 (i.e. the preexposure manipulation) in a deep encoding task rather than a shallow encoding task. Again, preexposure significantly increased the proportion of confident and non-confident false alarms while decreasing the proportion of confident correct rejections, and significantly decreased recognition accuracy. Recognition accuracy for both preexposed and non-preexposed items was poorer in Experiment 2 than in Experiment 1. As in Experiment 1, both false alarms and hits elicited a significant early frontal effect between 300-500 msec, although the amplitude of this effect was now maximal at posterior sites. It was argued that preexposed correct rejections did not elicit an early frontal effect because this response category was associated with a lower level of familiarity than false alarms. Both preexposed hits and preexposed false alarms elicited a parietal old/new effect, indicating that the deep preexposure manipulation increased noncriterial recollection, and that the ERP correlates of criterial and noncriterial recollection are qualitatively similar. Interestingly, all classes of old item also appeared to elicit a late negative wave relative to new items over mid and right parietal sites, an effect that had not been detected in Experiment 1. It was hypothesized that this effect was related to the increased difficulty experienced by subjects when discriminating studied from unstudied items in Experiment 2 relative to Experiment 1.

**Experiment 3: Functional characteristics of the late parietal negative wave.**

Experiment 3 tested the hypothesis that the late negative wave is only elicited when discrimination of studied items from unstudied items is relatively difficult, and investigated whether this effect was carried by old items or by new items. A between-subjects design was employed, in which all studied items were preexposed in a study task together with an equal
number of not-to-be studied items. This preexposure task was shallow for one group and
deep for the other group. At test, subjects were required to respond 'old' to studied items
('targets') and to respond 'new' to all other items. Items to be excluded included new items
and preexposed unstudied items ('nontargets'). Recognition accuracy was significantly
poorer in the group presented with the deep preexposure task than in the group presented with
the shallow preexposure task, indicating that this task caused greater interference and poorer
discrimination in the deep group than in the shallow group. A late negative wave was also
observed for targets and nontargets relative to new items in the deep group but not in the
shallow group. Between-group comparisons indicated that the late negative wave took the
form of greater negativity elicited by old items rather greater positivity elicited by new items.
It was therefore hypothesised that this effect may reflect the response competition
experienced for recognised items when the correct response is uncertain. It was also
observed that targets elicited an early frontal effect and a parietal old/new effect whereas
nontargets did not. It was hypothesised that no parietal old/new effect was elicited by
nontargets because subjects discounted contextual information from study phase 1, and that
subjects employed this retrieval strategy because contextual information from study phase 1
could not be employed to exclude nontargets.

Experiment 4: Does the parietal old/new effect reflect recollection of task-
relevant information?

Experiment 4 examined the hypothesis that subjects did not recollect nontargets in
Experiment 3 because the retrieval of source information from study phase 1 could not be
used to exclude nontargets. Experiment 4 therefore replicated Experiment 3, with the
exception that new words were presented in study phase 2 as opposed to repeated words from
study phase 1. Retrieval of contextual information from study phase 1 could now be
employed to exclude nontargets. However, although a parietal old/new effect was observed
for targets, no such effect was detected for nontargets. Following subject debriefing, it was
hypothesised that subjects may have adopted a retrieval strategy in which each test cue was
specifically probed for source information from study phase 2, and that subjects adopted this
strategy both because the task requirements only explicitly required the recollection of target
information, and because memory for targets was sufficiently good to support this strategy.
Both targets and nontargets elicited an early frontal effect in Experiment 4. As the nontarget
false alarm rate was lower in Experiment 4 than in the previous three experiments, it was
argued that subjects adopted a stricter response criterion when responding on the basis of familiarity in Experiment 4 than in earlier experiments, and that a larger proportion of correctly classified nontargets were highly familiar as a result. Targets and nontargets also elicited both a late negative wave and a right frontal old/new effect in Experiment 4. It was again argued that the former reflected the response competition experienced upon recognition of an item, and that the latter reflected monitoring and evaluation operations elicited by all recognised items which probed for source information from study phase 2.

**Experiment 5: Does the parietal old/new effect reflect recollection susceptible to retrieval strategy?**

Experiment 5 tested the hypothesis that nontargets did not elicit a parietal old/new effect in Experiment 4 because subjects probed memory selectively for source information from study phase 2. As it was argued that subjects were able to adopt this retrieval strategy because memory for targets was reliable, Experiment 5 replicated Experiment 4 with the exception that targets were presented in study phase 2 in a relatively shallow encoding task. This manipulation was intended to reduce the reliability of memory for targets, and to therefore encourage subjects to employ source information from study phase 2. The behavioural data showed that recognition accuracy associated with targets was lower in Experiment 5 than in Experiment 4, whereas nontarget accuracy did not vary across experiment. As predicted, a parietal old/new effect was now observed both for targets and for nontargets. This finding led to two possible conclusions; either nontargets in an exclusion task are not always recollected, or the parietal old/new effect is a correlate of additional processing contingent on recollection (e.g. attentional factors). Both targets and nontargets once more elicited an early frontal effect in Experiment 5. As the nontarget false alarm rate was again lower than in the first three experiments, it was argued that subjects adopted a stricter response criterion when responding on the basis of familiarity, so that correctly classified nontargets were associated with a higher level of familiarity than in the first three experiments. Targets and nontargets both elicited a late negative wave, whereas a right frontal old/new effect was only observed for targets. It was suggested that a right frontal old/new effect was not detected for nontargets in Experiment 5 because these items were confidently recollected due to their deep encoding, and that these items therefore required little monitoring now that subjects were employing source information from study phase 1.
Functional accounts of ERP correlates of recognition memory

The parietal old/new effect

The parietal old/new effect was one of the first ERP correlates of recognition memory to be identified, and a significant amount of research has therefore been dedicated to delineating the functional significance of this effect. A variety of studies have reported that the amplitude of the parietal old/new effect is sensitive to manipulations known to influence the recollective component of recognition memory. For example, it has been found that the amplitude of the parietal old/new effect is larger for Remember than for Know responses (Smith, 1993), larger for deeply studied than for shallowly studied items (Rugg et al., 1998), larger for word-pairs that are presented intact at test rather than rearranged (Donaldson & Rugg, 1998), larger for recognised words than for recognised pseudowords (Curran, 1999), and larger for recognised items that attract correct source attributions than for recognised items that do not (Wilding & Rugg, 1996; Rugg, Schloerscheidt, Doyle, Cox, & Patching, 1996; Curran, 2000; Curran, Schacter, Johnson, & Spinks, 2001; Nessler, Mecklinger, & Penney, 2001). It has also been reported in a number of neuropsychological studies employing ERPs that patients whose recollection is thought to be selectively impaired show only mildly impaired recognition performance but no parietal old/new effect (Tendolkar et al., 1999; Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997; Mecklinger, von Cramon, & Matthes-von Cramon, 1998). Although a number of these findings are open to refutation (see Chapter 4), this wealth of convergent evidence strongly suggests that the parietal old/new effect is a correlate of recollection-based recognition memory.

Several of the findings from the five experiments described within this thesis can be cited in support of this view. All five experiments employed variations on an exclusion task (Jacoby, 1991). Jacoby (1991) argued that correctly endorsed target items are recognised on the basis of a combination of recollection and familiarity, whereas incorrectly endorsed new items and nontargets (or ‘exclusion errors’) are recognised on the basis of familiarity alone. Therefore, the finding that correctly classified targets (or ‘preexposed hits’ and ‘non-preexposed hits’ in Experiments 1 and 2) elicited a parietal old/new effect in all five experiments whereas exclusion errors in Experiment 1 did not, supports the view that the parietal old/new effect reflects recollection. So strong is the link between recollection and the parietal old/new effect, one can argue that detection of a parietal old/new effect for a particular response category indicates that this response category is associated with recollection-based
recognition memory. If one adopts this view, it appears that preexposed false alarms in Experiment 2 were not recognised purely on the basis of familiarity but that they were also recognised on the basis of noncriterial recollection, as this response category elicited a parietal old/new effect whereas preexposed false alarms in Experiment 1 did not. This finding replicates Cycowicz et al. (2001) who also reported a parietal old/new effect for exclusion errors, although these authors interpreted this finding as evidence that the parietal old/new effect reflects familiarity as opposed to recollection (see Chapter 3). However, Cycowicz et al.’s (2001) data can also be explained in terms of noncriterial recollection, and when interpreted in this way are consistent with the findings from Experiment 2. Implications of these findings for the boundary conditions of the PDP will be discussed towards the end of this chapter.

One of the most interesting findings described in this thesis was that correctly excluded nontargets (or ‘preexposed correct rejections’ in Experiments 1 and 2) did not elicit a parietal old/new effect in Experiments 1-4. This finding was extremely surprising for a number of reasons; firstly, a further assumption underlying the PDP is that correctly classified nontargets are excluded on the basis of recollection (Jacoby, 1991). If this is the case, one would expect these items to elicit the parietal old/new effect if this effect is a correlate of recollection-based recognition. A second reason why this finding was surprising is that the majority of previous ERP studies employing exclusion-based tasks have reported parietal old/new effects both for targets and for nontargets, although the effect is typically smaller for nontargets than for targets (Rugg, Brovedani, & Doyle, 1992; Cycowicz, Friedman, & Snodgrass, 2001; Wilding & Rugg, 1997). However, one previous study has reported data comparable to that reported in this thesis, and has also provided some insight as to why this may have occurred (Dywan, Segalowitz, & Webster, 1998). Dywan et al. (1998) found that whereas young subjects showed a parietal old/new effect for targets but not for nontargets, both young subjects under conditions of divided attention and older subjects showed parietal old/new effects in response to targets and to nontargets. It was argued that young subjects under normal conditions had greater attentional resources and were able to exercise greater control during the task, and that the absence of a parietal old/new effect to nontarget stimuli reflected this attentional control (Dywan, Segalowitz, & Webster, 1998). However, it was unclear from this study at what level this attentional control was hypothesised to operate; whether recollection itself or the use of recollected information was subject to control.
It was demonstrated in Experiment 4 that the absence of a nontarget parietal old/new effect in Experiments 1-3 was not solely due to the inability of subjects to employ the recollection of source information from the nontarget study phase to exclude nontargets. It therefore appeared that nontargets in exclusion tasks are not necessarily recollected even if recollection of the source information associated with these items can in principle be used to exclude them. After establishing that source information from study phase 1 was available to episodic retrieval in Experiment 4 (by means of a small behavioural experiment), it was hypothesised that nontargets may not have elicited a parietal old/new effect in Experiments 1-4 because experimental conditions encouraged subjects to adopt a retrieval strategy in which source information from study phase 1 was not employed. It is argued that subjects adopted a retrieval strategy during the first four experiments in which they selectively probed each test cue for source information from study phase 2 at the expense of source information from study phase 1. It is proposed that subjects were encouraged to adopt this retrieval strategy both because test instructions only explicitly required the recollection of source information from study phase 2, and because memory for targets was sufficiently reliable to support this retrieval strategy, as all four experiments had employed a deep encoding task in study phase 2. Experiment 5 tested this hypothesis by removing one of the factors hypothesised to support this retrieval strategy; by replacing the deep encoding task in study phase 2 with a shallower encoding task, it was anticipated that it would no longer be efficient for subjects to adopt the retrieval strategy described above, as memory for targets would no longer be sufficiently reliable to support such a strategy. It was observed in Experiment 5 that as recognition accuracy associated with targets decreased, a parietal old/new effect emerged for nontargets, despite the fact that the behavioural data associated with nontargets did not change between Experiments 4 and 5. It was therefore argued in Chapter 9 that memory for targets in Experiment 5 was no longer sufficiently reliable to allow subjects to rely on this information alone when responding differentially to studied items, and that subjects now also had to attend to source information from study phase 1 in order to perform the task.

The pattern of results pertaining to nontarget parietal old/new effects across all five experiments arguably led to one of two possible conclusions. The first of these is that the parietal old/new effect is not an obligatory correlate of recollection, but that it rather reflects additional processing contingent on recollection. According to this interpretation, source information from both study phases may have been recollected in all five experiments, but subjects in Experiments 1-4 only attended to and employed source information from study
phase 2 at test. This hypothesis would state that the parietal old/new effect reflects the attentional and/or control processes that act upon recollected information as opposed to the recollected information itself. It could alternatively be concluded that if the parietal old/new effect is an obligatory correlate of recollection, the absence this effect for correctly classified nontargets in Experiments 1-4 indicates that these items were not recollected at all in the first four experiments. According to this interpretation, subjects were able to successfully suppress or discount recollection of source information deemed to be task-irrelevant as a consequence of the retrieval strategy employed. If this conclusion is correct, it again has implications for the boundary conditions of the PDP, as a further assumption underlying this procedure is that nontargets are correctly excluded on the basis of recollection (Jacoby, 1991). Such an account would also imply that one is able to differentially recollect contextual information available to episodic retrieval from different sources in accordance with task demands and retrieval strategies. These issues will also be discussed in greater detail towards the end of this chapter.

Certain theorists would argue that the two interpretations described above amount to the same thing, as attention, volition and control are perceived as being defining characteristics of recollection (e.g. Jacoby & Kelley, 1992). According to these theorists, a parietal old/new effect exhibiting these functional characteristics would therefore still be considered to be an obligatory correlate of recollection as operationalised in this way. However, other theorists would argue that these kinds of processes are additional to and independent from recollection, as recollection is conceptualised simply as the phenomenological experience of remembering some contextual aspect of the prior presentation (e.g. Gardiner & Java, 1993b). This school of thought would therefore argue that a parietal old/new effect dependent on attentional and control processes would not act as an obligatory correlate of recollection, and would perceive the two competing accounts described above as being mutually exclusive.

**The early frontal effect**

In all five experiments, certain classes of recognised items were associated with an early frontal effect which took the form of greater positivity elicited by recognised items than by correctly classified unstudied items, typically maximal at frontal sites between approximately 300-600 msec. This effect has previously been reported in a number of other studies (Curran, 1999; Curran, 2000; Curran, Schacter, Johnson, & Spinks, 2001; Rugg et al., 1998; Tendolkar
et al., 1999; Mecklinger, 1998; Duzel, Vargha-Khadem, Heinze, & Mishkin, 2001), and is currently considered to reflect familiarity-based recognition as described by dual-process models of recognition memory (Mandler, 1980; Jacoby & Dallas, 1981; Gardiner & Parkin, 1990; Jacoby, 1991). Evidence presented in this thesis was generally consistent with this hypothesis, although a number of questions remain.

It was argued in Experiment 1 that false alarms (i.e. unstudied items that incorrectly attract an ‘old’ response) are largely made on the basis of familiarity-based recognition memory (Schacter, Norman, & Koutstaal, 1998; Endl, Walla, Lindlinger, Deecke, & Lang, 1999), as the acontextual and therefore largely non-diagnostic nature of this form of memory does not allow one to determine the source of the familiarity. The extent to which subjects false alarm arguably depends on the extent to which they rely on familiarity-based recognition memory when making a recognition judgement. It should therefore follow that ERPs associated with false alarms can be interpreted as a correlate of familiarity. A pair of previous ERP studies of recognition memory employed a manipulation designed to increase the number of false alarms made during a recognition memory test on the basis of the assumption that false alarms provide a measure of familiarity (Curran, 2000; Curran, Schacter, Johnson, & Spinks, 2001). These studies presented a number of new items at test that were either plurality-reversals (Curran, 2000) or semantic associates (Curran, Schacter, Johnson, & Spinks, 2001) of words that had been presented at study (see Chapter 3). It was predicted that the false alarm rates associated with these lures would be significantly higher than those to new items unrelated to study items, in accordance with the theory that computation of global similarity underlies the familiarity-based recognition (Hintzman & Curran, 1994). False alarms were indeed higher for plurality-reversed and semantically-related lures, and the ERP correlate of these false alarms was an early frontal effect in which false alarms were more positive going than correctly classified new items over left frontal sites between 300-500 msec which dissociated qualitatively from the parietal old/new effect associated with veridical recognition memory judgements (Curran, 2000; Curran, Schacter, Johnson, & Spinks, 2001). However, as argued in Chapter 3, the conclusion that this effect is a correlate of familiarity can be criticised on the basis that false alarms to these kinds of lures (i.e. highly similar to studied items) can be made on the basis of false recollection rather than acontextual familiarity (Payne, Elie, Vlackwell, & Neuschatz, 1996; Roediger & McDermott, 1995).
Experiment 1 investigated ERP correlates of familiarity-based recognition employing a different kind of paradigm, although this paradigm was also based on the assumption that false alarms are made on the basis of familiarity-based recognition (Schacter, Norman, & Koutstaal, 1998; Endl, Walla, Lindlinger, Deecke, & Lang, 1999). However, rather than employing lures highly similar to studied items in an attempt to increase the number of false alarms, Experiment 1 instead used a preexposure manipulation in which half of all studied items and half of all new items were presented in a shallow encoding task prior to study. It was intended that this prior exposure would increase familiarity-based recognition memory while the shallow nature of the task employed would minimise the contribution of recollection to performance. Indeed, it was demonstrated that this preexposure phase substantially increased the proportion of false alarms made at test. An early frontal effect was observed for hits and for false alarms in Experiment 1, maximal at left frontal sites between 300-500 msec. This effect had highly similar spatio-temporal characteristics to the early frontal effect described by Curran (2000). The early frontal effect observed in Experiment 1 was qualitatively distinct from the parietal old/new effect that was detected for hits but not for false alarms. It was therefore concluded that the early frontal effect was a correlate of familiarity-based recognition memory independent from recollection. The finding that this effect occurred prior to the parietal old/new effect thought to reflect recollection-based recognition memory was also consistent with response deadline studies indicating that familiarity was available to subjects prior to recollection (Yonelinas & Jacoby, 1994; Hintzman, Caulton, & Levitin, 1998).

Experiment 2 employed the same design as Experiment 1, but employed a deep encoding task during the preexposure phase rather than a shallow encoding task. Again, the preexposure manipulation significantly increased the proportion of false alarms made at test, and greater positivity observed for hits and false alarms between 300-500 msec reached significance at mid-frontal sites. However, the distribution of this effect was different in Experiment 2 than in Experiment 1, as it was maximal at mid-parietal sites rather than at left frontal sites. Although it is likely that a greater number of false alarms in Experiment 2 will have elicited noncriterial recollection than in Experiment 1 (as evidenced by a parietal old/new effect now evident for false alarms in Experiment 2), it was argued that a large proportion of these items also elicited familiarity above that specified by the response criterion, and that false alarms to nontargets were therefore made on a combination of familiarity and noncriterial recollection. It appears from the particularly high false alarm rate in Experiment 2 that subjects must again
have relied on familiarity to a large extent when responding. Therefore, although it is argued that positivity observed for recognised items relative to correctly classified unstudied items between 300-500 msec reflects familiarity-based recognition, it appears that this effect has a scalp distribution that can shift with experimental conditions. One possible implication of this finding is that familiarity is not comprised of a single process, but that it is in fact a multi-componential basis for recognition consisting of dissociable processes such as perceptual fluency and conceptual fluency (Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998), and that the distribution of the ERP correlate of familiarity depends on the component/s recruited.

In both Experiments 1 and 2, no early frontal effect was observed for preexposed correct rejections. This finding was initially somewhat surprising, as one would arguably predict that an ERP correlate of familiarity would be elicited by all classes of studied item, regardless of response requirement. Indeed, Jacoby (1991) argued that both targets and nontargets in an exclusion task will elicit familiarity-based recognition, and that this familiarity must be opposed by recollection in order for targets to be correctly classified. However, it is likely that fewer preexposed correct rejections were recognised than preexposed false alarms, as all items attracting an 'old' response must by definition be recognised whereas preexposed unstudied items could be successfully excluded simply by being forgotten. In addition to this factor, preexposed unstudied items associated with higher levels of familiarity in the absence of recollection are more likely to intrude as exclusion errors (i.e. false alarms), whereas those associated with lower levels of familiarity are more likely to be correctly excluded (i.e. correct rejections). Therefore, the overall familiarity level associated with preexposed correct rejections is arguably almost always likely to be lower than that associated with preexposed false alarms. The level of familiarity associated with preexposed correct rejections in Experiments 1 and 2 may therefore have been too low to be detected in the ERPs associated with this response category.

The early frontal effect observed for targets in Experiment 3 was particularly unusual. Although this effect showed a mid-frontal maximum as in Experiment 1, it onset a little later than in the two previous experiments (400 msec), and was both extremely large in amplitude and sustained for several hundred milliseconds. The early frontal effect took this form for targets both in the shallow group and in the deep group, but it is unclear why this occurred. As discussed in Chapter 7, one possibility is that the fact that targets had been presented twice
together with the fact that targets had been presented relatively recently combined to result in extremely high levels of familiarity for this response category in Experiment 3, and that these high levels of familiarity were reflected in the amplitude of the early frontal effect. If this is the case, it is unclear why preexposed hits in Experiments 1 and 2 did not elicit an early frontal effect of such large and sustained proportions, as these items had also been presented both twice and most recently. It is unclear how these finding can be reconciled. One difference between Experiments 1-2 and Experiment 3 is that whereas all targets were presented twice in Experiment 3, only half of the comparable items in Experiments 1 and 2 were presented twice. Therefore, whereas subjects could in theory perform the task in Experiment 3 entirely on the basis of familiarity, the levels of familiarity associated with studied and unstudied items in Experiments 1 and 2 were not as distinct, and would arguably not have supported a retrieval strategy that relied exclusively on familiarity. It could therefore be argued that the early frontal effect is not a direct correlate of the phenomenological experience of familiarity per se, but that it rather reflects processes ‘downstream’ from familiarity that determine the degree to which familiarity information is utilised in deciding that an item is old. A functional characteristic such as this would suggest that the early frontal effect reflects the strategic use of familiarity, rather than being an obligatory correlate of familiarity.

As in Experiments 1 and 2, no early frontal effect was observed for correctly classified nontargets (the equivalent of preexposed correct rejections) in Experiment 3. Although the nontarget false alarm rate had dropped substantially between Experiment 2 and Experiment 3, it could still be argued that the most familiar nontargets were still attributed to the target study phase, and that the overall level of familiarity associated with correctly classified nontargets was still too low to manifest itself in the ERPs. However, the fact that three consecutive studies had reported an early frontal effect only for those items attracting an ‘old’ response suggested alternative hypotheses as to the functional significance of the early frontal effect; one possibility was that the early frontal effect is not an obligatory correlate of familiarity-based recognition, but rather that it reflects some kind of processing that occurs ‘downstream’ from familiarity itself. This possibility had already been proposed by Tsivilis et al. (2001), following the finding that not all correctly classified studied items elicited an early frontal effect. If this were the case, the fact that the early frontal effect onsets between 300-400 msec suggests that familiarity itself must onset prior to this point in time. This hypothesis is supported by various single-unit recording studies which place the onset of the
neural responses of ‘familiarity’ neurons (i.e. these neurons show single-trial learning, long-term and high-capacity storage, and response changes are endogenous and automatic regardless of behavioural requirements) in the perirhinal cortex at approximately 75 msec post-stimulus (for review see Brown & Aggleton, 2001). The pattern of data observed up to and including Experiment 3 also suggested that the early frontal effect may simply be a correlate of responding ‘old’, and that it may therefore reflect response-related processes that act upon familiarity. Similarly, as discussed above, it may be that the early frontal effect reflects the extent to which familiarity is employed when making an ‘old’ response. The fact that no previous study had reported an early frontal effect in the absence of an ‘old’ response made this possibility difficult to refute.

However, evidence to the contrary was presented in Experiments 4 and 5, in which early frontal effects were observed both for correctly endorsed targets and for correctly classified nontargets, although these effects only reached significance when analysed across the two experiments. It therefore appears that the early frontal effect is not dependent on an ‘old’ response, which in turn weakens the alternative hypotheses described above which were founded upon this possibility. The question therefore arises, if the early frontal effect reflects familiarity-based recognition, why was this effect not observed for preexposed correct rejections/nontargets in Experiments 1-3? The answer may lie in the false alarm rates observed in all five experiments; whereas the nontarget false alarm rate was over .20 in Experiments 1-3, the nontarget false alarm rates in Experiments 4 and 5 were .17 and .16 respectively. It therefore appears that subjects adopted a stricter criterion when responding on the basis of familiarity in the last two than in the first three experiments, and that fewer highly familiar items were attributed to the target study phase as a consequence. According to this interpretation, this shift in response criterion implies that the overall familiarity signal associated with correctly classified nontargets in Experiments 4 and 5 was greater than in Experiment 1-3, and that this higher familiarity level was manifested in the ERPs. This account rests on the assumption that the ratio of forgotten to familiar nontargets remained constant in the face of shifting false alarms rates.

**The right frontal old/new effect**

As discussed in Chapter 3, the right frontal old/new effect has been repeatedly reported in a variety of studies, the majority of which require some form of source discrimination to be
made. The fact that initial studies observed the right frontal old/new effect in recognition memory tests requiring the retrieval of source information led the authors of these studies to argue that this effect is contingent on recollection (Wilding & Rugg, 1996; Rugg, Schloerscheidt, Doyle, Cox, & Patching, 1996; Donaldson & Rugg, 1998). However, later studies reported that the right frontal old/new effect was neither contingent on, nor necessarily elicited in association with recollection (Wilding & Rugg, 1997; Senkfor & Van Petten, 1998; Trott, Friedman, Ritter., Fabiani, & Snodgrass, 1999; Ullsperger, Mecklinger, & Muller, 2001). This literature is discussed more fully in Chapter 3. On the basis of these findings, the right frontal old/new effect is currently considered to reflect monitoring and evaluation processes that are performed upon the products of retrieval. This retrieval need not take the form of recollection. Indeed, it appears that items associated with a relatively poor level of recognition likely to be based primarily upon familiarity can elicit larger right frontal old/new effects than well-remembered items (Rugg, Allan, & Birch, 2001).

Findings from the experiments contained within this thesis are largely consistent with this view. A double dissociation was demonstrated between recollection (as reflected by the parietal old/new effect) and the right frontal old/new effect in Experiments 4 and 5; whereas a right frontal old/new effect was observed in Experiment 4 for nontargets that did not elicit a parietal old/new effect (and which, it is argued, were not recollected), no right frontal effect was observed for nontargets in Experiment 5 despite the fact that these items were associated with a parietal old/new effect indicative of recollection. These findings therefore support the view that the right frontal old/new effect reflects processes that operate independently from recollection. Right frontal old/new effects were observed for both targets and nontargets in Experiments 3 and 4. This is consistent with the view that the right frontal old/new effect reflects monitoring and evaluation processes that operate on retrieved information, as it is likely that a large proportion of these items were recognised on some basis. The finding that a right frontal old/new effect was observed for both targets and nontargets in Experiments 3 and 4 is also arguably consistent with the hypothesis that subjects in these experiments probed each recognised test item for source information from study phase 2, as this hypothesis implies that monitoring and evaluation processing should have been equivalent for all recognised items. Interestingly, whereas a right frontal old/new effect was observed for targets in Experiment 5, no such effect was detected for nontargets. It is argued that no right frontal old/new effect was elicited by nontargets in this experiment because the different retrieval strategy thought to have been employed by subjects now focused on the retrieval of
contextual information from both study phases. As nontargets had been encoded in a very
deep encoding task (sentence generation), the finding that these items did not elicit a right
frontal old/new effect is arguably consistent with the view that well remembered items
necessitate fewer monitoring and evaluation operations (and therefore smaller or non-existent
right frontal old/new effects) than less well remembered items (Rugg, Allan, & Birch, 2001;
Ullsperger, Mecklinger, & Muller, 2001).

However, the fact that preexposed hits, non-preexposed hits and preexposed false alarms did
not elicit significant right frontal old/new effects in Experiments 1 and 2 appears to contradict
this account. If the right frontal old/new effect reflects monitoring and evaluation processes
contingent on recognition when discrimination of studied from unstudied items is relatively
difficult, one would have predicted that all recognised items in these first two experiments
would have elicited this effect. It is possible that no right frontal old/new effect was detected
for preexposed hits or preexposed false alarms in either Experiment 1 or Experiment 2
because these response categories were compared with preexposed correct rejections. As a
large proportion of preexposed correct rejections may also have been recognised on some
basis, it is possible that ERPs associated with these items also reflected monitoring and
evaluation processes; it is therefore possible that no right frontal old/new effects was
observed in the contrasts between preexposed correct rejections, preexposed hits and
preexposed false alarms because this type of processing was common to all three response
categories. However, a number of post-hoc comparisons conducted on data from the first two
experiments to investigate this hypothesis detected no right frontal old/new effects for
preexposed hits or for preexposed false alarms in either experiment, even when compared
against non-preexposed correct rejections; no effects of response category were observed in
any of the four post-hoc pairwise comparisons conducted at right frontal sites (F4, RF, F8)
between preexposed hits and non-preexposed correct rejections in Experiment 1, preexposed
false alarms and non-preexposed correct rejections in Experiment 1, preexposed hits and non-
preexposed correct rejections in Experiment 2, and preexposed false alarms and non-
preexposed correct rejections in Experiment 2.

Also, this interpretation does not explain why no right frontal old/new effect was detected for
non-preexposed hits either in Experiment 1 or in Experiment 2, as this response category was
contrasted with non-preexposed correct rejections which should have elicited little or no
monitoring and evaluation processes. It is possible that the shallow encoding task employed
during study phase 1 in Experiment 1 resulted in minimal source confusion at test, and that recognised items at test therefore required little or no monitoring prior to responding. This is not reflected in the accuracy data as discrimination of studied items from unstudied items was relatively poor, but it is possible that subjects misattributed familiarity associated with unstudied preexposed items to study phase 2 without acknowledging the competing source of familiarity (i.e. study phase 1). Consistent with this interpretation is the finding that both preexposed hits and preexposed false alarms were associated with significantly shorter reaction times than either class of correct rejection in Experiment 1, suggesting that subjects engaged in little or no monitoring before making a response.

It remains, however, unclear why no right frontal old/new effect was detected for old items in Experiment 2. The deep encoding of preexposed lures during study phase 1 in Experiment 2 should have resulted in a significant degree of source confusion at test, and recognised items should therefore have recruited monitoring and evaluation processes in order to respond accurately to these items. It is possible that the amplitude of the right frontal old/new effect observed for non-preexposed hits at right frontal sites was attenuated by the late negative wave elicited by these items over right parietal sites within the same latency region. This explanation is supported by the findings of Experiments 3 – 5, which used a different electrode placement system to demonstrate that the right frontal old/new effect was in fact maximal at right frontopolar sites in the presence of a late negative wave over right parietal sites, and that the right frontal old/new effect was at times completely eliminated at right frontal sites in the presence of this negativity. However, this explanation was also weakened following four post-hoc comparisons of ERP data from Experiment 2, as no right frontal old/new effect was detected for any type of response to an old item (preexposed hits, non-preexposed hits, preexposed false alarms, preexposed correct rejections) relative to non-preexposed correct rejections even when analysis was restricted to the right frontopolar site (Fp2).

The only remaining hypothesis consistent both with the role of the right frontal old/new effect as a correlate of post-retrieval processing, and with all the findings reported within this thesis, is that the late negative waves elicited by old items in Experiment 2 had a greater attenuating effect on right frontal positivity than they did in Experiments 3-5. This may have occurred either because the late negative waves observed in Experiment 2 were larger than those reported in Experiments 3-5, or because the right frontal old/new effects elicited in
Experiment 2 were smaller than those observed in later experiments, or a combination of the two. Unfortunately, there is no way to test this hypothesis. Even if the late negative wave and the right frontal old/new effect could be compared across experiments, the extent to which these ERP effects overlap and attenuate cannot be determined. In support of this hypothesis, the discrimination of studied from unstudied items was poorer in Experiment 2 than in later experiments, and it is plausible that this may have increased both source monitoring processes and perceived response conflict, both of which have been proposed as a functional basis for the late negative wave.

**The late negative wave**

Both targets and nontargets (i.e. non-preexposed hits and preexposed correct rejections in Experiment 2) elicited late negative waves relative to new items in Experiment 2, in the deep group in Experiment 3, and in Experiments 4 and 5. This effect was maximal over mid and right parieto-occipital sites, and onset at approximately 600 msec. This effect was not observed in Experiment 1, but appeared to be elicited by all types of old item relative to new items in Experiment 2. The finding that the discrimination of studied from unstudied items was poorer in Experiment 2 than in Experiment 1 led to the hypothesis that the late negative wave is elicited in recognition memory tasks requiring attribution of source only when discrimination of old items arising from different sources is relatively difficult. However, it was unclear at this point whether this effect resulted from greater positivity associated with new items in Experiment 2 than in Experiment 1, or whether it resulted from greater negativity associated with all old items in Experiment 2 than in Experiment 1. The between-group design employed in Experiment 3 indicated that this effect resulted from greater negativity elicited by all old items, and that this negativity was elicited by old items only when discrimination of studied from unstudied items is relatively difficult. It was also found in Experiments 4 and 5 that the late negative wave observed for nontargets onset between 650-700 msec whereas that associated with targets did not onset until 950-1000 msec. The amplitude of the nontarget late negative wave was also larger than that elicited by targets in Experiment 4.

Although late negative waves of this nature are not usually detected in yes-no recognition memory tests, a number of previous ERP studies requiring the retrieval of source information have reported late negative waves elicited by old items over parietal sites (Rugg,
Schloerscheidt, Doyle, Cox, & Patching, 1996; Nessler, Mecklinger, & Penney, 2001; Donaldson & Rugg, 1998; Wilding & Rugg, 1997; Cycowicz, Friedman, & Snodgrass, 2001). As in the experiments reported here, one of these studies employing an exclusion task also reported an earlier onsetting and larger amplitude late negative wave for nontargets than for targets (Wilding & Rugg, 1997). A number of competing hypotheses have been proposed to account for the functional significance of the late negative wave; the RT hypothesis (Wilding & Rugg, 1997; Nessler, Mecklinger, & Penney, 2001), the source monitoring hypothesis (Cycowicz, Friedman, & Snodgrass, 2001), and the response competition hypothesis (Mecklinger, 2000). A number of studies have reported that the amplitudes of late negative waves associated with various classes of old item are larger for response categories associated with longer RTs, and it was initially suggested on the basis of these findings that the late negative wave may be response-related (Wilding & Rugg, 1997; Nessler, Mecklinger, & Penney, 2001; Rugg, Schloerscheidt, & Mark, 1998). However, although targets and nontargets were both associated with significantly longer RTs than new items in the present experiments, no differences in RT were observed between targets and nontargets despite the fact that the late negative waves observed for nontargets were earlier onsetting and occasionally larger in amplitude than those observed for targets. Similarly problematic for this account is the fact that no late negative wave was detected for shallow nontargets in Experiment 3, despite the fact that these items were associated with longer RTs than shallow targets or new items. It therefore appears that while the late negative wave may be indirectly related to long RTs, the two are not causally related, and that the late negative wave may instead reflect processing that is highly correlated with RT.

Findings from a previous experiment are consistent with the argument that the late negative wave is not a correlate of longer RTs (Cycowicz, Friedman, & Snodgrass, 2001). Cycowicz et al. (2001) reported late negative waves maximal at parietal sites for both targets and nontargets in an exclusion task, despite the fact that RTs to these items did not differ significantly from RTs to new items. The finding that these late negative waves were only elicited by old items in an exclusion task and not by old items in an inclusion task indicated that this effect is related to the requirement to respond differentially to recognised items on the basis of source information, and it was therefore argued that the late negative wave reflects processes that search for or evaluate source information (Cycowicz, Friedman, & Snodgrass, 2001). The finding reported within this thesis that late negative waves were observed for correctly classified targets and nontargets only when discrimination of studied
from unstudied items was difficult is consistent with this hypothesis, as it is argued that source information associated with all recognised items had to be evaluated in order to respond accurately to these items. However, it is unclear why this kind of processing should have onset earlier for nontargets than for targets. It is possible that the late negative wave elicited by targets appeared to onset later than that elicited by nontargets simply because targets also elicited larger parietal old/new effects which had a greater attenuating effect on negativity at right parietal sites. This proposal is undermined by the finding that both targets and nontargets elicited parietal old/new effects of equal amplitude in Experiment 5 and yet the late negative wave still onset earlier for nontargets than for targets. Therefore, although some of the data from the experiments described in this thesis are consistent with the source monitoring hypothesis, other aspects of the data are not easily accommodated by this account. Reports from another study indicating that the requirement to retrieve source information is neither necessary nor sufficient to elicit a late negative wave (Donaldson & Rugg, 1998) weakens the link between processes that evaluate source information and the late negative wave still further.

The third hypothesis pertaining to the functional significance of the late negative wave proposes that this effect may reflect increased demands placed on attentional resources by the response competition that occurs when recognition of an item does not determine the response. This hypothesis was first proposed when the use of fMRI to constrain estimations of the neural generators of the late negative wave revealed that false alarms eliciting a late negative wave were also associated with activations in anterior cingulate cortex (Mecklinger, 2000). On the basis of the view that this region is part of an attentional network activated during response competition, it was proposed that both the anterior cingulate activation and the late negative wave may reflect response conflict and/or its associated attentional demands that occur when recognised words required a ‘new’ response (Mecklinger, 2000). This hypothesis would certainly explain why nontargets elicit a late negative wave in exclusion tasks, but does not speak directly to the fact that targets in exclusion tasks also elicit late negative waves, or to studies reporting late negative waves for old items that require a different kind of differential response such as Remember/Know (Rugg, Schloerscheidt, & Mark, 1998) or intact/rearranged word pairs, see Chapter 3).

As discussed in Chapter 7, it is possible the late negative wave reflects response competition and/or its attentional modulation when recognition of an item can lead to more than one
response, rather than specifically reflecting response conflict caused by the suppression of an ‘old’ response. According to this hypothesis, a late negative wave was observed for both targets and nontargets in the experiments contained within this thesis because both kinds of old item elicited this kind of response competition and required greater attentional resources prior to responding. Although response competition may often result both in delayed responding and in the further evaluation of source information, it is not causally related to either of these two factors. It is not clear how this hypothesis would account for an earlier onsetting nontarget than target late negative wave, although it is possible that the additional conflict involved in responding ‘new’ to a recognised item may feed into this effect.

However, the response competition hypothesis has difficulty in explaining why recognised word-pairs identified as being rearranged at test should elicit a late negative wave whereas those identified as being intact should not (Donaldson & Rugg, 1998), as response competition and its attentional modulation should arguably be elicited by all recognised items that can attract more than one response. Similarly, the finding that correctly recognised word pairs elicited a late negative wave in a second task that did not require differential responding (Donaldson & Rugg, 1998) is inconsistent with the hypothesis that the late negative wave reflects attentional modulation caused by response competition.

It therefore appears that none of the three hypotheses described above can account for all findings pertaining to the late negative wave reported to date. Work within this thesis has contributed to delineating the functional characteristics of the late negative wave by reporting that this effect is carried by greater negativity elicited by old items under conditions in which discrimination of studied from unstudied items is relatively difficult relative to old items in which discrimination of studied from unstudied items is easier. Further work is required to determine the functional significance of the late negative wave.

Implications for models of recognition memory

The five experiments described within this thesis explored ERP correlates of recognition memory employing tasks which required subjects to respond differentially to studied items on the basis of their source. These paradigms were derived from the exclusion task which is typically used as part of the PDP to dissociate measures of familiarity and recollection. During the test phase in all five experiments, subjects were required to respond ‘yes’ to studied items from a specified source (‘targets’) and to respond ‘no’ both to new items and to
studied items not from the specified source ('nontargets'). Amongst the assumptions underlying the PDP, it is argued that targets and nontargets in an exclusion task will be correctly classified on the basis of a combination of recollection and familiarity, and that incorrectly classified nontargets (i.e. exclusion errors) will intrude on the basis of familiarity in the absence of recollection (Jacoby, 1991). It was therefore anticipated at the beginning of this thesis that ERPs associated with recognition memory responses made on the basis of recollection and familiarity could be obtained and differentiated through the use of exclusion-based tasks. While recording ERPs during tasks employing these paradigms did allow an evaluation of the putative correlates of recollection and familiarity, these experiments also resulted in several unexpected findings that may have implication for some of the boundary conditions surrounding the PDP and for models of recognition memory in general.

Evidence dissociating familiarity and recollection

It was argued in Chapter 2 that qualitative differences between ERPs associated with different response categories indicate that those response categories reflect the activity of at least partially non-overlapping neural populations, whereas ERPs that differ quantitatively reflect neural activity that differs only in its magnitude. The finding in Experiment 1 that both correctly classified targets and exclusion errors elicited an early frontal effect that dissociated qualitatively from a parietal old/new effect that was elicited by targets alone therefore supported dual-process models that state that two distinct processes contribute to recognition memory performance (Mandler, 1980; Gardiner & Java, 1993a; Jacoby, 1991). Both of these ERP correlates of recognition memory had been previously described in the ERP literature; the early frontal effect had been cited as a putative correlate of familiarity whereas the parietal old/new effect was thought to reflect recollection-based recognition memory (see Chapter 3). The pattern of results observed in Experiment 1 were consistent with this hypothesis, as early frontal effects were observed for response categories assumed to be either partially or wholly based on familiarity-based recognition and parietal old/new effects were observed for response categories assumed to be made at least partially on the basis of recollection-based recognition. It is notable that the latency and the scalp distribution of the early 'frontal' effect appeared to vary throughout the course of the five experiments. It is possible that this variability reflects the possibility that familiarity is comprised of different processes as opposed to a single process, and that these different processes are differentially recruited according to the requirements of the task and the nature of the encoding conditions.

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This hypothesis is consistent with Yonelinas et al. (1998), who also argued that familiarity may be multi-componential.

There is now a considerable body of evidence linking the early frontal effect to familiarity and the parietal old/new effect to recollection (see Chapter 3). The rest of this chapter is therefore based on the assumption that the early frontal effect and the parietal old/new effect reflect familiarity and recollection respectively, although it is acknowledged that some of the results reported in this thesis could alternatively be interpreted as evidence that these two effects may only be indirectly related to the two putative components of recognition memory. These ERP correlates of recognition memory were observed throughout the five experiments described in this thesis, and although some of these observations were in accordance with the predictions made by dual-process models as operationalised in the PDP, others were not and therefore appeared to contravene some of these assumptions. These findings and their implications are discussed in greater detail below. The fact that the parietal old/new effect was always accompanied by an early frontal effect whereas the early frontal effect was at times observed in the absence of a parietal old/new effect may appear to suggest a relationship of redundancy between familiarity and recollection. However, as stated in Chapter 3, it is misleading to infer relational assumptions from patterns of ERP data, as the fact that ERPs are averaged signals means that they cannot be used to provide insight into the dynamics of their associated processes at the level of individual trials; although the averaged ERPs associated with recollected items showed both the early frontal effect associated with familiarity and the parietal old/new effect associated with recollection (suggesting a relationship of redundancy or independence), it is quite possible that the individual trials contributing to these averaged signals actually elicited either one effect or the other as would be expected in a relationship of exclusivity.

**How recollection and familiarity may contribute to recognition responses**

Familiarity is commonly perceived to be an acontextual automatic form of recognition memory which should in principle remain unaffected by factors such as response type and retrieval strategy. Indeed, one of the assumptions underlying the PDP is that both targets and nontargets elicit familiarity-based recognition, and that this must be opposed by recollection in order to meet the requirements of the exclusion task (Jacoby, 1991). It may therefore appear somewhat surprising that nontargets (or 'preexposed correct rejections') did not elicit
an early frontal effect in Experiments 1-3 if this effect is a correlate of familiarity-based recognition. However, as discussed above, the finding that an early frontal effect was observed for nontargets in Experiments 4 and 5 once the nontarget false alarm rate dropped suggests that detection of a nontarget early frontal effect in exclusion tasks may depend on the response criterion adopted by subjects when responding on the basis of familiarity. According to this account, all highly familiar nontargets in the absence of diagnostic recollection intrude as exclusion errors when subjects adopt a relatively lax response criterion, and the familiarity level associated with correctly classified nontargets is therefore too low to appear in the ERPs. On the other hand, when subjects adopt a strict response criterion when responding on the basis of familiarity, few highly familiar items intrude as exclusion errors and the familiarity level of correctly classified nontargets is sufficient to be observed in the ERPs. This account of the data is consistent with the view that familiarity is a continuously distributed signal detection process along which subjects place a response criterion (Yonelinas, 1994).

The argument that subjects adopted different response criteria when responding on the basis of familiarity in each of the five experiments implies that different retrieval strategies were adopted in which subjects relied differentially on familiarity-based recognition in each experiment. The question therefore arises, what factor or factors influenced subjects to differentially rely on familiarity-based recognition in each of the five experiments? One key difference between Experiments 1-3 and Experiments 4-5 is that whereas either half or all targets were also presented in the nontarget study phase in Experiments 1-3, the two classes of old item were studied independently in Experiment 4-5. It is therefore possible that subjects relied on familiarity-based recognition to a greater extent when recollection of nontarget source information could not be used to dissociate targets from nontargets. In support of this hypothesis, discrimination of targets from nontargets was poorer in the first three experiments (.42, .35 and .55 in Experiments 1, 2 and the deep group of Experiment 3 respectively) than in Experiment 4 (.59). Although discrimination of targets from nontargets was low in Experiment 5 (.48) due to relatively poor memory for targets (.63), behavioural and ERP evidence indicating that recognition accuracy for nontargets in this experiment was high (a correct classification rate of .84) suggests that subjects may have relied on the retrieval of this information to a greater extent than familiarity.
Similarly, the ERP evidence suggests that subjects adopted different retrieval strategies across the five experiments that made differential use of source information associated with targets and nontargets. Whereas the ERP correlate of recollection was observed for correctly classified targets but not for correctly classified nontargets in the first four experiments, parietal old/new effects were observed for both classes of studied item in Experiment 5. It was argued in Chapter 9 that whereas subjects in the first four experiments adopted a retrieval strategy in which they selectively probed each test cue for source information from the target study phase, subjects in Experiment 5 adopted a retrieval strategy in which they probed each test cue for source information from both study phases. It is therefore argued that nontarget information in Experiment 1-4 was either not recollected, or was recollected but not employed. One data point exists within this thesis that is inconsistent with this argument; the fact that preexposed false alarms in Experiment 2 elicited a parietal old/new effect indicates that nontarget source information was recollected for this response category. The failure to correctly categorise these items may have been related to the failure to suppress this information. This finding has parallels with the report that subjects showed a parietal old/new effect for nontargets only when discrimination of targets from nontargets was poor (Dywan, Segalowitz, & Webster, 1998). It was also argued in Chapters 8 and 9 that the fact that exclusion instructions only explicitly require the retrieval of target source information can cause subjects to selectively probe memory for target information unless memory for targets is too poor to support this strategy. Therefore, even if source information associated with nontargets is available to episodic retrieval, subjects in exclusion tasks may selectively employ source information associated with targets when making recognition decisions if memory for these items is good.

In sum, the findings from the present experiments suggest that the following cognitive events may occur when subjects are required to respond differentially to old items in recognition memory tasks on the basis of source information; exposure to studied items results in familiarity and/or recollected information becoming available to subjects. According to task instructions and experimental conditions, subjects adopt a retrieval strategy in which familiarity information and recollected information from different sources are allocated different saliences. This retrieval strategy is a state effect which remains constant across the test session. As discussed above, the retrieval strategy adopted appears to depend on factors such as the ease of discrimination between targets and nontargets, and the memorability of targets. These strategic processes may either occur prior to, or as part of monitoring and
evaluation processes that also operate on retrieved information. It is argued that these monitoring and evaluation processes are reflected by the right frontal old/new effect. Following the retrieval, monitoring and evaluation of information associated with a studied item, a response is selected. The response competition that arises from the fact that each recognised item may attract one of two responses is hypothesised to be reflected in the late negative wave. This account is not intended to be interpreted as a strict sequence of events. For example, it is possible that early non-diagnostic recognition (either in the form of familiarity or noncriterial recollection) primes the subject to make an 'old' response, but that response conflict is experienced while additional contextual information is retrieved and evaluated in order to choose a response.

Mechanisms underlying selective recollection

It is argued above that subjects during exclusion tasks are able to adopt retrieval strategies which differentially emphasise the retrieval of specific kinds of contextual information. This argument prompts the question, what possible mechanisms could allow subjects to selectively recollect some types of information at the expense of others? A number of possible mechanisms have been proposed, each of which is comprised of three components; a cue representation which prompts a memory search, one or more target representations which form the focus of the memory search, and associative links connecting the target representations to the cue representations (Anderson & Bjork, 1994). Two of the mechanisms proposed by Anderson and Bjork (1994) could possibly account for the findings reported in this thesis; one possibility is that subjects were able to selectively recollect target source information at the expense of nontarget source information via a mechanism referred to as 'cue bias' (Anderson & Bjork, 1994). According to this hypothesis, subjects adopted a retrieval orientation which optimised the processing of test items as cues for the recollection of target information while rendering these items ineffectual as cues for nontarget recollection. Anderson and Bjork (1994) argued that cue bias could either take the form of 'meaning bias' or 'context bias'. The context bias hypothesis states that recollection will fail when the contextual representation used to conduct the memory search does not match the contextual representation that was present at encoding. Therefore, if subjects in the present experiments employed a contextual representation during the memory search that only matched the contextual representation formed during the encoding of targets, nontargets would be rendered irretrievable. This account also has parallels with the principles of transfer.
appropriate processing (Morris, Bransford, & Franks, 1977) and encoding specificity (Tulving & Thomson, 1973), which state that the extent of retrieval success depends upon the degree of overlap between processes engaged at encoding and processes engaged at retrieval. The present findings can be interpreted within this kind of a framework by proposing that subjects selectively probed memory for target information by recapitulating processing operations carried out during study phase 2 in the test phase. Indeed, a number of subjects in Experiment 4 reported attempting to recapitulate the target encoding task during test in order to determine whether test items had been presented in study phase 2.

A second possibility is that a ‘target bias’ strategy was involved in which all recollected information was subject to ‘attentional bias’ (Anderson & Bjork, 1994). According to this account, representations associated with both targets and nontargets were activated in all five experiments, but attentional processes enhanced the activations elicited by targets and decreased the activations associated with nontargets in all experiments except Experiment 5 (Anderson & Bjork, 1994). Anderson and Bjork (1994) argued that this attentional suppression can be applied to any representation which is perceived to interfere with performance. This hypothesis is consistent with other evidence suggesting that the parietal old/new effect is sensitive to the ‘task relevance’ of retrieved information. For example, the magnitude of the parietal old/new effect is typically larger in direct tests of recognition memory than in indirect tests such as semantic classification when episodic retrieval is incidental to the task (Duzel et al., 1999; Paller, Kutas, & McIsaac, 1995; Rugg & Wilding, 2000). Rugg and Wilding (2000) argued that these findings may reflect not so much the failure to retrieve study information in indirect tasks, as the failure to allocate processing resources to the information once retrieved (cf. Rugg, Fletcher, Frith, Frackowiak, & Dolan.R.J., 1997).

In addition to specifying possible mechanisms by which subjects are able to selectively recollect one type of source information at the expense of another, it is also necessary to consider what factors may encourage subjects to adopt this kind of retrieval strategy. Although subjects appeared to adopt this retrieval strategy in Experiments 1-4, other studies have reported parietal old/new effects for both targets and nontargets, indicating that subjects recollected both types of studied item (Wilding & Rugg 1996; Cycowicz, Friedman, et al. 2001; Rugg, Brovedani, & Doyle, 1992). As discussed above, one such factor appears to be the memorability of targets, in that low levels of memory associated with targets may not
support the adoption of a retrieval strategy which selectively probes for target information at the expense of nontarget information. This factor was identified in the comparison of Experiments 4 and 5 when it was found that that a parietal old/new effect was only elicited by nontargets once recognition accuracy for targets decreased. However, this does not appear to be the sole factor influencing the nature of the retrieval strategy adopted by subjects; although target recognition accuracy was low (.58) in one of the previous studies reporting a nontarget parietal old/new effect (Wilding & Rugg 1996), target recognition accuracy was as high or higher than that observed in Experiment 4 in both the Cycowicz et al. (2001) and Rugg et al. (1992) studies (.76 and .92 respectively). Conversely, although Dywan et al. (1998) reported a parietal old/new effect for targets only, recognition accuracy associated with these items was relatively poor (.58).

Further examination of the data available suggests that an additional factor may be the nature of the exclusion criterion specified to discriminate between targets and nontargets at test. Whereas all studies reporting both target and nontarget parietal old/new effects adopted exclusion criteria which emphasised relatively superficial characteristics such as voice gender (Wilding & Rugg, 1997) picture colour (Cycowicz, Friedman, & Snodgrass, 2001) or recency of presentation (Rugg, Brovedani, & Doyle, 1992), all of the experiments described within this thesis adopted an exclusion criterion which emphasised the distinctive conceptual encoding episode in which targets were presented. It may therefore be the case that the exclusion criterion must emphasise highly distinctive differences between targets and nontargets in order for subjects to be able to selectively probe for one kind of source information. This hypothesis is consistent with the context bias hypothesis, which states that the contextual representation used to search memory must be sufficiently distinct from the contextual representation associated with nontargets in order for the recollection of these items to fail (Anderson & Bjork, 1994).

Related to the factor of target/nontarget distinctiveness is the way in which targets and nontargets are presented at study. Both in the experiments described within this thesis and in the study by Dywan et al. (1998), target and nontarget items were presented in separate study phases. However, all previous experiments reporting parietal old/new effects for both targets and nontargets intermixed the two classes of item either within a single study phase (Wilding & Rugg, 1997; Cycowicz, Friedman, & Snodgrass, 2001) or within a continuous recognition task (Rugg, Brovedani, & Doyle, 1992). Thus, it appears that the adoption of a retrieval bias
in favour one of two sources may be facilitated by the temporal segregation of the relevant encoding episodes. The extent of the segregation of targets and nontargets during encoding may arguably influence the retrieval strategy adopted by subjects in much the same way that the nature of the exclusion criterion is argued to influence retrieval strategy; namely by increasing the distinctiveness between targets and nontargets. It is likely that complex interactions between various factors such as memorability of targets, target/nontarget distinctiveness and encoding conditions influence the retrieval strategy that subjects employ during exclusion tasks, and further work is required to identify and examine the various factors contributing to strategic recollection.

**Implications of experimental findings for the PDP**

A number of the findings reported within this thesis did not concur with predictions made on the basis of assumptions underlying the PDP, and therefore suggest that the experiments described within this thesis violated the boundary conditions of the PDP to such an extent that the PDP would no longer be able to accurately estimate the contributions of familiarity and recollection to performance. One such assumption is that exclusion errors are made on the basis of familiarity-based recognition memory in the absence of recollection (Jacoby, 1991). However, the finding that preexposed false alarms in Experiment 2 elicited a parietal old/new effect in addition to an early frontal effect suggests that exclusion errors were contaminated by noncriterial recollection. The PDP has frequently been criticised for this very reason (see Chapter 1), and the retort has typically been that as noncriterial recollection acts in the same way as familiarity, it is not considered to be a true form of recollection (Yonelinas & Jacoby, 1996). The finding in Experiment 2 that the parietal old/new effects associated with correctly endorsed targets and with exclusion errors are qualitatively indistinguishable does not support this argument, as this finding provides no evidence that the two parietal old/new effects reflect the activity of qualitatively distinct neural populations. If this is indeed the case, the implication that ERPs to correctly classified targets and exclusion errors reflect the same underlying process suggests that exclusion errors are contaminated by recollection, and that using the rate of exclusion errors as a process pure measure of familiarity may therefore lead to an underestimation of the contribution of recollection to recognition memory performance under certain conditions. However, as argued in Chapter 3, the finding that ERPs to two response categories do not dissociate qualitatively cannot be cited as evidence that the two responses are not associated with the activity of qualitatively distinct neural populations, as
differential activity could be occurring in neural populations to which the ERP technique is blind.

A second PDP assumption contravened by the data reported in this thesis is that correctly classified nontargets are excluded on the basis of recollection (Jacoby, 1991). However, it appears that nontargets were not excluded on the basis of the recollection of associated source information in Experiments 1-4, but rather through the failure to recollect source information associated with targets. This finding either implies that nontargets were not recollected at all, or that recollected information was not employed in the exclusion of these items. Similarly, these findings are also inconsistent with the assumption that recollection is equivalent in both inclusion and exclusion tasks, as subjects would arguably not have failed to recollect nontargets (or to use recollected nontarget information) if these items had required a 'yes' response. The present findings therefore highlight the fragility of the boundary conditions surrounding the use of the exclusion task to assess recollection, as even when they receive ‘standard’ exclusion instructions that emphasise the utility of retrieving nontarget source information, subjects may make differential use of this information depending upon the accessibility and distinctiveness of target information. The exclusion tasks employed in Experiments 4 and 5 differed from the classical exclusion task as described by the PDP only in two ways; targets were presented in the second study phase rather than in the first study phase, and targets and nontargets were encoded using different study tasks rather than the same task. It therefore appears that the boundary conditions of the PDP can be violated either by changing the order of presentation of targets and nontargets at study, or by rendering targets sufficiently distinct from nontargets (in this case by presented them in different encoding tasks). This suggests that the assumptions underlying the PDP can only remain valid under highly specific (and arguably artificial) conditions, and that any deviation from these specified conditions violates the boundary conditions within which these assumptions operate.

Conclusions

The present thesis employed variations on an exclusion task in order to examine ERP correlates of familiarity and recollection, and to investigate the functional characteristics and dynamics of these two putative processes. It was found that familiarity and recollection were associated with qualitatively distinct patterns of neural activity, thus supporting dual-process
models of recognition which state that familiarity and recollection are independent processes as opposed to points on a continuum of trace strength. Familiarity appeared to be reflected by an early frontal effect, whereas the parietal old/new effect was associated with recollection. The latency and distribution of the early frontal effect shifted throughout the five experiments. It was suggested that this variability may support the hypothesis that familiarity is not a unitary process, but that it is instead comprised of different components that may be differentially recruited according to experimental conditions (Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998). Two other ERP correlates of recognition memory were examined within this thesis; the right frontal old/new effect and the late negative wave. Consistent with other studies, the right frontal old/new effect appeared to reflect monitoring and evaluation processes that operate on recognised items, and the magnitude of this effect appeared to be proportional to the difficulty of the recognition decision. A number of functional hypotheses were considered regarding the late negative wave; the data indicated that this effect is not a correlate of RT as previously suggested (Wilding & Rugg, 1997), but that it may either reflect processes contributing to an evaluation of source information or attentional processes related to the response competition experienced when recognition can lead to more than one response.

Throughout the course of the five experiments, it was argued that the combination of ERP and behavioural data indicated that that familiarity is a continuously distributed signal detection process along which subjects place a response criterion, and that this response criterion shifts according to the emphasis that subjects place upon familiarity when responding. Similarly, it appeared that subjects were also able to differentially recollect contextual information from different sources, and to selectively retrieve specific contextual information perceived to be necessary for accurate responding. On the basis of the collective findings from Experiments 1-5, it was proposed that familiarity information and recollected information from different sources are endowed with different saliences by strategic processes which dictate the extent to which these different types of information will be used when making a recognition decision. These strategic processes may either occur prior to retrieval as part of a cue-bias mechanism, or may occur conjointly with post-retrieval monitoring processes as part of an attentional bias mechanism. Strategic and post-retrieval monitoring processes should be viewed as being distinct, in that the former are state-related processes whereas the latter are item-related processes. Further work is required to delineate and fractionate the different types of strategic, monitoring and evaluation processes, and to
evaluate in what way and under what circumstances these processes contribute to recognition memory performance.

Further work

A number of interesting avenues for further investigation arise from the main experimental findings described within this thesis. Many of the interpretations discussed above rely on the ability to use ERP data to make inferences about behaviour. Although this is in line with the convergent operations approach adopted in neuroimaging, it is often possible to explain patterns of imaging data in more than one way. Further work is therefore required to examine the arguments made within this thesis in greater detail, and to test the hypotheses arising from these interpretations. As such, the highest priority avenue of research arising from this thesis is arguably to collect additional behavioural evidence which speaks directly to the issue of whether subjects are recognising various items on the basis of familiarity or on the basis of recollection. Use of the Remember/Know procedure in conjunction with variations on the exclusion-style paradigms adopted throughout this thesis should allow further examination of these issues, and should therefore permit a distinction to be made between the various cognitive interpretations of the ERP data described within this thesis.

In addition to the behavioural verification and examination of the functional significance of various patterns of ERP data observed within this thesis, other future research objectives include greater specification of the factors which influence the strategic use of familiarity and recollection during exclusion tasks, and a specification of the level at which these strategic factors operate (e.g. cue bias vs attentional bias). For example, it is argued above that subjects were at times able to adopt a retrieval strategy in which they probed specifically for target source information, but it remains unclear what experimental factors allowed subjects to do this. Further experiments which systematically vary the temporal presentation of targets and non-targets, the difficulty of the criterial question, and the memorability of targets should result in a greater understanding of this issue. Similarly, manipulation of the probability of targets, the overlap between targets and non-targets, and target/non-target distinctiveness is required in order to determine what factors influence the extent to which familiarity is employed as a basis for responding in exclusion tasks. A systematic investigation of the influence of manipulations such as levels-of-processing and symbolic form on ERPs is also required to determine in what way the scalp distribution of the early frontal effect covaries.
with factors such as these. An examination of other paradigms in which familiarity is
though to contribute to performance would also be of interest in order to ascertain whether or
not this effect replicates across different materials and paradigms.
Appendix A. Behavioural study assessing the retrievability of nontargets in Experiment 4

Aims: To examine whether or not source information associated with nontargets presented during study phase 1 in Experiment 4 was available to subjects at test.

Subjects: Six subjects participated, four of which were male. The mean age of the subject pool was 23 years (range: 19 – 26).

Stimuli, design and procedures: The experimental design, stimuli and procedures employed in the pilot study were identical to those described for Experiment 4, with the exception that subjects were instructed to respond ‘old’ only to words that had been presented in study phase 1 and to respond ‘new’ to all other words.

Results:
Mean proportion of responses to each item type and their associated RTs were as follows:

<table>
<thead>
<tr>
<th>Stimuli type</th>
<th>Response Category</th>
<th>Proportion (SD)</th>
<th>RT (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>Hits</td>
<td>.86 (.08)</td>
<td>1461 (250)</td>
</tr>
<tr>
<td></td>
<td>Misses</td>
<td>.14 (.08)</td>
<td>1995 (670)</td>
</tr>
<tr>
<td>Nontarget</td>
<td>Correct rejections</td>
<td>.87 (.12)</td>
<td>1611 (396)</td>
</tr>
<tr>
<td></td>
<td>False alarms</td>
<td>.13 (.12)</td>
<td>1539 (377)</td>
</tr>
<tr>
<td>New</td>
<td>Correct rejections</td>
<td>.97 (.04)</td>
<td>1216 (211)</td>
</tr>
<tr>
<td></td>
<td>False alarms</td>
<td>.03 (.04)</td>
<td>1357 (363)</td>
</tr>
</tbody>
</table>
Appendix B. Pilot study conducted prior to Experiment 5

Aims: To identify a study phase 2 encoding task that reduces recognition accuracy for targets without increasing false alarm rates to nontargets and to new items, while maintaining comparable RTs to correctly classified targets and nontargets.

Subjects: Four subjects participated, two of which were male. The mean age of the subject pool was 24 years (range: 21 – 27).

Stimuli, design and procedures: The experimental design, stimuli and procedures employed in the pilot study were identical to those described for Experiment 4, with the exception that subjects were instructed to read words aloud presented during study phase 2.

Results:
Mean proportion of responses to each item type and their associated RTs were as follows:

<table>
<thead>
<tr>
<th>Stimuli type</th>
<th>Response Category</th>
<th>Proportion (SD)</th>
<th>RT (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>Hits</td>
<td>.47 (.15)</td>
<td>1784 (175)</td>
</tr>
<tr>
<td></td>
<td>Misses</td>
<td>.53 (.15)</td>
<td>1700 (113)</td>
</tr>
<tr>
<td>Nontarget</td>
<td>Correct rejections</td>
<td>.92 (.07)</td>
<td>1473 (120)</td>
</tr>
<tr>
<td></td>
<td>False alarms</td>
<td>.08 (.07)</td>
<td>2170 (368)</td>
</tr>
<tr>
<td>New</td>
<td>Correct rejections</td>
<td>.94 (.16)</td>
<td>1461 (306)</td>
</tr>
<tr>
<td></td>
<td>False alarms</td>
<td>.06 (.16)</td>
<td>2090 (301)</td>
</tr>
</tbody>
</table>
Abbreviations

A' = A-prime
A/D = analogue to digital conversion
ANOVA = Analysis of variance
AP = scalp location along anterior/posterior axis
BESA = brain electrical source analysis
CC = response category
d' = d-prime
DC = direct current
EEG = electroencephalography
EOG = electro-oculogram
ERP = event related potential
F = familiarity
fMRI = functional magnetic resonance imaging
HM = hemisphere
MSEC = millisecond
ON = old/new
PCA = principal components analysis
PDP = process dissociation procedure
PET = positron emission tomography
PN = preexposed/non-preexposed
R = recollection
R/K = remember/know
ROC = receiver operating characteristic
RT = reaction time
SD = standard deviation
ST = site (scalp location along left/right axis)
TLE = temporal lobe epilepsy
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