Metamemory or just Memory?

Searching for the Neural Correlates of Judgments of Learning

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Declaration

I declare that this thesis is a presentation of my original work that has not been submitted for any other degree or award. All additional sources of contribution have been acknowledged accordingly.

The work was completed under the supervision of Professor David I. Donaldson and Dr. Edward L. Wilding and conducted at the University of Stirling, United Kingdom.

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Publications

The following journal article and conference presentations have been adapted from experimental work reported in this thesis:

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Skavhaug, I., Wilding, E.L. & Donaldson, D.I. (2008). Separating judgments of learning from memory retrieval: an event-related potential study. Poster presented at The Annual Meeting of the Psychonomic Society, Chicago, IL.

Skavhaug, I., Wilding, E.L. & Donaldson, D.I. (2008). Separating judgements of learning from memory encoding: an event-related potential study. Poster presented at The Annual Cognitive Neuroscience Society Meeting, San Francisco.

Skavhaug, I., Wilding, E.L. & Donaldson, D.I. (2007). Dissociating judgments of learning from memory encoding: an event-related potentials study. Poster presented at The Annual Meeting of the Psychonomic Society, Long Beach, CA.

Skavhaug, I. & Donaldson, D.I. (2007). Searching for the neural correlates of judgments of learning: distinguishing metacognition from memory retrieval. Poster presented at The Joint Meeting of EPS and The Psychonomic Society, Edinburgh, UK.

Abstract

Judgments of Learning (JOLs) are judgments of the likelihood of remembering recently studied material on a future test. Although JOLs have been extensively studied, particularly due to their important applications in education, relatively little is known about the cognitive and neural processes supporting JOLs and how these processes relate to actual memory processing. Direct access theories describe JOLs as outputs following direct readings of memory traces and hence predict that JOLs cannot be distinguished from objective memory encoding operations. Inferential theories, by contrast, claim JOLs are products of the evaluation of a number of cues, perceived by learners to carry predictive value. This alternative account argues that JOLs are made on the basis of multiple underlying processes, which do not necessarily overlap with memory encoding. In this thesis, the neural and cognitive bases of JOLs were examined in a series of four ERP experiments.

Across experiments the study phase ERP data showed that JOLs produce neural activity that is partly overlapping with, but also partly distinct from, the activity that predicts successful memory encoding. Furthermore, the neural correlates of successful memory encoding appear sensitive to the requirements to make a JOL, emphasising the close interaction between subjective and objective measures of memory encoding. Finally, the neural correlates of both JOLs and successful memory encoding were found to vary depending on the nature of the stimulus materials, suggesting that both phenomena are supported by multiple cognitive and neural systems.

Although the primary focus was on the study phase ERP data, the thesis also contains two additional chapters reporting the ERP data acquired during the test phases of three of the original experiments. These data, which examined the relative engagements of retrieval processes for low and high JOL items, suggest that encoding processes specifically resulting in later recollection (as opposed to familiarity) form one reliable basis for making JOLs.

Overall, the evidence collected in this series of ERP experiments suggests that JOLs are not pure products of objective memory processes, as suggested by direct access theories, but are supported by neural systems that are at least partly distinct from those supporting successful memory encoding. These observations are compatible with inferential theories claiming that JOLs are supported by multiple processes that can be differentially engaged across stimulus contents.

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A PhD thesis cannot be successfully completed in solitude!

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Table of Contents

List of Tables

List of Figures

Chapter 1.

Memory and Metamemory

The world's first psychological laboratory was founded in Leipzig by the German physiologist Wilhelm Wundt during the mid 1800s. Wundt showed a specific interest in the study of human consciousness and mental processes, which he studied systematically and mainly through the means of introspection. His successors of the psychological discipline did, however, soon judge introspection to be an unscientific method of investigation and following the rise of behaviourism, the study of mental life was practically abandoned. Behaviourism, and its focus on overt, rather than covert, behaviour dominated psychology for over fifty years. It was not until the 1970s that researchers yet again turned their attention towards the subjective facets of cognition. It was this decade that saw the birth of metacognition. Cognitive monitoring is a component of metacognition which has rightfully received a vast amount of attention. This is primarily because cognitive monitoring has been shown to be essential for effective learning to take place. One such example is how memory predictions (as measured by Judgments of Learning; JOL) seem to guide the allocation of study time to material of varying difficulty. Considering the wealth of research that has been devoted to investigating Judgments of Learning, relatively little is known about the cognitive bases of these metacognitive judgments. In particular, arguments focus on the degree that actual memory processes contribute to the final product. The series of experiments reported in this thesis systematically investigate the interplay between predicted memory performance (JOLs) and actual memory performance using Event-Related Potentials (ERPs).

The purpose of the present chapter is to provide an overview of the organisation of memory, keeping the focus on episodic long-term memory, followed by an overview of the organisation of metamemory, keeping the focus on JOLs and the proposed theories regarding the possible basis of JOLs. Frameworks for understanding fundamental concepts such as memory and metamemory are continually evolving and it is therefore beyond the following sections to outline every aspect of the existing theories. Rather, the intention is to provide a general outline of the current perspectives, the details of which are currently the subject of ongoing debate.

1.1. The Organisation of Memory

Memory is a fascinatingly complex phenomenon, and has for that reason posed a great challenge for scientists throughout the history of psychology during attempts to understand its workings and components. At a basic level memory is described as manifesting itself though three separate stages: encoding, storage and retrieval. Encoding refers to the formation of memories and can be subdivided into two discrete steps: memory acquisition and consolidation. Whereas acquisition involves registering and analysing sensory input, consolidation is a process which stabilises and strengthens a memory trace following acquisition. The result of encoding is storage, which refers to the record of the representation of the information that has been learnt. Finally, retrieval refers to the process of reactivating the information that is being stored. Failure to remember can be the consequences of deficiencies at any of the three stages, as successful recovery of memories is dependent on successful encoding and storage as well as retrieval. This fact is important to consider when investigating memory through the observation of patients suffering memory difficulties. And as the subsequent sections will disclose, a large amount of knowledge about memory systems has been collected through such observations.

The broadest division of memory is traditionally made between sensory, short-term and long-term memory systems (see Figure 1.1). According to Atkinson & Shiffrin's (1968) modal model of memory, sensory information first enters a sensory register, in which it remains for milliseconds or seconds at the most. Items that are selected by attentional processes are then moved into short-term memory storage, where they can remain for a longer, but still very limited, duration of seconds or minutes. Only if information is rehearsed can it enter long-term memory storage, in which it may possibly remain indefinitely.

A few years after Atkinson & Shiffrin introduced their modal model of memory, Baddley & Hitch (1974) developed their working memory theory, which was an extension of the previously proposed short-term memory concept. Working memory consists of three components; the phonological loop, the visuospatial sketch pad and the central executive. In brief, the phonological loop and the visuospatial sketch pad are assumed to be subordinate systems responsible for maintenance of acoustical and visual information respectively. The central executive, on the other hand, is conceptualised as a command and control centre.

1.1.1. Long-term Memory System

Given the purpose of this thesis, the properties of the temporary memory systems described above are not going to be explored further. Rather, the focus will be on long-term memories that are retained for significant time periods. First, however, some of the evidence which support the division between temporary (short-term/working memory, henceforth short-term memory) and long-term memory will be considered.

A lot of the neuropsychological evidence contributing to memory research comes from observation of patient H.M. (see Corkin, 2002). As a young man in the 1950s, H.M. had a temporal lobectomy (removal of the temporal lobes bilaterally) performed to alleviate serious epilepsy. Although his initial condition was significantly improved, the surgery left him suffering from anterograde (and limited retrograde) amnesia (Scoville & Milner, 1957). Specifically, H.M. demonstrated severe amnesia for all events following surgery, whereas his memory for events that occurred prior to 19 months preceding surgery seemed to be spared. Importantly, however, his memory deficits seemed to be restricted to long-term memory as he was able to remember information over shorter intervals of time (see Corkin, 2002). Although this observation is important and supports the distinction between short-term and long-term memory, it only demonstrates a single dissociation. To reject the possibility that long-term memory tasks are not simply more difficult than short-term memory tasks, it is necessary to demonstrate deficient short-term memory abilities in the absence of long-term memory difficulties.

This pattern of behaviour was observed in patients K.F. (Shallice & Warrington, 1969) and E.E. (Markowitsch, Kalbe, Kessler, Von Stockhausen, Ghaemi & Heiss, 1999). Patient K.F. suffered damage to the left perisylvian cortex and demonstrated severely reduced digit span abilities. Digit span refers to the number of items an individual can retain in memory over a short time and digit span tests are widely used in assessments of short-term memory abilities. Whereas healthy individuals typically display a digit span of 5-9, K.F. was only able to remember two items. He did, however seem capable of forming new memories that lasted longer than a few seconds. Similarly, patient E.E. became amnesic after removal of a circumscribed left hemispheric tumour. His problems were selectively affecting short-term memory for abstract verbal material and numbers. Importantly, his long-term memory for both verbal and non-verbal material seemed normal. All together, the observations of H.M., K.F. and E.E. provide strong support for the view that neurally and functionally distinct systems support the formation of short-term and long-term memories.

But what are the important characteristics of long-term memories except from their relative long lasting qualities? A general description of long-term memory is difficult to provide as a vast body of evidence suggest further divisions are necessary to accommodate the involvement (or not) of consciousness and separations based on memory content. The exact nature and formulations of these divisions remain to this date contentious, however, Figure 1.1 provides a useful hypothetical illustration based on Gazzaniga et al. (2008), which is comparable to theoretical taxonomies proposed by both Tulving (see Schacter & Tulving, 1994) and Squire (see Squire, 2004).

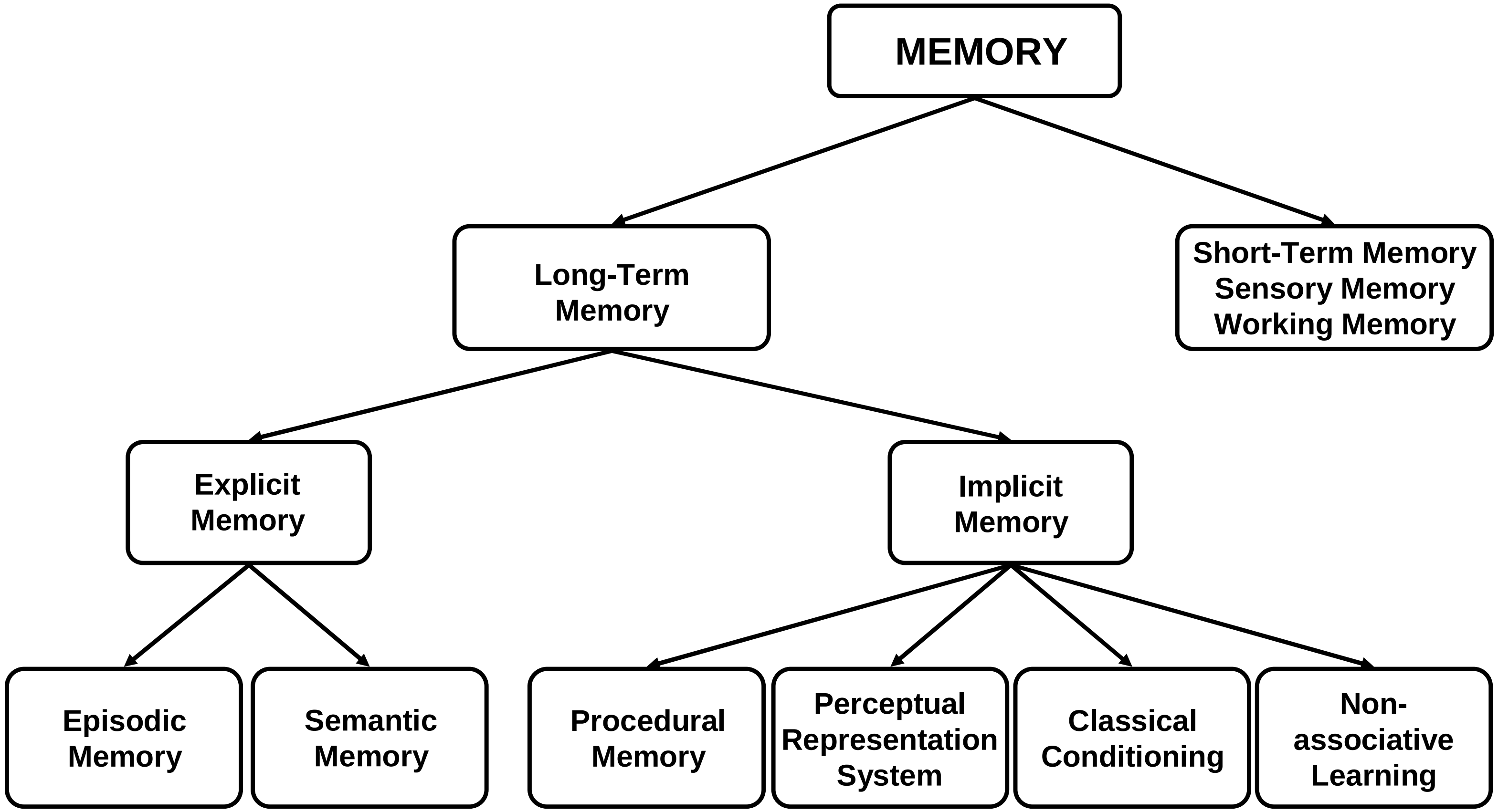

Figure 1.1 Theoretical organisation of human memory.
Adapted from Gazzaniga et al. (2008).

1.1.2. Declarative Memory

Some amnesic patients who demonstrate severe difficulties with conventional long-term memory tasks have shown intact performance on tests of motor skill learning (Corkin, 1968; Milner, 1962) and perceptual priming (facilitated processing of information resulting from prior exposure; Postle & Corkin, 1998). Patient H.M., for example, demonstrated decreased completion time and error rates across days of training on a mirror tracing task (Corkin, 1968). The mirror tracing task required him to draw a line along the outlines of a star shaped pattern. The challenge of such tasks is that the pencil and the stars are not directly visible but rather reflected in a mirror. Despite showing improved mirror tracing abilities with practice, each time H.M. performed the task he reported no conscious recollection of having performed it previously.

Patient K.C., who suffered severe amnesia following a motorcycle accident, has been extensively studied by Tulving and colleagues and also been found to exhibit certain forms of long-term memory (see Rosenbaum et al., 2005; Tulving, 2002). For example, McAndrews, Glisky & Schacter (1987) presented amnesics (including K.C.) and controls with sentence puzzles that were nearly impossible to understand in the absence of a critical solution word. One example sentence is “haystack was important because the cloth ripped”. This sentence makes little sense until the solution word “parachute” is revealed. Participants read the sentences and were provided with the solution words when they could not produce them themselves. Sentences to which solution words could not be produced were re-presented to the participants after delays ranging from one minute to one week and once again participants were asked to produce the solution word. K.C. and the other amnesic patient demonstrated priming following a single exposure at all delays (about 50% correct solutions were generated in response to previously unsolved sentences). The magnitude of the priming effect did not change between the different delays or number of study repetitions (ranging from one to five). Interestingly, the patients did not consciously remember having read any of the sentences previously. McAndrews et al.'s (1987) findings show that priming can be preserved in patients with otherwise severe long-term memory difficulties and that this sort of memory can last at least a week.

Based on observations such as the above, it is theorised that long-term memory is split into two main divisions: nondeclarative memory and declarative memory[1] (Squire, 1992). Nondeclarative memory refers to a group of nonconscious learning outcomes that are expressed mainly through performance and allows limited access to any conscious memory content. This group of memories are products of motor and cognitive skill learning (e.g. knowing how to ride a bike) and also priming, classical conditioning and nonassociative learning (habituation and sensitisation). Declarative memories, by contrast, include consciously accessible personal knowledge (episodic memory; e.g. 'I had cereal for breakfast this morning') and world knowledge (semantic memory; e.g. 'the capital of Denmark is Copenhagen'. The remainder of this thesis will focus on declarative memory and specifically on episodic memory, which is outlined below.

[1] Similar concepts are explicit and implicit memory (Schacter, 1987). Tests of declarative and non declarative memory are therefore often referred to as explicit and implicit memory tests.

1.1.3. Episodic Memory

Episodic memory is unquestionably the kind of memory that most closely resembles the layman's conceptualisation of memory; the re-experiencing of the past. The distinct qualities of episodic memory are summarised in the following quote by Tulving (2002, p. 2): "When one thinks today about what one did yesterday, time's arrow is bent into a loop. The rememberer has mentally travelled back into her past and thus violated the law of the irreversibility of the flow of time. She has not accomplished the feat in physical reality, of course, but rather in the reality of the mind, which, as everyone knows, is at least as important for human beings as is the physical reality."

Although the distinction between episodic and semantic memories (first proposed by Tulving, 1972) seems intuitively reasonable, the proposition was initially greeted with criticism (Tulving, 2002). To date there has been a growing agreement that a theoretical division is practical; however the exact nature of semantic and episodic memory, and the anatomical bases of these, remains debatable. Tulving's view is that episodic memory has evolved out of, and is hence an extension of, semantic memory (Tulving, 2002). Accordingly, episodic memory has additional inherent characteristics that necessitate the involvement of the hippocampus, which is not an anatomical necessity of semantic memory (Tulving & Markowitsch, 1998). Squire and colleagues, conversely, view episodic and semantic memory as equally dependant on hippocampal and medial temporal lobe structures, and argue for the additional involvement of the frontal lobes for episodic memory (Squire & Zola, 1998).

Disagreements about the anatomical bases of episodic and semantic memory are not easily resolved because, as Tulving (2002, p. 12) points out, “the probability of the kind of brain damage that neatly cleaves the brain function along the lines of such complex systems is small”. Instead, damage is likely to affect multiple systems and result in diffuse cognitive impairment. For example, neuropsychological case studies are, for that reason, often interpreted differently by different investigators and this is true even for some of the most influential case studies relevant to the distinction between episodic and semantic memory. For example, Vargha-Khadem, Gadian, Watkins, Connelly, Van Paesschen & Mishkin (1997) carried out extensive observations of three children that acquired amnesia due to anoxic accidents producing bilateral hippocampal pathology at birth and the ages of 4 and 9 respectively. The children were unable to recollect episodic events from their lives and scored within the amnesic range on most standard memory tests. However, they appeared to acquire some semantic knowledge through formal schooling. Vargha-Khadem et al. (1997) and later Tulving & Markowitsch (1998) interpreted the data to mean that semantic memory had been relatively spared because of its relative independence of the hippocampus. Squire & Zola (1998), on the other hand, were of the opinion that slow educational progress could have been possible through limited episodic learning (permitted through intact frontal lobe functioning), which would have been hard to detect with standardised assessment procedures.

The declarative memory system is a large and complex system, and it is unlikely that its exact nature will be fully revealed in the near future. As previously stated, the distinction between episodic and semantic memory has proven useful, and further speculations regarding the nature of the two types of memory would fall beyond the scope of this thesis. Nevertheless, it is important to point out that any theory of the divisions within the declarative memory system need to take into consideration the close interaction between episodic and semantic memory (e.g. Greve, Van Rossum & Donaldson, 2007) and the fact that the two types of memory are not easily isolated even under artificial laboratory situations such as those described below.

1.1.4. Studying Episodic Memory

As outlined earlier, memory is believed to encompass three equally important stages: encoding, storage and retrieval. Since memory failures (measured as an inability to retrieve) can be caused by interruptions at any one of these stages, it is important to carefully consider aspects of study, retention and test phases of experiments designed for the purpose of investigating episodic memory.

The most widely used paradigm for systematically investigating episodic memory function in humans involves exposing participants to a series of stimulus materials and later assessing memory for the material on a subsequent test. Memory tests can be provided in a range of different formats. However, before these are considered, it is necessary to review a few of the many factors present during the study phase of experiments that seem to affect later memory for the material that is under study. One such factor is the amount of attentional resources that the participants have available at the time of encoding. It has been repeatedly shown that when participants are required to divide their attention between an encoding task and a secondary task, the result is a decrease in subsequent memory performance (e.g. Anderson, Craik & Naveh-Benjamin, 1998; Iidaka, Anderson, Kapur, Cabeza & Craik, 2000.). Other important factors include the duration of stimulus exposure time (von Hippel & Hawkins, 1994) and list length (number of items participants are required to learn; Cary & Reder, 2003; Strong, 1912; Yonelinas & Jacoby, 1994).

Given the large number of factors believed to influence memory processes at the time of encoding, it is crucial that paradigms are carefully designed to ensure that the factors are kept constant and have the same effect on the performance of each individual participant. Not all factors, however, are as easily controlled by the experimenter. For example, the amount of attention each individual devotes to the task (independent of specific attentional manipulation inherent in the paradigm) is one factor that the experimenter will typically have problems exerting control over. One other important consideration is what the participants choose to do with the to-be-remembered material, as this is known to be a strong determinant of subsequent memory. The level of processing framework developed by Craik & Lockhart (1972) predicts better memory for material that has been processed in a deep, as opposed to shallow, manner. Deep processing implies greater mental elaboration at the time of study, for example considering the semantic meaning of a study word. Shallow processing, on the other hand, typically involves consideration of the physical characteristics of materials; for example determining the number of letters that makes up the study word. Numerous experiments have validated the level of processing prediction (e.g. Craik & Tulving, 1975; Fisher & Craik, 1977, 1980) and to encourage participants to behave as homogenously as possible, experimenters usually provide specific instructions regarding the use of encoding strategies. Levels of processing manipulations have frequently been used in electrophysiological investigations of memory encoding and retrieval and this topic will be revisited in Chapter 3.

In the same way that memory encoding conditions need to be kept constant, the time in between study and test also needs to be equal for each participant. If the memory test occurs after a delay, the activities that the participants are engaging in during the delay need to be the same. For example, if a delay is necessary, it is common to provide the participants with filler tasks, such as counting backwards in twos or filling out a questionnaire.

The final stage of a typical memory experiment is the test phase, in which the memory performance is recorded. Traditional memory tests typically took the form of free recall, in which participants were instructed to report all the study items that they could remember, usually in no particular order. Brown (1923) presented participants with such a free recall test immediately after the study phase and then again after a 30 minutes delay. Surprisingly, memory performance was better on the second, rather than the first, test. This observation strongly suggests that one single test is an imperfect indicator of memory (see Roediger & Thorpe, 1978). Memory tests now come in many different formats, and the test format is important to consider because different tests will invariably produce different memory scores (Migo, Montaldi, Norman, Quamme & Mayes, 2008). One of the most important differences between memory tests is the provision of retrieval cues. A retrieval cue is a stimulus which can facilitate memory performance through appropriately guiding memory search. Effective cues are usually related to the target information and are often fragments of a study episode. For example, on cued recall tests, participants may study a list of word pairs and later be instructed to recall one word from the pair when they are presented with the other. The effectiveness of using retrieval cues led some researchers to believe that forgetting (in normal healthy people) is often caused by failure to access memories rather than that the memory trace has ceased to exist (see Tulving, 1974).

1.1.5. Recognition Memory

One special type of retrieval cue that is frequently used in memory experiments is the target item itself. This is the case in recognition memory experiments: participants are presented with a number of previously studied (old) items intermixed with (new) lure items. Memory performance is measured as the ability to successfully discriminate between old and new items. It is commonly believed that successful recognition memory is supported by two distinct processes; familiarity and recognition (Atkinson & Juola, 1973; 1974; Jacoby, 1991; Jacoby & Dallas, 1981; Mandler, 1980; Yonelinas, 1994; 2002). Recollection is conceptualised as a relatively slow process that involves detailed retrieval of context and information from a previous study episode. In contrast, familiarity is believed to be a faster process which gives rise to a notion of having encountered an episode before in the absence of the recovery of contextual details. The typical example researchers use to explain this distinction is the experience of meeting a person whom one recognises but cannot remember the name of.

To attempt segregation of familiarity and recollection processes, experimenters have instructed participants to make secondary responses following old recognition judgments that can be used as indicators of which process was underlying the initial response. One such type of subsequent memory assessment is provided by the Remember/Know (R/K) paradigms (Tulving, 1985; also covered in Chapter 3). In R/K paradigms participants are asked to indicate whether they specifically *remember* having encountered the test item before or whether they simply *know* the item is old. The assumption behind this procedure is that R responses serve as indicators of recollective experiences and that K responses reflect feelings of familiarity. Although R/K paradigms have been widely used in recognition memory investigations, one fundamental predicament with the paradigm is determining how closely the two response categories map onto the theoretical memory processes. Assuming that such mapping is possible, the instructions that are given to the participants regarding when to make R and when to make K responses remain crucial to ensure as pure a measure as possible (Eldridge, Sarfatti & Knowlton, 2002; Geraci & McCabe, 2006; Geraci, McCabe & Guillory, 2009; McCabe & Geraci, 2009; Rotello, Macmillan, Reeder & Wong, 2005).

An alternative to R/K judgments are confidence ratings, which involve participants indicating their level of confidence following retrieval by the use of a rating scale. Here, the assumption is that recollected memories are accompanied with higher confidence relative to familiar memories. When confidence judgments are recorded, hit (old items correctly identified as old) rates can be plotted against false alarm (FA; new items incorrectly classified as old) rates as a function of confidence to form Receiver Operating Characteristic curves (ROC curves). In brief, changes in the shape of ROC curves across conditions seem to require the involvement of two separate parameters (the subtleties of the ROC method will not be covered in this thesis, see Yonelinas &

Parks, 2007, for further reading). Much of the additional evidence in support of a distinction between recollection and familiarity processes comes from brain imaging studies and will therefore be reviewed in Chapter 3.

1.1.6. Process Purity

Although dual process theories of recognition memory have been devoted much attention in the literature, they remain controversial primarily because of the difficulties in obtaining definite estimates of recollection and familiarity. Many single-process theorists therefore claim that familiarity does not exist as a separate process per se, but rather reflects a weaker form of memory (Hintzmann, 1988; Gillund & Shiffrin, 1984; Murdock, 1997; but see Mickes, Wais & Wixted, 2009, for a recent attempt to reconcile single and dual process theories). One of the challenges associated with evaluations of potentially qualitatively different retrieval processes is the concept of process purity. Process purity refers to a circumstance in which the contrast between two experimental conditions has successfully isolated the operation of one single (pure) process. Given the intricacy of the human memory system, it is very unlikely that process purity will be fully achieved, even when experiments are very carefully designed. Tulving (2002, p. 5) points out that the episodic memory system is merely a hypothetical one and not defined or represented by a specific test, but more likely determined by multiple systems. For example, when accessing semantic knowledge from memory, it is possible that the specific episode in which the semantic knowledge was required is recollected simultaneously.

1.1.7. Section Summary

Memory is not a unitary system but consists of multiple components that together make up a complex and interrelated system, which has been studied extensively, particularly through observations of patients suffering from amnesia (memory loss). Many theoretical distinctions are made between long-term memory and temporary memory (short-term memory, working memory and sensory memory). Long-term memory is further subdivided into declarative and non declarative memories, which refer to consciously accessible knowledge and knowledge that is typically expressed through behaviour (such as motoric skills and simple habituation) respectively. Declarative memory is believed to consist of episodic memory (personal memories about one's past) and semantic memory (knowledge about the world).

Memory experiments in the laboratory involve presenting participants with a set of stimuli during a study phase which they are later asked to remember during a memory test. Memory tests come in many different formats, including free recall, cued recall and old/new recognition, each of which provides different measures of memory performance. According to dual process theories of recognition memory, successful performance on such memory tests can be based on either recollection or familiarity. Recollection refers to the conscious and detailed retrieval of a specific event that has taken place in the past, whereas familiarity refers to the feeling of having encountered an event before without the accompaniment of such contextual details.

Finally, one of the most fundamental challenges in theoretical memory research is being able to isolate and examine one single cognitive process at the time. This is because most tasks involve input from several systems that most likely interact closely. Importantly, however, this problem of process purity is not exclusive to memory investigations, but applies to most cognitive phenomena, including metacognition, which will be the focus of the remainder of this chapter.

1.2. Metamemory and Judgments of Learning

Metacognition (from Greek Meta ‘over’ and Latin Cognitio ‘knowledge’) has yielded an impressive number of publications in psychological journals notwithstanding its novelty as a field of research. The traces of metacognition in the literature typically lead back to John Flavell’s research on the development of memory skills in children. Flavell (1976, p. 232) initially provided the following definition of metacognition: "Metacognition refers to one's knowledge concerning one's own cognitive processes or anything related to them, e.g., the learning-relevant properties of information or data. For example, I am engaging in metacognition if I notice that I am having more trouble learning A than B; if it strikes me that I should double check C before accepting it as a fact.” Following this definition, the aspect of metacognition that distinguishes it from ‘ordinary’ cognition is, hence, that the content of the cognitive engagement is cognition itself. This thesis is focussed on a subcategory of metacognition which specifically concerns memory. This subcategory has been appropriately coined metamemory and is described by Dunlosky & Bjork (2008, p. 11) as “people’s knowledge of, monitoring of, and control of their own learning and memory processes.”

1.2.1. A Framework of Metamemory Research

The history of metamemory research is difficult to formalise, and this is possibly because it took a long time for metamemory to obtain its identity within the discipline of memory. The majority of experimentation was conducted in isolation (see Dunlosky & Bjork, 2008) and researchers working within the discipline had relatively little connection with each others (and even less with researchers within the broader discipline of memory). The problem seemed to be the lack of a formal structure describing the relationship between different metamemory components. This structure was provided by the influential framework for metamemory research developed by Nelson & Narens (1990). The Nelson & Narens' (1990) framework describes metamemory as consisting of two main processes: monitoring and control. Monitoring refers to the subjective assessments about the learning progress, based on the experienced feelings of, for example, comprehension of the study material. Control processes, on the other hand, refer to behavioural strategies that can be initiated following the product of monitoring. One example of such a strategy is the differential allocation of study time between items. The relationship between monitoring and control has traditionally been described as one directional (i.e. monitoring causes control, see Van Overschelde, 2008), however it has recently been suggested by Koriat (2008) that information can flow in both directions, implying that control sometimes causes changes in metamemory knowledge and monitoring.

Figure 1.2 illustrates monitoring and control processes in the temporal order in which they may occur during the stages of encoding (acquisition), retention and retrieval. Operationalisations of the monitoring judgments are necessary to ensure that the concepts are similarly applied across experiments and these are provided by Dunlosky & Bjork (2008, p. 17) as the following:

- *Ease-of-Learning (EOL) judgments:* Judgments of how easy to-be-studied items will be to learn.

- *Judgments of Learning (JOL):* Judgments of the likelihood of remembering recently studied items on an upcoming test.

- *Feeling-of-knowing (FOK) judgments:* Judgments of the likelihood of recognising currently unrecallable answers on an upcoming test.

- *Source-monitoring judgments:* Judgments made during a criterion test pertaining to the source of a particular memory.

- *Confidence in retrieved answers:* Judgments of the likelihood that a response on a test is correct.

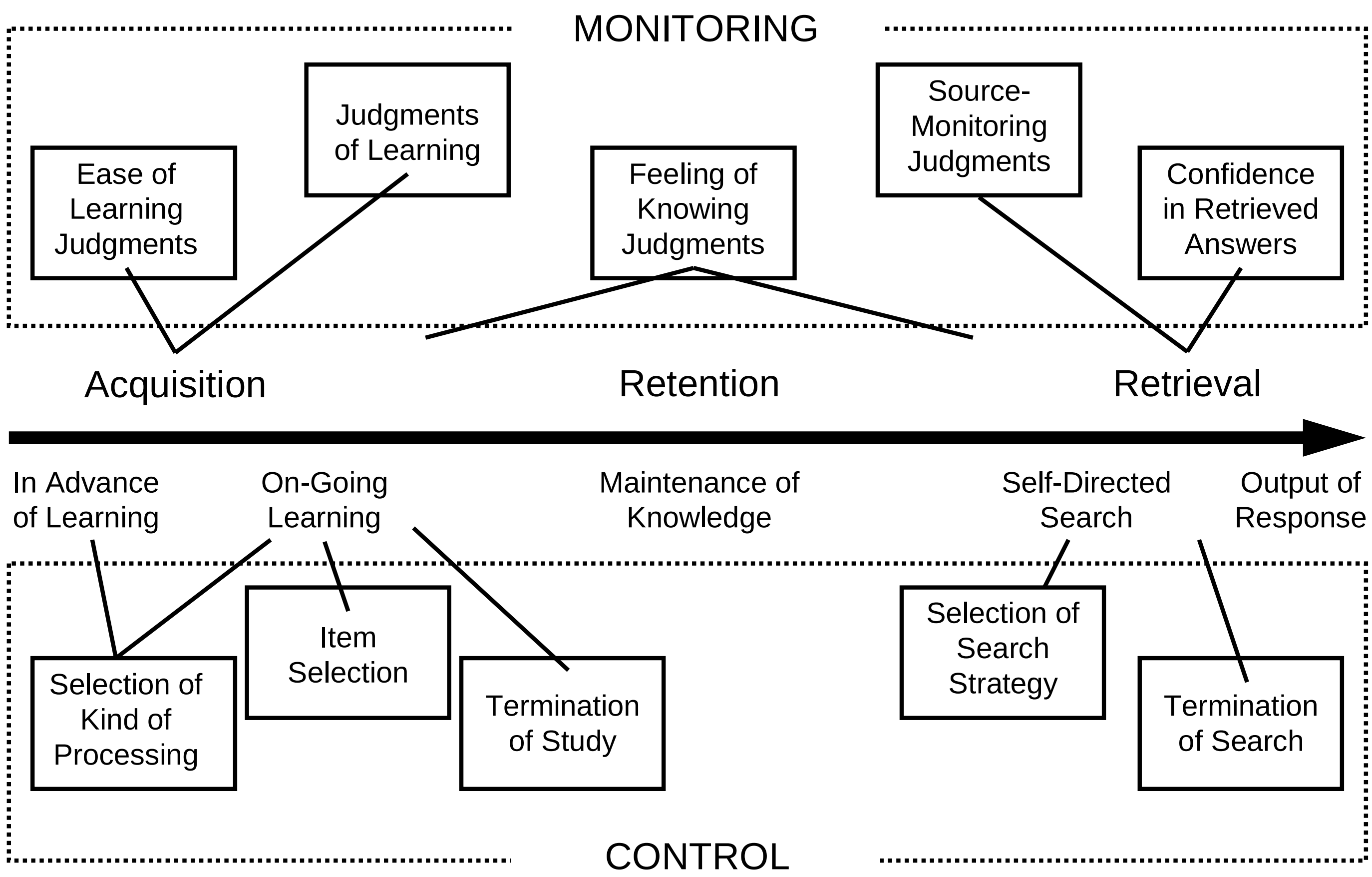

Figure 1.2 A framework for metamemory research.
Adapted from Nelson & Narens (1990).

The monitoring judgments summarised above have in common that they rely on metamemorial knowledge that closely interact with actual memory processes (see Dunlosky & Bjork, 2008). The nature of this interaction is, however, still relatively poorly described and complicated by the fact that researchers have found no, or only weak, correlations between different types of metamemory judgments (Leonesio & Nelson, 1990; Souchay, Isingrini, Clarys, Taconnat & Eustache, 2004). Moreover, Modirrousta & Fellows (2008) observed patients with damage to the medial prefrontal cortex and found impaired FOK judgments and recall confidence, but intact JOLs, indicating that this region of prefrontal cortex is critical for the former metamemory judgments but not the latter. Such observations suggest that different metamemory judgments could be tapping different aspects of memory and that findings from one kind of judgments cannot be generalised to others. Additionally, the tasks that are used to investigate the various metamemory phenomena differ substantially, thereby further complicating potential comparisons (Schwartz, 1994). For these reasons, the focus of this thesis will remain on one set of metamemory judgments – Judgments of Learning – without the attempt to relate these to other monitoring processes outlined in the Nelson & Narens' (1990) framework. This is not to suggest that the framework is superfluous, as it has provided an important context and structure for metamemory research. Furthermore, the establishment of the relationships between metamemory judgments remains an important subject. However, individual descriptions of those judgments need to be considered alongside the development of a general framework to complement the literature. The primary aim of the series of experiments reported in this thesis is to provide such a description of JOLs.

1.2.2. Judgments of Learning

Since the formal introduction of metamemory, the scientific interest in JOLs has proven to be substantial. One of the reasons for its popularity is its direct applicability to education. For example, JOL has repeatedly been found to guide study time allocation (Mazzoni & Cornoldi, l993; Metcalfe, 2002; Thiede, 1999, also see Son & Kornell, 2008) and JOL accuracy has been associated with higher memory performance (Maki & Berry, 1984; Thiede, 1999). The assumptions regarding the relationship between JOL, study time allocation and memory performance is described by Benjamin, Bjork & Schwartz (1998, p. 65) in the following way: "poor self-monitoring capacity necessarily entails poor selection and execution of relevant control processes: If you do not know what you do not know, you cannot rectify your ignorance."

1.2.3. The Cognitive Basis of JOLs

Despite the wide acknowledgment of the importance of JOLs for successful learning, the cognitive basis of JOLs is relatively poorly understood. Although there is a general agreement that actual memory processes contribute to the JOL assignment, the extent of this contribution is under ongoing debate. Traditionally, the understanding was that people have privileged access to memory content and are thus able to directly monitor the strength of memory traces and translate these into recall probabilities (JOL). These original ideas were generally referred to as "direct access" or "trace access" views (e.g. Arbuckle & Cuddy, 1969; King, Zechmeister & Shaughnessy, 1980). One important implication of direct/trace access views is that the same variables that affect subsequent memory performance should also have comparable effects on metamemorical monitoring judgments (see Schwartz, Benjamin & Bjork, 1997). Although JOLs and test performance are often found to be sensitive to the same experimental manipulations, this is not invariably the case (Castel, McCabe & Roediger, 2007; Dunlosky & Nelson, 1994; Koriat & Bjork, 2005; Koriat & Bjork, 2006; Tide & Leboe, 2009). For example, studies have shown that participants sometimes underestimate the memory performance benefits of using imagery encoding strategies as opposed to rote rehearsal (for a summary see Dunlosky & Nelson, 1994).

Further evidence against direct/trace access theories come from psycho-pharmacological studies and observations of neuropsychological patients. If the ability to make JOLs is reliant on the same systems that support memory processes, drugs that are known to affect memory performance should have a comparable effect on metamemory. Experiments have shown, however, that benzodiazepines, such as Midazolam and Triazolam, produce severe anterograde amnesia without affecting the magnitude of JOL responses (Merritt, Hirshman, Hsu & Berrigan, 2005; Weingartner, Joyce, Sirocco, Adams, Eckardt, George & Lister, 1993; but also see Izaute & Bacon, 2005). For example, Merritt et al. (2005) found that participants who were given Midazolam injections produced JOLs that were equivalent to participants who were given saline injections, despite demonstrating inferior memory performance. Surprisingly, participants had been informed about the adverse effects that Midazolam would have on memory, but this seemed not to influence their memory monitoring. In similar vein, Nelson, Graf, Dunlosky, Marlatt, Walker & Luce (1998) found that alcohol intoxication had a detrimental effect on memory that participants seemed relatively unable to correct for when making metamemory judgments.

Observations of neuropsychological patients with damage to the frontal lobes have also revealed differential impairments in metamemory abilities relative to memory, when compared to control participants (see Pannu & Kaszniak, 2005). For example, Vilkki, Servo & Surma-aho (1998) found that patients with damage to the right frontal lobe were significantly worse at predicting recall for words compared to patients with right posterior damage and control participants. These findings were later replicated using memory predictions for spatial locations (Vilkki, Surma-aho & Servo, 1999).

The above observations led some researchers to hypothesise that JOLs are not products of memory strength readings, but that people have to rely on other sources of information when making JOLs. These alternative views describe JOL assignments as inferential processes, which involve the evaluation of available cues that people perceive as indicators of future memory performance (Koriat, 1997; Schwartz, 1994; Schwartz et al., 1997). Koriat's (1997) influential "cue-utilization approach" systematically describe a range of such cues and divides them into specific categories of intrinsic, extrinsic and mnemonic cues (see Figure 1.3). Intrinsic cues pertain to certain pre-experimental characteristic of the study stimuli. Examples of such characteristics are, in the case of word pairs, the associative relatedness between the cue and the target words, and, in the case of single words, imagery value. Hence, intrinsic cues are inherent to the stimuli and not dependent on the learner or the study situation. Extrinsic cues, in opposition, are directly related to the study regime, examples of which are the total number of items to be studied and the duration of time available for studying each of them. Koriat (1997) expresses a particular concern that people generally seem to underestimate the predictive value of such extrinsic cues. Finally, mnemonic cues concern experiences assembled during the learning (or retrieval) situation. The participant’s choice of encoding strategy (for example imagery encoding versus rote learning) would be one such important source of information.

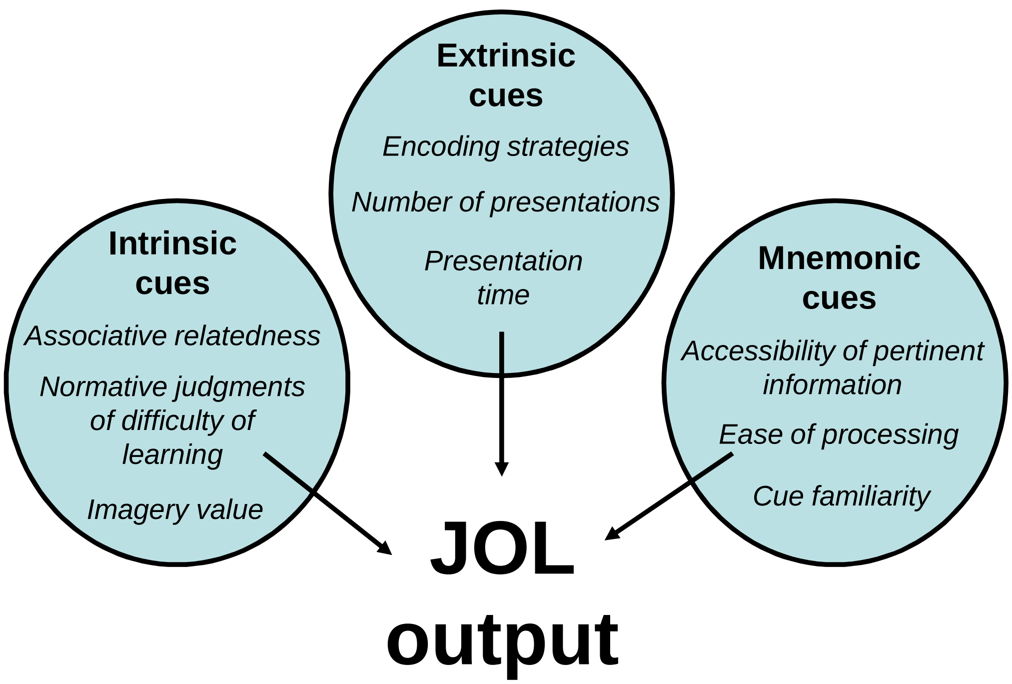

Figure 1.3 Schematic illustration of Koriat’s (1997) cue-utilization approach.

As outlined at the start of this sub-section, the core of direct/trace access views is the reading and translating of memory trace strengths. Koriat’s (1997) cue-utilization view also acknowledges that JOLs can be based on actual memory processing, just in a more indirect way. Rather than relying on privileged access to memory traces, participants can, for example, actively engage in retrieval attempts and base their JOLs on the outcome of these attempts. What is most critical about Koriat's viewpoint, however, is that JOLs can be, and probably often are, based on factors other than memory and hence research should focus on understanding and identifying the most reliable factors (cues). Inferential theories, such as the cue-utilization approach, readily explain why JOLs are sometimes inaccurate and do not show the same sensitivities to experimental variables as subsequent memory does. For example people may assign disproportional importance to the wrong kind of cues (Benjamin et al., 1998) or they may ignore cues that are in fact informative (Dunlosky & Nelson, 1994; Koriat, 1997). To assess the value of different types of cues within a given context, or for a particular type of stimuli, it is necessary to determine and compare participants' JOL accuracy scores across experiments. The different conceptualisations and calculation of JOL accuracy will be the focus of the next sub-section of this chapter.

1.2.4. Measures of JOL Accuracy

The metamemory literature reports the use of two separate measures of monitoring accuracy: absolute accuracy and relative accuracy (see Hacker, Bol & Keener, 2008). Absolute accuracy, also known as calibration, refers to the specific correspondence between JOL and actual memory performance. Hence, absolute accuracy provides an exact measure of participants' predicted memory. Calibration is perfect if participants successfully remember 0% of all items rated 0% likely to be remembered, 20% of all items rated 20% likely to be remembered, 40% of all items rated 40% likely to be remembered and so on. Bias is indicated by the signed differences between JOLs and later performance: positive values indicate overconfidence and negative values indicate underconfidence. Relative accuracy, also known as resolution, is a measure of how accurate participants are at predicting the likelihood of remembering one study item *relative* to another. This is an important skill in situations that require the allocation of limited amounts of study time between materials.

Surprisingly, research has failed to establish a correlation between absolute and relative accuracy and it has recently been suggested that the two measures may tap different aspects of metacomprehension (Maki, Shields, Wheeler & Zacchilli, 2005). Relative accuracy does, however, appear to be a more stable measure of metamemory accuracy than absolute accuracy, and is possibly less sensitive to individual differences (Maki et al., 2005; van Overschelde & Nelson, 2006). Therefore keeping in line with previous metamemory research, relative accuracy will be reported throughout this thesis.

Until recently, relative accuracy has been provided principally by calculating the Goodman-Kruskal Gamma correlation coefficient (Goodman & Kruskal, 1954; 1959; also see Benjamin & Diaz, 2008; Spellman, Bloomfield & Bjork, 2008) as recommended by Nelson (1984). Metamemory studies often require measuring the association between two sets of values, $\boldsymbol{X}$ and $\boldsymbol{Y}$, of which $\boldsymbol{X}$ might be a set of JOL responses and $\boldsymbol{Y}$ the corresponding set of recognition test responses. The Gamma coefficient G provides one such measure, based on the total number of concordant and discordant pairs. A concordant pair (*i*,*j*) is one for which $\boldsymbol{X}_i > \boldsymbol{X}_j$ and $\boldsymbol{Y}_i > \boldsymbol{Y}_j$, i.e. the trial with the highest value in one condition also has the highest value in the other. A discordant pair is the opposite: $\boldsymbol{X}_i > \boldsymbol{X}_j$ but $\boldsymbol{Y}_i < \boldsymbol{Y}_j$. *G* can be empirically calculated by the following formula:

$$G = \frac{C - D}{C + D}$$

C and *D* represent the number of concordant and disconcordant pairs respectively, and *G* can vary between –1 (perfect negative correlation) and 1 (perfect positive correlation). For a JOL study, this is mathematically equivalent to the (rescaled) probability that a subject will assign a higher JOL to a trial they later remember than to a trial they later forget.

A major advantage of *G* is that it is nonparametric: it makes no assumption about the underlying distribution of the data. However, it disregards tied pairs (trials *i* and *j* for which $\boldsymbol{X}_i = \boldsymbol{X}_j$ or $\boldsymbol{Y}_i = \boldsymbol{Y}_j$), discarding information and making the coefficient less stable. Perhaps most importantly, *G* has been shown to vary with response bias, leading some researchers to recommend an alternative approach based on Signal Detection Theory (SDT, Masson & Rotello, 2009). In this case, the information used to form JOLs (though not necessarily the JOL rating itself) is assumed to be a continuous, unidimensional, and normally distributed value for both subsequently remembered and subsequently forgotten items. Participants assign JOL ratings based on this underlying information, giving higher JOLs to trials with higher values. The ability of the participant to discriminate between later remembered and later forgotten items can therefore be characterised by the distance d_a between their distributions:

$$d_a = \frac{\mu_R - \mu_F}{\sqrt{(\sigma_R{}^2 + \sigma_F{}^2)/2}}$$

Here μ_R and μ_F denote the mean JOL ratings for remembered and forgotten items respectively, similarly $\sigma_R{}^2$ and $\sigma_F{}^2$ denote their variances. Unlike *G*, the discrimination d_a uses all the information available and is invariant to response biases. It does, however, rely on an unproven assumption that the underlying distributions are normal. Hence, *G* and d_a rely upon different assumptions and are robust under different circumstances. To safeguard against biases or errors associated with each measure, both are reported throughout this thesis.

Having established the different means of conceptualising and calculating JOL accuracy, one important question arises: exactly how accurate are JOLs as predictions of future memory performance? The answer to this is not straightforward because it heavily depends on *when* the JOL is being made. This question and its implications will be the focus of the remainder of this chapter.

1.2.5. Immediate versus Delayed JOLs

Nelson & Narens' (1990, p. 130) original definition of JOLs read as follows: "Judgments of learning (JOL) occur during or after acquisition and are predictions about future test performance on currently recallable items". Later, however, they revised this definition to “Judgments of learning (JOL) occur during or soon after acquisition and are predictions about future test performance on recently studied items” (Nelson & Narens, 1994, p. 16). This revised definition, which does not imply that items need be recallable at the time of the JOL decision, seems particularly appropriate given the important distinction that has been made between immediate and delayed JOLs (Nelson & Dunlosky, 1991). In contrast to immediate JOLs, which are made during or immediately after the appearance of the to-be-remembered stimuli, delayed JOLs are made after a pre-determined delay. The typical delayed JOL paradigm involves the consecutive presentation of paired associates (a cue and a target) and after a certain number of trials, the cue from the first pair is represented along with the prompt to indicate the probability of later retrieval of the target stimulus. Hence, the delays in these kinds of experiments are filled with additional study trials, and are therefore determined by the number of intervening trials and the duration of each of these.

Since Nelson & Dunlosky (1991) described the delayed JOL effect almost two decades ago, the literature has consistently reported a substantial improvement in monitoring accuracy for delayed, as opposed to immediate, JOLs (e.g. Dunlosky & Nelson, 1992; Dunlosky & Nelson, 1997; Kelemen & Weaver, 1997; Meeter & Nelson, 2003; Weaver & Kelemen, 1997). When JOLs are immediate, G has been found to be about 0.30, however, when the JOLs are delayed, G typically increases to over 0.80 (see, for example Weaver & Kelemen, 1997). Consistent with these general observations, Nelson & Dunlosky (1991) found that G increased from 0.38 to 0.90 when JOLs were delayed by about one minute after initial study.

Intuitively, it might seem perplexing that delays should improve accuracy. However the explanation for this observation possibly lies in the amount of information available at the time the JOL is decided, rather than the timing of the response per se. In the case of immediate JOLs, the study stimulus (in full) is presently available on-screen or is presumably still fresh in memory (when the prompt is presented independently of the stimulus). In the case of delayed JOLs, on the other hand, only the cue stimulus is accessible and the JOL has to be produced in the absence of crucial information. Nelson & Dunlosky (1991) therefore hypothesised that immediate JOLs could be based partly on short-term memory (STM) processing, whereas delayed JOLs rely on long-term memory (LTM) processing exclusively. Since later test performance is dependent on successful retrieval from LTM, the additional reliance on STM adds noise to the monitoring, resulting in less accurate immediate JOLs. Nelson & Dunlosky (1991) called this idea the Monitoring Dual Memories (MDM) principle and recommended that, to ensure optimally accurate monitoring, JOLs should be made after a delay that is long enough to exceed the duration of information in STM (Nelson & Dunlosky, 1991).

Although the delayed-JOL effect is generally agreed to be a real phenomenon, the validity of the MDM principle has been a hot topic of debate (Kimball & Metcalfe, 2003; Spellman & Bjork, 1992; also see Dunlosky & Bjork, 2008). For example, some researchers argue for a transfer-appropriate monitoring hypothesis, which assumes that as the similarity between the processes engaged in at the JOL stage and at the retrieval stage increases, the accuracy of monitoring will improve (Begg, Duft, Lalonde, Melnick & Sanvito, 1989; Dunlosky & Nelson, 1992). Spellman &

Bjork's (1992) self-filling prophecy hypothesis, on the other hand, claims that delayed JOLs are more accurate because participants covertly attempt to retrieve the correct answer when making a delayed judgment and consequently base the JOLs on the success of retrieval. Hence, they explain the delayed JOL effect in terms of retrieval practice (also see Finn & Metcalfe, 2008; Kimball & Metcalfe, 2003; Son & Metcalfe, 2005); when retrieval is successful the outcome is a high JOL and a memory boost, however when retrieval is unsuccessful the outcome is a low JOL and no memory boost. Finally, Koriat (1997) has suggested that the delayed JOL effect is caused by a shift from relying on intrinsic cues to relying on personal internal mnemonic cues.

The debate concerning the delayed-JOL effect is not the central question under investigation in this thesis, which will focus specifically on the cognitive and neural basis of *immediate* JOLs. The reason behind this decision was that the majority of behavouiral experiments and all existing brain imaging experiments (see Chapter 3) have foccused on immediate JOL, and have thus provided a starting point for investigations. Nevertheless, the distinction between immediate and delayed JOLs is an important one to make. Critically, any conclusion about JOLs made in this thesis cannot be interpreted as reflecting all JOL processes. Research following up on the current experiments will need to additionally investigate the neural correlates of delayed judgments to establish how these compare to the neural correlates of immediate judgments.

1.2.6. Section Summary

Since the late 1970s, psychologists have shown an increased interest in the study of metamemory, which refers to the knowledge that people have about the workings of their own memory. In 1990 Nelson & Narens developed a framework for studying metamemory systematically, providing a new starting point in metamemory research. Nelson & Narens (1990) described metamemory as consisting of a monitoring component and a control component which interact closely. The monitoring component refers to metamemory knowledge gained through subjective assessments of the learning episode and the control component refers to the behavioural strategies used to regulate learning.

One important and widely researched metamemory component is Judgments of Learning (JOL), which are estimates of future remembering of recently studied material. JOLs are considered important aspects of human learning because they are believed to guide the allocation of study time and thereby improve subsequent memory performance. Despite of its acknowledged importance, little is known about the basis on which such prospective memory estimates are made. The traditional view is that people are able to directly assess the strength of memory traces and base their JOLs on the reading of these. However more recently, researchers have questioned whether privileged access to memory traces is an actual possibility. Alternative theories have been suggested, such as Koriat's (1997) cue-utilization approach, which emphasises the importance of evaluating cues that are perceived by the learner to be reliable predictors of memory performance. These theories do not suggest that actual memory is never the basis of JOLs, however they suggest memory plays a more indirect (and also fallible) role in the assignment process.

The reliability of JOLs, as predictors of memory performance, is assessed through evaluating absolute accuracy (calibration) or, more commonly, relative accuracy (resolution). Relative accuracy is typically obtained by calculating the Gamma (G) correlation coefficient (Goodman & Kruskal, 1954; 1959). Some researchers have, however, expressed concerns of possible biases associated with the use of G (e.g. Masson & Rotello, 2009) and have therefore recommended the use of Signal Detection Theory (SDT) to evaluate relative JOL accuracy. Reviews of the literature suggest that JOLs made during stimulus presentation (or very shortly after) are only weakly, or moderately, predictive of future memory (as measured by G). By contrast, when the JOL is made after a delay of several minutes, accuracy is considerably higher. This delayed-JOL effect (Nelson & Dunlosky, 1991) is a well established phenomenon. Nonetheless, researchers are not in agreement about its underlying cause.

The research in this thesis will focus on the neural and cognitive bases of immediate JOLs. These bases will be investigated using standard behavioural methods and the use of Event-Related Potentials (ERPs), which provide a measure of electrophysiological activity originating from the brain in response to a stimulus event. A full outline of the ERP methods will be provided in the following chapter.

Chapter 2.

Event-Related Potentials

Activity in the brain is a product of electrical and chemical changes in the tissue. Communication of information between neurons involves the flow of ions across the neuronal membrane, producing a voltage field surrounding the active neurons, which can be detected by scalp electrodes connected to an amplifier. The output is a pattern of changes in voltage over time; this voltage variation constitutes the Electroencephalogram (EEG). The EEG reflects the sum of simultaneously ongoing neural processes in the brain (see Andreassi, 2000; Hugdahl, 1995). Therefore, looking at the raw EEG output, it is possible to differentiate between gross changes in mental state (such as alertness and sleep), but the EEG is not sensitive enough to reveal subtle changes in mental activity (Andreassi, 2000). Such changes can be detected, however, by time-locking the EEG recording to a stimulus event, and examining the brain's average response to many such presentations. The resulting waveform reflects activity which is consistently associated with the event of interest; this signal constitutes the Event-Related Potential (ERP; Coles & Rugg, 1995).

The main advantage of using ERPs in cognitive research is their high degree of temporal resolution. In fact, it is possible to track information processing with millisecond precision, starting with the initial registration of a stimulus followed by the preparation and execution of a response (Coles & Rugg, 1995). Such a quality is invaluable in investigations of sequences of cerebral events. This chapter will provide an outline of the procedures that are used to record, process and analyse ERP data, followed by a discussion concerning the inferences that can be drawn from the end product. First, however, a basic description of how the ERP signal is produced will be provided.

2.1. The Neural Origin of the EEG

2.1.1. Electrogenesis

The general structure of a typical neuron is illustrated in Figure 2.1. The neuron is surrounded by a neuronal membrane containing cytoplasm and the nucleus. The cytoplasm, which is also referred to as the intracellular fluid, consists mainly of water and electrolytes (electrically charged molecules and ions). The membrane works as a barrier between the intracellular and the extracelluar fluids and controls the flow of ions entering and exiting the neuron, which in turn determines the difference in voltage between the inside and the outside of the neuron. This ability is maintained by the protein molecules that the membrane is made from. Some of these molecules are attached to the surface of the membrane whereas others penetrate the membrane and create a bridge between the inside and the outside of the neuron. These bridges are known as ion channels.

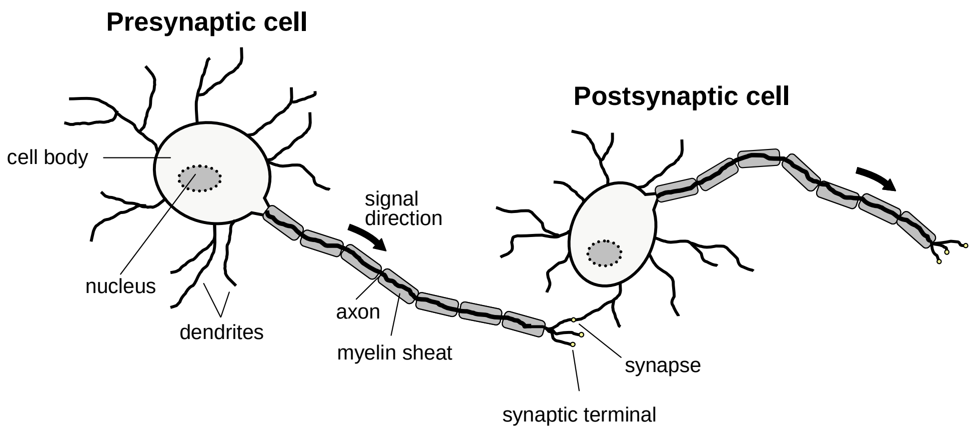

Figure 2.1 The basic structure of a neuron.
Features include the dendrites, cell body and axon. Action potentials travel down the axon in the direction indicated by the arrows. Information is exchanged between neurons at the synapse; action potentials cause neurotransmitters to be released from the presynaptic cell and bind to receptors in the postsynaptic cells causing ion channels to open or close. This reaction results in a postsynaptic potential: graded change in potential across the membrane.

When a neuron is resting, the separation of positive and negative charges across the cell membrane sustains an electrical potential of approximately -70 mV (by definition, the outside of the neuron has an electrical potential of 0). The negative resting potential is primarily caused by a higher concentration of potassium ions in intracellular compared to extracellular fluids (due to the large numbers of open potassium channels in the membrane). When a neuron is stimulated, the electrical potential rapidly changes and, if the neuron is depolarised sufficiently, the result is an action potential that propagates to the terminal of the neuron. The action potential works on an all-or-nothing basis; as long as the neuron's potential reach a certain threshold, the electrical impulse will be initiated to its full intensity. The sudden change in voltage in one area in the axon of the neuron will elicit a similar reaction in a nearby area and in this way the impulse will travel the full length of the neuron in the manner of a chain reaction. It is important to note that the only matter that actually *moves* along the axon during this progression is the electrical current;

the ions move restrictively in and out of the cell membrane and the surrounding fluids stay in position. When the action potential reaches the terminal of a neuron, chemical neurotransmitters are released at the synapse. The neurotransmitters fit into receptors at the dendrite of the post-synaptic neuron. When the neurotransmitters combine with the receptors this causes ion channels to open or close resulting in a graded change in potential across the membrane, known as a postsynaptic potential. Hence, action potentials reflect transfer of information *within* a neuron (intracellular potentials), whereas post-synaptic potentials reflect transfer of information *between* two or more neurons (extracellular potentials).

Although action potentials can be measured using invasive single-unit recordings, they are generally not registered by scalp electrodes (Luck, 2005) because neurons that are aligned in parallel to each other are likely to send action potentials down the axons at the same time. This synchronisation would not be a problem if the action potentials were triggered in *perfect* synchrony, but this is often not the case. When there is a slight time delay, one neuron will be letting ions *out* through the membrane when another neuron is letting ions *in* at the same spatial location. The action potentials then cancel each other out and therefore produce a signal that is too small to be detected from the scalp (Luck, 2005).

Post-synaptic potentials, on the other hand, last longer than action potentials, are typically restricted to the one location (the dendrites) and arise instantaneously. Post-synaptic potentials are therefore the signals that are picked up by EEG recording electrodes placed on the scalp. It is important to note, however, that for the signal to be detectable, a relatively large population of neurons must a) fire simultaneously, and b) be arranged in an “open field” geometric configuration. In open field configurations neurons are aligned in a parallel orientation and when the population of neurons fire simultaneously, the electrical fields generated by each neuron will sum together. A great proportion of the cerebral cortex is structured in this way (Coles & Rugg, 1995). However, neurons in some regions of the brain, especially subcortical structures, are arranged with the cell bodies clustered in the centre and dendrites reaching out in all directions. Such an arrangement is known as a “closed field” configuration, and activity from neurons aligned in this manner is very unlikely to be picked up by scalp electrodes (Coles & Rugg, 1995). One critical factor that follows from the selective sensitivity of EEG to particular types of neural activity is that when no difference in ERP activity is present as a function of experimental manipulations, one cannot confidently conclude that no such differences exist because they could simply be invisible at the scalp.

2.1.2. Volume Conduction

ERPs inherently provide less accurate spatial information compared to haemodynamic imaging methods (such as fMRI and PET), because they only measure signals from the surface of the head. EEG activity recorded from the scalp can be the result of a near infinite number of intracerebral sources that cannot easily be identified; a problem which is known as the “inverse problem”. The main reason for the poor spatial resolution is that the inside of the skull acts as a volume-conducting space. The electrical signals are smeared out as they pass through the brain, severely distorting the voltage distribution as it appears on the surface. The signal recorded from a location on the scalp depends on the position and orientation of the neural generators as well as the resistance and shape of the brain and the skull.

The inverse problem is the reason why ERPs are not an ideal methodology for investigating the various anatomical structures underlying cognition. However the distribution of ERP activity across the scalp still contains some valuable information. For example, in cognitive research, it is sometimes sufficient to determine whether or not the neural processes observed in two experimental conditions are engaged by the same or different neural systems. In the case when two experimental conditions give rise to ERPs of differing topographic distribution, it is reasonable to conclude that different sets of neural generators are engaged across the conditions (or at best, that there is differential engagement of generators). Unfortunately, since an infinite number of dipoles can give rise to the same pattern of voltage distributions, meaning that when no topographic differences are present it is still possible that different subsets of generators are involved across conditions. It is, however, important to emphasise that the source localization of EEG signals can be estimated based on MRI and head models. Source localization was not attempted in this thesis because the primary focus was kept on the temporal characteristics of memory and metamemory-related ERP activity rather than the anatomical structures involved.

2.2. Recording the EEG

Having described the neural origin of the electrical signals that constitutes the EEG, the next section of this chapter will be concerned with the equipment and procedures used to acquire a clean and artifact-free EEG recording.

2.2.1. Active Electrodes and Reference Electrodes

Scalp electrodes are typically made from small discs of conductive metal. It is important to choose a metal that does not corrode quickly (hence losing their conductance) and that causes minimal attenuation of low frequency signals (Luck, 2005). The most commonly used metal today is silver silver-chloride, but tin is also a suitable alternative. Conductive gel is inserted between the electrodes and the surface of the scalp to maintain recording integrity over prolonged periods. Because current takes the path of least resistance, it is important that the impedance (impediment to current flow) between the scalp and the electrodes is kept stable and to a minimum. Reducing the impedance minimizes the risk of contamination by low frequency noise (caused by electrode and environmental artifacts) and can be done by gently abrading the skin to remove the outer layer of dead skin cells.

Scalp electrodes measure the changes in potentials over time in a basic electric circuit conducting between an active electrode and a reference electrode each placed at a separate location. Ideally, the reference electrode should be placed on an electrically neutral site; however in practice no such site is obtainable. The recorded signal will therefore not only reflect activity from the active electrode, but also from the reference electrode. The activity from the reference electrode contributes equally to each active electrode. However, the difference across active electrodes will still remain informative. That is not to say that the position of the reference electrode is completely arbitrary. For example, it is essential that the reference is not biased towards either one of the brain hemispheres because such a bias would result in a systematic difference in the recorded signal between the left and the right hemispheres. It is also recommended that an investigator chooses the reference site which is most widely used by other investigators in his or her area of research. This is because the morphology of the ERPs will differ depending on the location of the reference, and direct comparisons across experiments would therefore be challenging.

In cognitive neuroscience, the most frequently used reference sites are the bony protrusions (mastoids) behind each ear. Previously, it was common practice to physically link the left and the right mastoid electrodes with a wire; however linking the electrodes in this way generates a zero-resistance path between the hemispheres allowing current to flow out of the scalp at one location and back into the scalp at a second location (Luck, 2005). To circumvent this problem, recordings are now usually carried out referenced to the left mastoid only and are later re-referenced offline, creating a virtual reference from the average potential of the left and right mastoids.

2.2.2. Electrode Placement (the International 10-20 System)

To allow a systematic investigation of the topography of ERP effects across the scalp, it is necessary to record the EEG from multiple electrode sites using a montage of electrodes. The location of EEG scalp electrodes is standardised in the International 10-20 System developed by Jasper (1958). The International 10-20 system is based on the correspondence between the location of the electrode and the underlying area of cerebral cortex. Electrode placements are labeled firstly by a letter, which refers to the lobe. Hence, the letters F, T, C, P, and O stand for frontal, temporal, central, parietal and occipital respectively (although there is no central lobe, the distinction has been made for the sake of identification). Secondly, each recording site is assigned a number; left hemisphere locations are identified by odd numbers and right by even numbers, and the smaller the number the closer the site is to the midline. There are also electrodes placed on the actual midline, referred to by the letter ‘z’.

In the International 10-20 system the electrodes are placed at points 10 and 20 percent of the measured distance from the nasion (the depression at the top of the nose) to the inion (the prominent projecting point at the base of the skull) and from the left to the right pre-auricular points (the bony indentations in front of the ears). This is to ensure maximal coverage of the brain. While a minimal configuration consists of one active electrode and one or two reference electrodes, a multi-channel configuration can comprise 128 or 256 electrodes. In such extended versions of the International 10-20 system (see Chatrian, Lettich & Nelson, 1985), electrodes are added to the array by using the spaces in between the standard configuration.

Although alternative electrode systems exist (for example the Queen Square system; Blumhardt, Barrett, Halliday and Kriss, 1977), the International 10-20 system (including the extended versions 10-10 and 10-5) are usually employed in experimental investigations.

2.2.3. Analogue-Digital (A/D) Conversion

EEG recordings are analogue: data are collected continuously over time with a corresponding continuous range of amplitudes. For computers to be able to store and process EEG data it is required that the analogue signal is amplified and changed into a multi-level digital signal (in which discreet changes in amplitude are measured at discrete moments in time). This process is performed by an analogue-to-digital converter (ADC). It is essential that the ADC device has a sufficient resolution, ensuring that the critical content of the EEG recording is not altered. EEG amplifiers also amplify unwanted electromagnetic noise (from the brain or from the testing environment) and this noise can appear in the EEG recording (aliasing) unless the sampling rate of the ADC is sufficiently high (Picton et al., 2000). The *Nyquist theorem* (see Luck, 2005) therefore recommends that the sampling frequency should be at least twice the highest frequency in the signal.

Following digitisation, the EEG signal is passed through two filters: a low-pass filter which passes low-frequency signals and attenuates high-frequency signals (which might cause aliasing), and a high-pass filter which passes high-frequency signals and attenuates low-frequency signals (which can block the ADC).

Frequencies are defined as low and high relative to a predefined cut-off frequency (which varies from filter to filter).

2.3. From EEG to ERPs

To extract ERPs from the EEG recording, steps must first be taken to reduce the impact of random or systematic artefacts of which there are many to consider (see Rowan & Tolunsky, 2003 for an overview). Muscular tension and electrical noise from the surrounding environment are common problems to which the easiest solutions are to eliminate their original causes (by making sure the participants are comfortable and that any unnecessary electrical equipment is switched off). Artefacts due to eye movement and eye blinks, on the other hand, can be reduced by the use of data processing procedures outlined below.

2.3.1. Ocular Artefact Reductions

Electrical changes due to eye movements and eye blinks are a major contaminant of EEG recordings, with the problem being most noticeable in data recorded from frontal electrode sites. One way of approaching this problem is to ask participants to refrain from blinking and moving their eyes during critical epochs; however this instruction poses a secondary task for participants to attend to during the experiment (a cognitive confound) and could also cause unnecessary tension which ultimately will reduce the quality of the recording (a physical confound). By collecting Electro-Oculogram (EOG) data collected at the same time as EEG allows excessive eye- blinks and movements to be identified. The EOG measures differences in electrical potential between electrodes placed above and below one of the eyes (vertical EOG; VEOG) and between electrodes placed on the outer canthi to the left of the left eye and to the right of the right eye (horizontal EOG; HEOG). Once identified, one possibility is to simply throw out all of the contaminated segments of EEG, but this can potentially cause a lot of data to be lost. Instead, most researchers make use of EOG correction procedures, which rely on regression techniques to determine the degree of correlation between the EOG and the EEG signal. The calculated regression coefficient is used to remove a proportion of EOG from each active electrode channel. Although correction procedures significantly reduces ocular artefacts, it is important to keep in mind that the EOG can also pick up brain activity and for that reason useful neural information can potentially be lost.

2.3.2. Averaging

After ocular artifacts have been removed from the continuous EEG recording, the signal of interest is still masked by background noise, such as ongoing cognitive processes not directly relevant to the processing of the experimental stimulus event. As described earlier, ERP signals are very small, with amplitudes in the order of microvolts, and therefore need to be physically extracted from the rest of the EEG. The most common procedure for improving the signal-to-noise ratio is averaging (Dawson, 1951; 1954), which involves time-locking the EEG recording to the onset of the stimulus event and examining the brain’s average response to many such events. When all the time-locked epochs of brain activity are averaged together, the random background noise is (approximately) eliminated, whereas the ERP signal, which is assumed to be present in all epochs, will be retained. The signal-to-noise ratio increases as a function of the square root of the number of trials included in the average (Perry, 1966); consequently, adding trials improves the quality of the ERPs, but the gain from adding more trials becomes increasingly smaller.

A few important assumptions underlie the averaging technique, including a) that the noise is uncorrelated with the signal of interest, and b) that the signal is exactly the same on every trial (Luck, 2005). In reality, however, the background noise in an EEG recording is unlikely to be completely random and unrelated to the signal in every instance. Similarly, the second assumption is also rarely met; it is unrealistic to expect the signal of interest to show no variation in amplitude and latency across experimental trials. For example, it is likely that the signal of interest could be absent on some trials, such as when people are correctly guessing during a memory test. Variation in waveforms can also be caused by phases of fatigue or participants' attention becoming diverted from the task. In practice, however, amplitude variation across trials is not necessarily a serious problem, as real differences in amplitudes across experimental conditions are still expected to be reflected in the averaged waveforms. By contrast, latency jitter is more of a challenge; if the latencies of individual waveforms differ from trial to trial, the amplitude of the averaged waveforms will be reduced and distorted in shape. The serious implication of latency jitter is that amplitude differences between experimental conditions (or groups of participants) can be the result of latency jitter rather than of differences in activity of the underlying generators. One potential solution to latency jitter is to employ Woody filter techniques (see Woody, 1976), but this approach relies heavily on the ability to identify ERPs in individual trials, which is often not possible.

2.4. Deducing Psychology from ERPs

The assumption in cognitive neuroscience is that electrophysiological activity maps directly (or indirectly) onto psychological phenomena. It is important to keep in mind, however, that the observed ERPs merely correlate with the cognitive processes under investigation and cannot be assumed to be straightforward manifestations of those processes. Regardless, when the ERPs have been extracted from the ongoing EEG recording, an attempt must be made to somehow interpret them with regard to their cognitive meaning. The first step in this process is to appropriately identify and select the ERP components to be examined.

2.4.1. Component Selection

In the early days of ERP research, components were defined in terms of their polarity, latency and distribution on the scalp (Luck, 2005), however these qualities of are not very informative as a way of identifying the cognitive processes that the ERPs correspond to. Many researchers (e. g. Donchin, Callaway, Cooper, Goff, Hillyard & Sutton, 1977) have therefore adopted a "functional approach", focussing on an ERP component's relationship with experimental variables rather than its peaks and troughs. To follow the functional approach it is necessary to design tasks that have the potential to isolate and contrast specific cognitive processes, allowing ERPs elicited in two different experimental conditions to be subtracted from one another (see Rugg & Coles, 1995). The resulting component reflects the difference in activity that distinguishes the experimental variables.

The functional approach includes two underlying assumptions: the latency of the ERPs to be subtracted must be equal and the experimental conditions that produce them must differ with regard to only the cognitive process of interest. If the first assumption is not met, the subtraction will produce separate peaks in the waveform and thereby mistakenly give impression that the two processes differ qualitatively. The second assumption, also known as the *pure insertion principle* (Donders, 1868), presupposes that cognitive functions are additive and do not interact with each other. In most cases, however, this assumption is unlikely to be valid; two conditions will consist of a number of shared cognitive components, each of which will be influenced by the introduction of additional components. Consequently, the subtraction will reflect a combination of the added and the shared (but adapted) components. It is worth noting, however, that violation of the pure insertion principle is not unique to ERP research but applies to all experiments that involve comparisons by subtracting data (including behavioural experiments and other experiments using other neuroimaging methods).

2.4.2. Making Inferences from ERPs

Identifying that experimental manipulations give rise to different patterns of brain activity does not in itself inform the specific nature of these differences. Interpreting ERPs is a notoriously difficult process, complicated by many of the issues covered in above sections. Nonetheless, the consistency of findings across numerous studies provides confidence in its value as a tool for investigating human cognition. ERPs can be interpreted in terms of their temporal, size and distributional characteristics, each of which will be discussed in turn below.

The major advantage of using the ERP technique over haemodynamic imaging methods (such as fMRI and PET) is their high temporal resolution; latency differences can help establish the time it takes the brain to differentiate between two experimental conditions. Importantly, however, the ERPs can only provide an upper-bound estimate of timing differences, because earlier differences could occur which are not detectable on the scalp. Amplitude differences, on the other hand, are believed to correspond to the strength or degree of processing. Higher amplitudes elicited by one condition over another suggest that the same process is occurring in both cases but is differentially engaged across the conditions (although it is also possible that differences in amplitudes are caused by an ERP effect being present on a different proportion of trials, rather than being smaller in magnitude per se). Also, as noted earlier, differences in latencies across individual trials can result in erroneous amplitude differences in the averaged waveform; hence the interpretation of quantitative differences must always be made with caution.

When one experimental condition gives rise to an ERP with a particular amplitude and latency at one location of the scalp, and another condition gives rise to an identical ERP but at a different location, it is reasonable to assume that the two conditions engage neurally and functionally distinct processes which happen to overlap in time (Rugg & Coles, 1995) [2]. Although ERPs cannot provide accurate information about the specific anatomical structures involved, the differential distribution of effects is informative in itself. Unfortunately, in practice there are

[2] The polarity of ERP effects are also of interest in this regard: when two effects differ in polarity it does not mean that different neural structures are giving rise to the two effects, but it does necessitate that different cognitive functions are operating (that might or might not be supported by the same underlying structures). Note, however, that polarity of an ERP effect does not carry any additional interpretational information.

serious challenges associated with statistically verifying that such qualitative differences actually exist. The repeated measures ANOVA (also used for analyses of quantitative differences) is based upon an additive model, whereas differences in dipole strength are multiplicative rather than additive. This mismatch has the potential consequence of producing the appearance of differences between conditions at some locations compared to others, which are not caused by differential activation in different underlying sources. During the analysis of effects, a simple main effect of condition could be wrongly interpreted as an interaction between condition and location. As a possible solution to this problem, McCarthy & Wood (1984) recommend that ERP data are rescaled prior to the analysis of topographic distribution, as this would minimise the unwanted multiplicative effects. The most commonly used scaling strategy is the minimum-maximum method which involves normalisation of the data. The use of rescaling is vigorously debated (see Haig, Gordon & Hook, 1997; Ruchkin, Johnson & Friedman, 1999; Urbach & Kutas, 2002; Wilding, 2006), but is still preferred by many researchers due to the reduced likelihood of type 1 errors.

2.5. Summary

Event-related potentials reflect activity (predominantly caused by postsynaptic potentials) originating mainly in the cortex which is consistently associated with the processing of a stimulus event. ERPs are extracted from the ongoing EEG, which is recorded by using electrodes situated on the surface of the scalp. The EEG needs to be amplified, digitised and filtered before multiple trials can be averaged together and the ERPs revealed. ERPs can be characterized in terms of their latency, amplitude and distribution on the scalp – all of which provide information regarding the processes believed to be producing the signal.

ERPs are considered to be an important and useful tool with which to examine functional models of cognition, allowing cognitive processes to be defined according to their neurophysiological correlates. Although the spatial resolution offered by the ERP technique is rather poor, it provides excellent temporal resolution and is therefore an optimal choice for investigating timing aspects of mental operations.

Chapter 3.

Event-Related Potentials and Memory/Metamemory

ERPs have been extensively employed in investigations of human memory processes. As outlined in the Chapter 2, they provide excellent temporal resolution and can be used to identify the timing aspects of cogntive functions and how these differ across experimental conditions. This chapter will provide an outline of some of the past ERP research that has contributed to our understanding of how the brain encodes, stores and retrieves memories. The focus will then shift to the use of brain imaging in studies of metamemory. The literature is less extensive in this area, but the few experiments that have been conducted and the conclusions they have supported will highlight the purpose of the research reported in this thesis.

3.1. The Neural Correlates of Recognition Memory

3.1.1. Subsequent Memory Effects

The successful retrieval of past episodes and the quality of the memories recovered are both dependent on the encoding processes that were engaged when the memories were first formed. For example, depth-of-processing experiments (see Craik & Lockhart, 1972) have repeatedly demonstrated that study items which are deeply encoded (e.g. through making semantic judgments about words) are better remembered compared to items which are shallowly encoded (e.g. through making judgments about the physical characteristics of words). Although an encoding-retrieval relationship is unmistakably present, the neural systems that establish memory traces are themselves still poorly understood.

ERP investigations of memory formation typically use the procedure of backsorting study trials according to whether stimuli were remembered or forgotten at test. Subsequent incorrect trials are subtracted from subsequent correct trials and the resulting difference waveform (see Figure 3.1) is the subsequent memory (SM) effect (also known as *difference* due to *memory*; *Dm*; Paller, Kutas & Mayes, 1987). Hence, SM effects refer to the activity that follows the presentation of a to-be-remembered stimulus, which is predictive of whether or not that particular stimulus will be later remembered or forgotten. SM effects have been demonstrated in experiments using words (Fernandez, Weyerts, Tendolkar, Smid, Scholz & Heinze, 1998; Friedman & Trott, 2000; Otten, Quayle, Akram, Ditewig & Rugg, 2006; Otten & Rugg, 2001a; Sanquist, Rohrbaugh, Syndulko & Lindsley, 1980), pictures (Duarte, Ranganath, Winward, Hayward & Knight, 2004), sounds (Cycowicz & Friedman, 1999), Chinese characters (Guo, Zhu, Ding, Fan & Paller, 2004) and faces (Sommer, Schweinberger & Matt, 1991).

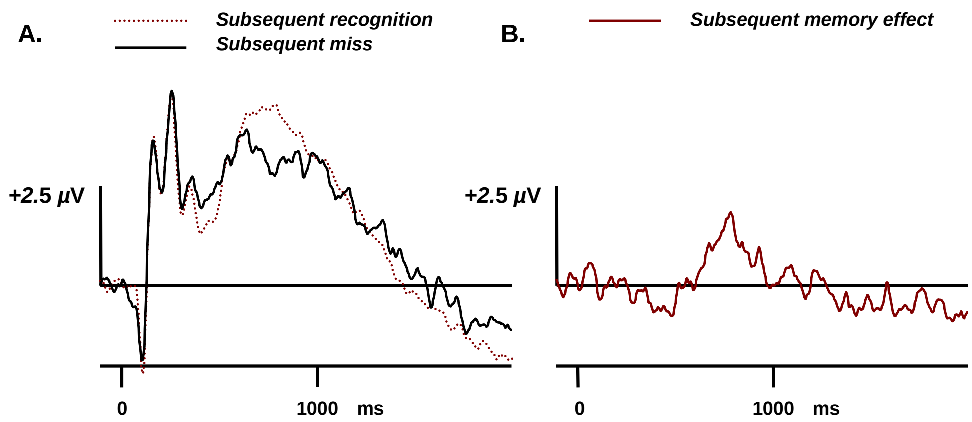

Figure 3.1 SM effect.
Grand-average waveforms recorded at study for subsequent hits (red) and subsequent misses (black), plotted as a function of time (Skavhaug, Wilding & Donaldson, unpublished data). Positive voltage is plotted upwards and zero indicates stimulus onset. The subsequent hit waveform is more positive-going compared to the subsequent miss waveform between approximately 500 and 1000 ms (A). Subsequent misses have been subtracted from subsequent hits and the resulting waveform is a SM effect (B).

SM effects have been found to onset as early as 200 ms post-stimulus often with a frontal distribution (latency- and topographic differences across experiments are discussed below). Importantly, the SM effects have been differentiated from other, often co-occurring, processes such as implicit memory and distinctiveness detection (Fernandez et al., 1998). The first ERP studies investigating encoding (Sanquist et al., 1980) examined SM effects elicited by words studied during either a semantic or an orthographic encoding task. First of all, these studies found that items that were subsequently recognised produced a more positive waveform compared to items that were subsequently missed. Second, the SM effect was considerably larger for items studied during the semantic task compared to items studied under the orthographic task. These early studies employed a very limited number of electrodes however, and for that reason could not offer sufficient coverage of the scalp to support strong claims about scalp topography. Later studies have nevertheless replicated Sanquist et al.'s (1980) main findings (although for an exception see

Otten & Rugg, 2001a) and added further valuable information as advances in equipment and technology have progressed. This growing body of evidence suggests that there is no single representative (typical) SM effect; the topography and time-course seem heavily influenced by a number of factors.

As pointed out above, the nature of the encoding task was originally found to be an important determinant of the magnitude of the SM effect (Sanquist et al., 1980). Many studies have since reported that the effect is either reduced or even absent when items are studied during shallow rather than deep encoding requirements (Paller et al., 1987; Paller & Kutas, 1992; Ritter & Snodgrass, 1996). Otten & Rugg (2001a), on the other hand, found that depth-of-processing manipulations led to qualitatively (rather than quantitatively) different SM effects. In their experiment, participants were presented with a series of word preceded by a cue in the form of an “X” or an “O”. The presentation of an “O” called for the participants to decide whether or not the following word was animate (deep encoding task) and the presentation of an “X” called for the participants to decide whether or not the first and the last letters of the word were in alphabetical order. At test, the study words were presented along with a number of new words and participants were required to make an old/new judgment for each. Following each memory judgment confidence judgments were also recorded, allowing only items that were recognised with high-confidence to be included in the grand averages. Reliable SM effects were found for both the animacy and the alphabetical task during three time windows: 0-350 ms, 550-1000 ms and 1300-1900 ms post-stimulus. In the animacy task, the effect started with a left frontal focus, which changed to fronto-central recording sites and back to left frontal recording sites. By contrast, for the alphabetic task the scalp distribution was restricted to the centro-parietal recording sites. The most apparent discrepancy between the two conditions, however, was that they were reversed in polarity; the animacy task elicited positive-going effects (consistent with the majority of findings in the literature) whereas the alphabetic task elicited negative-going effects. The observed change in polarity led Otten & Rugg (2001a) to conclude that successful memory encoding is supported by multiple, task-specific, neural systems.

According to Otten & Rugg (2001a), there are three possible reasons why previous studies have failed to detect qualitative differences using paradigms similar to theirs: first of all, SM effects in shallow tasks had not been statistically evaluated independently of effects in deep tasks (Paller et al., 1987). Second, shallow tasks usually produced insufficient number of trials for such an assessment to be adequately carried out in the first place. Finally, response confidence at test had not been considered. The last point is particularly important because shallow tasks often result in poorer memory performance both with regard to number of remembered items and the level of confidence reported. It is highly possible that only trials associated with confident judgments at test will show SM effects at study and, if this is the case, the typically reported reduction in SM effects for shallow encoding could be due to a higher proportion of non-confident judgments and guesses (Otten & Rugg, 2001a).

It is not only the polarity of the SM effect that can be affected by changes in study task, as differences in scalp topography across experiments have also been widely demonstrated (see Fernandez et al., 1998, Wagner, Koustaal & Schacter, 1999). In terms of topography, two main categories of SM effect have been described (Fernandez & Tendolkar, 2001; Fernandez et al., 1998): one with centro-parietal maxima (Besson & Kutas, 1993; Fernandez et al., 1998; Neville, Kutas, Chesney & Schmidt, 1986; Paller et al., 1987; Sanquist et al., 1980; Van Petten & Senkfor, 1996) and one with frontal maxima (Duarte et al., 2004; Fabiani, Karis & Donchin, 1990; Karis, Fabiani & Donchin, 1984; Klingberg & Roland, 1998; Weyers, Tendolkar, Smid & Heinze, 1997). It is unclear exactly what the differences in topography signify, however it is hypothesised hat centro-parietal effects are caused by rote learning strategies whereas frontal effects are the product of elaborate strategies. For example, Fernandez et al. (1998) encouraged their participants to avoid elaborate encoding strategies and found SM effects with a focus on centro-parietal recording sites. Likewise, the use of elaborative encoding strategies (e.g., relating list items to each other or to personal experience) has been found to suppress the centro-parietal effects in Von Restorff[3] paradigms and generated frontal effects (Fabiani et al., 1990; Karis et al., 1984).

The experimental evidence outlined above clearly demonstrates how sensitive the SM effect is to task instructions at study. Since the backsorting method involves sorting study trials based on later memory retrieval performance, the instructions participants are given at test are also important to consider. Different forms of

[3] Subjects are better at remembering items that are distinct in one or more dimension. This phenomenon has been called the Von-Restorff effect (e.g. see Fabiani & Donchin, 1995).

memory retrieval assessment and the neurophysiological correlates they elicit at test are topics that will be covered in detail later in this chapter. It is, however, also necessary to outline some of the existing test paradigms here – to evaluate the consequences they have for memory encoding investigations.

A great deal of human memory experiments rely on recognition memory tests for evaluating performance. Recognition paradigms involve the presentation of stimuli at study that are later re-presented at test, usually intermixed with an equal number of new stimuli. Participants are required to correctly identify items that were included in the study phase (old items) and reject those that were not (new items); a task referred to as an old/new judgment. Sometimes old/new judgments can be followed by ratings of confidence (e.g. Otten & Rugg, 2001a), which allow the exclusion of trials recognised on the basis of weak memory traces or pure guessing. Alternatively, participants can be instructed to provide additional information regarding the original study episode (e.g., the colour in which a word was presented). Such tasks are known as source judgments tasks and place considerably more demands on the participants. Other forms of memory assessments procedures include cued recall tasks (in which parts of a study item is re-presented as a retrieval cue and the participant needs to provide the remaining content) and free recall tasks (in which participants have to recover the study item from memory without the aid of a retrieval cue).

As stated previously (see Chapter 1), it is widely believed that there are two routes to recognition: familiarity and recollection (Bridson, Fraser, Herron & Wilding, 2006; Curran, 2000; Mandler, 1980; Rugg & Curran, 2007; Rugg & Yonelinas, 2003; Yonelinas, 2002), and that these two forms of recognition memory are supported by distinct cognitive and neural processes (Bridson et al., 2006; Rugg & Curran, 2007; Rugg, Mark, Walla, Schloerscheidt, Birch & Allan, 1998; Rugg & Yonelinas, 2003; Vilberg, Moosavi & Rugg, 2006; Woodruff, Hayama & Rugg, 2006; Yonelinas, 2002; Yonelinas, Otten, Shaw & Rugg, 2005). Many researchers have investigated the familiarity/recollection distinction by using versions of the Remember/Know (R/K) paradigm (Tulving, 1985; see Chapter 1). In R/K paradigms, participants are first required to make old/new judgments at test, and following each old decision, they are additionally asked to indicate whether they specifically *remember* having seen the item at study (a response believed to indicate recollection) or simply *know* that the item is old (a response believed to indicate familiarity[4]).

Although the R/K paradigm has been a key task used to investigate memory retrieval processes, researchers have also questioned whether differences in the SM effects can be found as a function of type of judgment given at test (Duarte et al., 2004; Friedman & Trott, 2000; Mangels, Picton & Craik, 2001; Smith, 1993). This question elicited interest because a number of ERP retrieval experiments using the R/K paradigms have concluded that familiarity and recollection are supported by distinct neural systems (outlined later in this chapter). If familiarity and recollection are dissociable at the time of retrieval, it is reasonable to assume they are also

[4] There is some debate surrounding this claim, see Gardiner & Java (1990).

dissociable during encoding. The findings from encoding studies using the R/K paradigm have, however, to this date been inconclusive.

In one of the earliest investigations, Smith (1993) found reliable SM effects for items that were subsequently judged as remembered as well as for items subsequently judged as known. These effects were relatively widespread and long lasting (appearing between 200 and 900 ms post-stimulus), with R responses eliciting a larger effect than K responses, but with equivalent scalp topography. Friedman & Trott (2000), on the other hand, found an effect only for items that were remembered (an effect appearing between 400 and 1100 ms post-stimulus with a left frontal focus). Friedman & Trott reconciled their findings with those obtained by Smith (1993) in terms of instructions; claiming that Smith's instructions were simply inconsistent with the typical R/K paradigm. Moreover, Duarte et al. (2004) reported effects for both subsequently known and remembered items which had similar onset times, but different scalp distributions and offset times. Whereas known items gave rise to a left frontal effect between 350 and 450 ms post-stimulus, remembered items were associated with a right-frontal effect occurring between 300 and 450 ms, shifting to a more bilateral distribution between 450 and 600 ms. Similarly, Yovel & Paller (2004) found that right-hemispheric activity predicted subsequent face familiarity (retrieval without context), whereas bilateral activity predicted subsequent face recollection (retrieval with context).

Although it is difficult to draw definitive conclusions from the R/K studies carried out to date, they highlight the general complexity that is currently present in the memory encoding literature. In addition to encoding tasks and retrieval instruction, other factors known to further influence the timing and distribution of SM effects are intentions of encoding (Cycowicz & Friedman, 1999) and even mood (Kiefer, Schuch, Schenck & Fiedler, 2007). In addition, Otten et al. (2006) have demonstrated that activity preceding a to-be-remembered word is also predictive of later memory for that stimulus. Otten & Rugg (2001a) had previously hypothesised, based on the sometimes very early onset of SM effects, that critical processes could already be active before an encoding event takes place, possibly elicited by a pre-stimulus cue. To investigate this possibility Otten et al. (2006) presented participants with a cue signalling the nature of the encoding task for the upcoming word (either semantic or orthographic) and time-locked the EEG recording to the cue rather than the word using a backsorting procedure. They found negative-going pre-stimulus SM effects present at the front of the scalp occurring 250 ms before stimulus onset. Similar results were found in a second experiment when the pre-stimulus cues warned the participant of the modality of the upcoming word (either visual or auditory).

Whilst compelling, the findings of Otten et al. (2006) are difficult to reconcile with previous theoretical accounts; how can SM effects occur before the onset of to-be-remembered stimuli? One intuitive answer to this question is that participants are differentially allocating their attentional resources prior to an experimental trial. However, Otten et al. (2006) provide a number of reasons why this explanation should be rejected. For example, if pre-stimulus SM effects reflect recruitment of attention, they should be present across all the experimental conditions, but they only occur for cues that signalled semantic encoding tasks (experiment one) and visual presentation modality (experiment two). Thus, having rejected an attentional account, the authors explain their findings in terms of adaptations of specific task sets during encoding – specifically that the frontal activity reflects working memory control processes (for more information about the possible role of working memory in long-term memory formation see Fernandez & Tendolkar, 2001; Wagner et al., 1999). Regardless of whether this interpretation of the findings is correct, the data clearly demonstrate the complexity of the processes involved in the formation of new episodic memories in humans.

Most of the evidence reviewed above is consistent with Otten & Rugg's (2001a) earlier claim that memory encoding is supported by a number of task-specific neural systems and evidence gathered through the use of alternative imaging methods, including intracerebral recordings (Fernandez et al., 1999) and in particular fMRI (Brewer, Zhao, Desmond, Glover & Gabrieli, 1998; Erk, Kiefer, Grothe, Wunderlich, Spitzer & Walter, 2002; Fernandez & Tendolkar, 2001; Otten & Rugg, 2001b; Park & Rugg, 2008; Rugg, Otten & Henson, 2002; Wagner et al., 1998), is supportive of this view. fMRI studies of successful memory encoding have consistently reported the engagement of the prefrontal cortex (PFC) as well regions situated within the medial temporal lobes (MTL; for reviews see Spaniol, Davidson, Kim, Han, Moscovitch & Grady, 2009; Wagner et al., 1999). Recent work has also explored a possible important role played by the posterior parietal cortex (PPC), possibly linked to attentional mechanisms (Uncapher & Wagner, 2009).

Although it is difficult to integrate current ERP and fMRI findings, evidence points towards a link between the frontally distributed SM ERP effects and activity in the PFC (e.g. Wagner et al., 1999). For example, fMRI data have suggested that episodic encoding is facilitated by working memory processes mediated within the PFC (the exact location depending on the nature of the stimulus materials; see Wagner et al., 1999) and the region has also been linked to control processes such as selection of goal-relevant item information (Blumenfeld & Ranganath, 2007).). Since the first observations of patient H.M. it has been generally agreed that the MTL, particularly the hippocampus, also have important implications for episodic memory. It is therefore surprising that some fMRI studies of successful memory encoding have failed to detect any significant activation of these structures (see Henson, 2005). According to Jackson & Schacter (2003), the reason for these null results is that studies have focussed primarily on subsequent memory for individual items. As MTL structures are possibly responsible for creating associations between items they will specifically be required under circumstances when two or more items are ‘bound’ together. Whether the posterior SM ERP effect reviewed above reflects consequences of activity in the MTL projecting onto the scalp is a definite possibility, however one that is impossible to ascertain. Nevertheless, when interpreting SM ERP effects it is important to consider the growing amount of fMRI evidence in the memory encoding literature to further the understanding of how the brain forms memories that remain accessible in the future.

In summary, SM effects refer to activity that follows the presentation of a to-be-remembered stimulus, which predicts whether or not that same stimulus will be remembered during a later test. The effects are generally characterised by an increase in positivity for subsequently remembered stimuli relative to subsequently forgotten stimuli, however the time-course and scalp distributions have been found to vary greatly depending on a number of factors (including stimulus content, encoding tasks, intentions to encode and retrieval instructions). Formation of new memories, for that reason, is probably not a unitary process but rather supported by activity in a number of specialised neural systems. By this view, a generic memory encoding operation does not exist, and behaviour is better explained as the result of more extensive processing resources being allocated to some stimuli, which increases the probability that those stimuli will later be remembered when required. The nature of SM effects is therefore dependent on the nature of the processes engaged.

3.1.2. Old/New Retrieval Effects

Interestingly, relative to SM effects, memory retrieval effects have been relatively well-characterised in the literature. Research has established that ERPs to hits (old items correctly identified as old) are typically more positive-going than those to correctly rejected new items; a pattern of activity referred to as ‘old/new effects’. At least three distinct old/new effects, with different functional interpretations, have been identified and dissociated at retrieval (for reviews see Allan, Wilding & Rugg, 1998; Friedman & Johnson, 2000; Rugg, 1995; Rugg & Curran, 2007); the early mid-frontal effect, the left-parietal effect and the late right-frontal effect. Although other effects have been identified (e.g. the late posterior negative slow wave, see Wolk et al., 2006; Wolk et al., 2007), the three traditional effects are most relevant to the studies reported in this thesis and will for that reason be the focus of the next section of this chapter.

The earliest of the main retrieval effects, the mid-frontal old/new effect, typically occurs between approximately 300 and 500 ms post-stimulus with maxima over mid-frontal electrodes (see Figure 3.2). This effect is also referred to as the FN400 effect by some researchers (see Curran, 1999) because of its resemblance in time course to the N400 (Kutas & Hillyard, 1980) often observed in language studies of semantic incongruity (this choice of terminology tends to cause confusion and will not be used in this thesis). There is some debate surrounding the functional interpretation of the mid-frontal effect, however the general view seems to be that it reflects processes supporting familiarity-based recognition memory (Bridson et al., 2006; Curran & Cleary, 2003; but also see Paller, Voss & Boehm, 2007; Tsivilis, Otten & Rugg, 2001; Yovel & Paller, 2004).

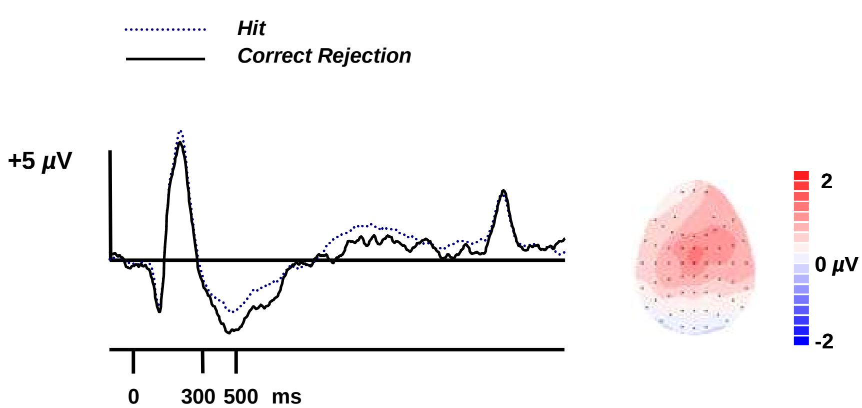

Figure 3.2 The mid-frontal ERP old/new effect at electrode FCZ.
Grand-average waveforms recorded at test for correctly recognised old items (blue) and correctly rejected new items (black) are plotted as a function of time (Skavhaug, Wilding & Donaldson, unpublished data). Positive voltage is plotted upwards and zero indicates stimulus onset. The old waveform is more positive-going compared to the new waveform between approximately 300 and 500 ms. The difference in activity (old minus new) is displayed in a topographical map (the front of the head is pointing upwards) that illustrates the mid-frontal distribution of the effect.

The mid-frontal effect's association with familiarity is based partly on findings from dept-of-processing studies. Rugg et al. (1998) found that shallowly and deeply encoded words elicited equivalent mid-frontal effects (but, as described below, the left-parietal effect was modulated by the experimental manipulation). Based on the assumption that depth of processing does specifically affect recollection rather than familiarity, Rugg et al.'s (1998) findings suggest that the mid-frontal effect is linked with familiarity.

Additional evidence in support of a familiarity account of the mid-frontal effect stems from the observation that it is sometimes present for false alarms (new items mistaken for being old; Curran, 2000; Curran & Cleary, 2003; Nessler, Mecklinger & Penney, 2001; Wolk et al., 2006). In a recognition study by Curran (2000), participants studied a number of words and were later tested with old study items, new words and lure words which were the same as the old word but reversed in plurality (for example, if the participants had studied *frogs*, the lure word would be *frog*; a paradigm originally developed by Hintzman & Curran, 1994). Curran (2000) found that the mid-frontal effect was of comparable magnitude for old responses to old words and to similar lures, but the index of recollection was larger for old items only. The assumption that similar lures should attract high levels of familiarity also readily explains why they are associated with more incorrect old responses than new words. Similar results have been found using lures that were semantically related to the old words (Nessler et al., 2001) and mirror-reversed pictures (Curran & Cleary, 2003). The last of these experiments is also important in another respect; it demonstrated that the mid-frontal effect is unaltered by a change of stimulus material. Other experiments have replicated this finding (Curran & Dien, 2003; Nessler et al., 2001; Wilding, Doyle & Rugg, 1995; but for an exception see Joyce, Paller, Schwartz & Kutas, 1999) adding evidence to the view that familiarity represents an amodal global-matching process.

Although the mid-frontal effect has been found to vary systematically with behavioural measures of familiarity, some evidence suggest that it could reflect processes that often co-vary with familiarity. For example, Tsivilis et al. (2001) suggest that the mid-frontal effect is related to a novelty detection process, whilst Yovel & Paller (2004) claim that it reflects conceptual priming. According to the latter authors, words (or other forms of stimuli with pre-existing semantic representations) are not suitable stimuli for investigations of familiarity because they have been encountered before (and are therefore familiar prior to the experiments). When a word is encountered in the study phase of an experiment, this leads to a processing facilitation when the word is later re-encountered at test. By this argument, mid-frontal effects are present for similar lure items (plurality-reversed words, semantically similar words or mirror-reversed pictures) because they share conceptual features with the old items.

To test the conceptual priming hypothesis, Yovel & Paller (2004) used unfamiliar faces as stimuli – faces that the participants would not have been exposed to previously. The faces were presented along with an occupation label, which the participants were later instructed to report if they could remember it at test. No mid-frontal effects were observed. Instead a posterior effect was present, which increased in size with the amount of information that could be recovered. Yovel & Paller (2004) therefore concluded that their paradigm had eliminated conceptual priming and that that familiarity (behaviourally measured as the inability to report the occupation which the faces had been paired with at study) and recollection produce similar effects which only differ in size. Null-results as those obtained by Yovel & Paller (2004) must, however, be interpreted with caution and it is worth noting that Curran & Hancock (2007) have claimed that mid-frontal effects can be found for novel faces, whilst Curran, Tanaka & Weiskopf (2002) report mid-frontal effects for computer-generated two-dimensional polygons ("blobs").

Although the debate concerning the functional significance of the mid-frontal effect is far from resolved, there is greater agreement about the interpretation of the later onsetting left-parietal old/new effect (also referred to as the P600 or the Late Positive Complex, Curran, 1999; Wolk et al., 2006, respectively). This effect, which has been found to occur between approximately 500 and 800 ms post-stimulus, maximal over left-parietal electrodes (see Figure 3.3), is believed to constitute the ERP correlate of recollection (Hayama, Johnson & Rugg, 2008; Li, Morcom & Rugg, 2004; Schloerscheidt & Rugg, 2004; Smith, Dolan & Rugg, 2004; Vilberg et al., 2006; Woodruff et al., 2006; for reviews see Allan et al., 1998; Rugg, 1995; Rugg & Curran, 2007).

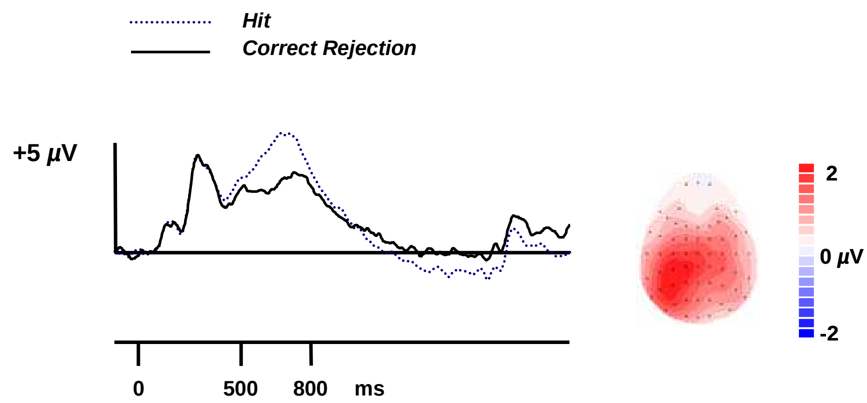

Figure 3.3 The left-parietal ERP old/new effect at electrode P3.
Grand-average waveforms recorded at test for correctly recognised old items (blue) and correctly rejected new items (black) are plotted as a function of time (Skavhaug, Wilding & Donaldson, unpublished data). The old waveform is more positive-going compared to the new waveform between approximately 500 and 800 ms. The difference in activity (old minus new) is displayed in a topographical map that illustrates the left-parietal distribution of the effect**.**

Convincing evidence for the functional interpretation of the left-parietal effect is provided from experiments demonstrating that the effect is larger for hits compared to false alarms (Curran, Schacter, Johnson & Spinks, 2001) and for items judged to have been *remembered* rather than *known* to be old (Curran, 2004; Duzel, Yonelinas, Mangun, Heinze & Tulving, 1997; Rugg, Schloerscheidt & Mark, 1998; Vilberg et al., 2006; but see Spencer, Vila Abad & Donchin, 2000). It is, nonetheless, source memory paradigms in particular that have laid the foundation for the functional interpretation of the left-parietal effect (Smith et al., 2004; Trott, Friedman, Ritter & Fabiani, 1997; Wilding & Rugg, 1996, 1997a; Wilding et al., 1995). In source paradigms, items are presented in one of two (or more) contexts at study and at test participants are required to recognise a studied item *and* provide information regarding the context it was presented in. Source memory experiments have demonstrated that the size of the left-parietal effect correlates with the amount of contextual information that has been recovered, regardless of whether the source attribute is temporal information (Trott et al., 1997), study modality (Wilding et al., 1995) or speaker's voice (Wilding & Rugg, 1996, 1997a). For example, Wilding & Rugg (1996) presented participants with a number of spoken words, half of which were spoken in a male voice and half spoken in a female voice. At test, old words were presented visually intermixed with an equal number of new words. Participants were initially required to make an old/new judgment and following each old judgment they were asked to make a second judgment about the gender of the voice that spoke the word originally. The left-parietal effect was considerably larger when recognition was accompanied with correct source judgment compared to incorrect source judgment, strongly suggesting that the effect reflects processes contingent upon recollection-based recognition.

The Wilding & Rugg (1996) study described above also made an important additional observation, reporting a relatively late onsetting positive-going effect that was maximal over right-frontal recording sites. This effect has since been reported in many recognition memory experiments (Donaldson & Rugg, 1998; Duzel et al., 1997; Hayama et al., 2008; Li, Morcom & Rugg, 2004; Ranganath & Paller, 1999; Schloerscheidt & Rugg, 2004; Smith et al., 2004; Wilding, 1999; Wilding & Rugg, 1997a, 1997b; Woodruff et al., 2006) and has became known as the right-frontal old/new effect (see Figure 3.4). The right-frontal effect has been found to onset shortly after the left-parietal effect (approximately 800 ms post-stimulus) and often lasts until the end of the recording epoch.

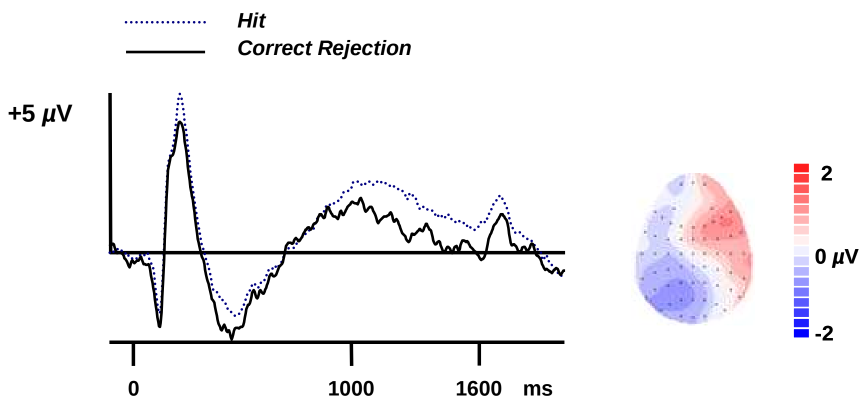

Figure 3.4 The right-frontal ERP old/new effect at electrode F6.
Grand-average waveforms recorded at test for correctly recognised old items (blue) and correctly rejected new items (black) are plotted as a function of time (Skavhaug, Wilding & Donaldson, unpublished data). The old waveform is more positive-going compared to the new waveform between approximately 1000 and 1600 ms. The difference in activity (old minus new) is displayed in a topographical map illustrating the right-frontal distribution of the effect.

In Wilding & Rugg's (1996) original experiment it was found that the right-frontal effect was larger for correct compared to incorrect source judgments, leading the authors to speculate that the effect was linked to the retrieval of contextual information – in much the same manner as the left-parietal effect. Later evidence, however, suggested that the right-frontal effect is not specifically dependent on the retrieval of source information, or even retrieval success per se (Ranganath & Paller, 1999; Trott et al., 1997; Wilding & Rugg, 1997b). For example, in one study, Trott et al. (1997) found that the effect was slightly larger following incorrect compared to correct source judgments, leading to the conclusion that the parietal and frontal old/new effects reflect separate functional processes (Curran et al., 2001; Duzel et al., 1997; Hayama et al., 2008; Senkfor & Van Petten, 1998; Trott, Friedman, Ritter, Fabiani & Snodgrass, 1999; Wilding & Rugg, 1997a). In particular, the late timing of the right-frontal effect has been taken as evidence that it reflects processes occurring after retrieval itself. For example, Curran et al. (2001)

investigated potential differences in ERP old/new effects between good and poor performers and found that only good performers produced a right-frontal effect (characterised by increased positivity for targets and lures relative to new items). They interpreted the effect as reflecting “post-retrieval evaluation processes that were more likely to be engaged by Good than Poor performers” (p 201). Why good and poor performers should differentially engage in post-retrieval monitoring is not entirely clear, however Van Petten, Luka, Rubin & Ryan (2002) have theorised that Good performers, relative to Poor performers, adopt a more successful strategy for post-retrieval monitoring through employing “a lower threshold for what sort of stimuli require close scrutiny” (p. 1190).

Although the exact functional interpretation of the right-frontal effect is yet to be determined there is currently a general agreement that it is related to post-retrieval monitoring processes. Curran et al. (2001) suggested that these processes act on the retrieval product when the outcome of retrieval attempts needs monitoring or evaluation. More recent evidence, however, suggests that the right-frontal effect can also be elicited when there is no need to monitor the products of retrieval (Hayama et al., 2008). Hayama et al. (2008) cued participants to make one of two semantic judgments on a number of pictures presented at study. In the semantic test phase, participants first made an old/new judgment and following each old response, made a third semantic judgment (e.g. does the picture denote a living object?). In the source test phase on the other hand, participants first made an old/new judgment and, following each old response, indicated which semantic judgment had been initially made for the item (source judgment). Reliable right-frontal effects were observed regardless of which task participants performed at test, indicating that the effect is not exclusively present for monitoring of episodic content.

To exclude the possibility that the right-frontal effect was elicited by the initial successful retrieval (preceding the secondary judgment) Hayama et al. (2008) also employed a recognition task that varied with respect to the class of test item that were to receive additional semantic judgments. In one task old items were followed by a semantic judgment and in the other task new items were followed by a semantic judgment. If the right-frontal effect is selectively elicited when episodic memory judgments are made, it should be present when participants perform the former but not the latter task. Instead, Hayama et al. (2008) found reliable right-frontal effect for test items which required the semantic judgment and concluded that the effect reflects more generic monitoring, possibly related to decision-making processes.

3.1.3. Anatomy of Episodic Memory

Episodic memory retrieval has been extensively investigated through the use of alternative imaging methods. Mapping ERP results onto findings from experiments using different methodologies is challenging, however, due to their different qualities and limitations (notably, the variable levels of temporal and spatial resolution that each method provides). Additionally, it is problematic to draw causal inferences from what is, ultimately, merely correlational data. Researchers have, however, formed theories about the anatomical structures that might give rise to the ERP old/new effects described in this chapter, largely based on the functional parallels observed between these effects and analogous fMRI effects (see Rugg et al., 2002).

Comparisons between fMRI and ERP findings have led many researchers to conclude that the medial temporal lobe serves a crucial role in memory retrieval. In particular, it is widely believed that recollection and familiarity depend on activity in separate components of the medial temporal lobes; whilst recollection seems to depend on activity in the hippocampus and parahippocampal cortex, familiarity seems to be supported by separate temporal lobe regions, possibly perirhinal cortex (see Eichenbaum, Yonelinas & Ranganath, 2007; Yonelinas, 2002; Yonelinas & Rugg, 2003). This observation is clearly consistent with the ERP findings, which also suggest that recollection and familiarity are dissociable processes produced by separate neural generators. By contrast, the right-frontal effect is believed to be produced by neural generators localised in the right prefrontal cortex, possibly right dorsolateral prefrontal cortex (Achim & Lepage, 2005; Hayama & Rugg, 2009; Rugg, Henson & Robb, 2003).

3.2. The Neural Correlates of Metamemory

Despite the breadth of ERP studies investigating memory encoding and retrieval, the number of ERP studies investigating metamemory is currently limited, with only a single study having directly investigated judgments of learning. Even the inclusion of fMRI data adds only one additional study. As a result, most of the knowledge and theories about the neural basis of metamemory stems from the study of neuropsychological patients rather than brain imaging experiments (see Chapter 1).

To date, the only published study that has used ERPs to investigate JOLs was carried out by Sommer, Heinz, Leuthold, Matt & Schweinberger (1995). Sommer et al. (1995) employed faces as stimuli, and asked participants to make a JOL to each face using a four point scale. A second group of participants was instructed to make distinctiveness ratings to the same set of faces, as the authors had hypothesised that distinctiveness could be one possible basis upon which participants made JOLs. Both groups had their memory for the faces assessed in a standard recognition memory test. Sommer et al. (1995) contrasted the study phase ERP activity that differentiated (i) items remembered or forgotten at test, (ii) items rated likely or unlikely to be remembered later (high versus low JOL), and finally (iii) items rated high or low in distinctiveness. First of all, it was found that ERPs were more positive for subsequently recognised faces relative to missed faces at frontal recording sites, whereas the opposite was true for posterior recording sites. The SM effects were evident from approximately 200 ms post-stimulus, lasted throughout the recording epoch (1000 ms post-stimulus) and were relatively similar for both groups of participants.

From 300 to 500 ms post-stimulus, all three contrasts revealed similar ERP effects with no differences in scalp topographies. The JOL and distinctiveness effects are, however, notably smaller in amplitude compared to the SM effect. From 500 ms post-stimulus, the topographies of JOL and distinctiveness effects differ from SM effect, but Sommer et al. (1995) made the decision not to elaborate on these differences due to potential eye movement artefacts during the last 500 ms of the recording epoch (this decision was made despite the authors claiming that the observed effects were unlikely to have been derived from such artefacts). Given the restricted time window examined, Sommer et al.'s (1995) results can, at best, be considered weak evidence in support of their conclusion that "recognition predictions, facial distinctiveness, and later recognition are all linked to ERP differences that start relatively late and are indistinguishable in scalp topography, consistent with the possibility of a common basis at the level of underlying brain processes" (p. 10).

Sommer et al.'s (1995) results give some indication that there could be a degree of overlap between SM and JOL effects during an early time window, however null results should always be interpreted with caution. More convincing evidence regarding the neural basis of JOLs is provided by Kao, Davis & Gabrieli (2005) who reported fMRI results suggesting JOLs are based on a combination of shared and independent neural circuitry. Participants were presented with a number of images (depicting indoor and outdoor scenes) and asked to make a JOL to each image using a two point scale (*will remember* or *will forget*). In keeping with previous memory findings (e.g. Qin, Piekema, Petersson, Han, Lou & Fernandez, 2007; Wagner et al., 1998; for reviews see Diana, Yonelinas & Ranganath, 2007; Fernandez & Tendolkar, 2006), study items that were subsequently remembered rather than forgotten were associated with increased activity in the medial temporal lobes (MTL). More importantly, whilst some brain regions (including left lateral prefrontal cortex; PFC) were equally active for successful encoding and JOLs, other regions (including left ventro-medial and dorso-medial prefrontal cortex; VMPFC and DMPFC) were more active for JOLs than for successful memory encoding.

Although closer examination of Kao et al.'s (2005) results suggest that the JOL effect is relatively widespread (and is not focused in any specific way to the frontal regions highlighted by the authors), part of their findings are consistent with Sommer et al. (1995), suggesting that JOLs and memory encoding rely upon at least partially overlapping neural systems. The fMRI results do, however, also indicate the involvement of separate anatomical structures both in the making of JOLs and in the formation of new memories, which could explain why one phenomenon can be spared in cases where another is damaged. For example, studies of neuropsychological patients with damage to the frontal lobes have revealed specific impairments of metamemory relative to memory (see Pannu & Kaszniak, 2005). A significant problem with patient studies, however, is that the damage to the brain is usually diffuse, and as a result the impairments are often non-specific. Nevertheless, the possible involvement of PFC in metamemory appears reasonable as metamemory processes are thought to be closely related to executive functions (Fernandez-Duque, Baird & Posner, 2000), which are themselves widely believed to rely, at least partly, on the frontal cortex (see Alvarez & Emory, 2006). Conceptualising the link between metamemory and executive functioning is, however, inherently problematic; the lack of exact definitions of both metamemory and executive functioning, along with the complexity and multidimensionality of both phenomena, makes even a systematic investigation extraordinarily complicated. For example, Souchay et al. (2004) observed a correlation between FOK (see Chapter 1) judgments and executive measures, but not between JOL and executive measures. In other words, if a correlation is present between one metamemory component and executive measures, this need not be the case for other components. In addition, any correlations are equally likely to depend on the kind of procedures that are used to measure executive functioning. To be clear, the key point here is that evidence linking metamemory to the PFC (or other neural structures) should come directly from appropriate studies of metamemory, not from inferred evidence linking metamemory to other ambiguous concepts. For that reason the focus of this thesis will remain strictly on judgments of learning without attempting to link it to other related metamemory or non-metamemory phenomena.

The patient observations in combination with Kao et al.'s (2005) fMRI findings have contributed to important knowledge about the anatomical structures believed to support JOLs. The temporal characteristics of JOLs (in relation to actual memory) have, however, gone largely unexplored. Although Kao et al. (2005) report that JOLs are associated with processing in regions that are separable from the regions involved in successful memory encoding, no conclusions regarding the timing of the JOL-specific activity can be made based on fMRI data alone. Whether this activity precedes, follows or overlaps with successful memory encoding has clear implications for the interpretation of the data.

3.3. Summary

The formation of new episodic memories is associated with a pattern of ERP activity referred to as SM effects. SM effects are usually characterised by an increase in positivity by subsequently remembered items relative to subsequently forgotten items. It has proven difficult to identify or characterise a typical SM effect because their timings and distributions seems heavily dependent on the nature of the encoding task and intentions to encode, as well as on stimulus modality and test instructions. Nonetheless, ERP encoding effects can broadly be divided into two subtypes; frontal effects believed to reflect elaborative encoding strategies and centro-parietal effects which have been linked with rote learning strategies.

The ERP effects associated with retrieval of episodic memories are relatively well-established in the literature and seem to be less affected by the factors that influence the SM effect. Retrieval effects distinguishes activity that is associated with correct identification of previously studied items and correctly rejected new items, referred to as old/new effects. Old/new effects are generally characterised by an increase in positivity for correctly classified old items relative to new items and have been observed in a variety of retrieval tasks. A vast amount of research has indicated that old/new effects can be split into at least three components, each with a distinct time-course and scalp topography. An early effect, occurring between approximately 300 and 500 ms post-stimulus over mid-frontal recording sites, is widely believed to reflect familiarity based recognition processes. A second effect, most evident between 500 and 800 ms over left-parietal recording sites, has been linked with recollection. And a third long-lasting effect, onsetting shortly after the left-parietal effect, with a maximal over right-frontal electrode sites, seems to be associated with post-retrieval monitoring processes.

To date, however, few experiments have attempted to investigate the neural correlates of metamemory and little is therefore currently known about the processes that support judgments of learning. The limited neuroimaging evidence that exists has been taken to suggest that judgments of learning and memory formation are reliant on both partially overlapping and partially non-overlapping processes. Moreover, one fMRI study, in combination with patient studies, has indicated that metamemory is (at least partially) reliant on prefrontal brain structures.

Having reviewed the literature on the electrophysiology of memory and metamemory, the following chapter describes the general methods employed in subsequent experimental chapters, before the first empirical study is introduced in Chapter 5.

Chapter 4.

General Methods

The preceding chapters have covered the theoretical background that forms the rationale for the research reported in the remainder of this thesis. First, however, the present chapter provides an outline of the basic methods used in the experiments, covering experimental procedures, ERP acquisition and data analyses.

4.1. Experimental Procedures

4.1.1. Participants

All participants were members of the University of Stirling student population, mainly recruited through the university's online experiment management system. The remainder responded to poster adverts. All participants were right-handed native English speakers between the ages of 17 and 35, with no known neurological disorders. Informed consent was always obtained prior to the experiment and participants were reimbursed at a rate of £5 per hour (psychology students had the option of receiving 2 course credits instead of monetary payment for the first hour).

4.1.2. Stimulus Materials

Stimuli from Experiments 1-3 consisted of 432 word pairs (examples are presented in Table 4.1) made up from common English verbs, nounds and adjectives. The two words in each pair had a mean forward associative strength of 0.42 and a mean backward associative strength of 0.02 (according to the norms of Nelson, McEvoy & Schreiber, 1998). Two hundred and eighty words were randomly selected to be shown at study and the remaining 140 were shown as new items, intermixed with the old items at test. Only the first word in each pair was presented at test. Twelve word pairs were used for practice. All words were presented on a computer monitor in 18 point Courier New font, using upper case white letters against a blue background. From a viewing distance of approximately one meter the word pairs presented at study and the single words presented at test subtended a vertical visual angle of 1.4° and 0.3° respectively. The maximum horizontal visual angle for both word pairs and single words was 4.9°.

Table 4.1 Typical word pairs included in Experiments 1-3.

WORD1	**WORD2**	**Forward Association**	**Backward Association**
ACRE	LAND	0.68	0.02
PRINCIPAL	SCHOOL	0.31	0.00
LUMBER	WOOD	0.59	0.00
MOP	FLOOR	0.24	0.04

Experiment 4 consisted of two blocks; one using single item picture stimuli and one using single item word stimuli. The pictures were a selection of the “indoor scenes” used by Kao et al. (2005; and previously by Brewer et al., 1998) and were all presented in colour. No persons or animals were depicted in the pictures (examples are shown in Figure 4.1). A total of 312 pictures were employed; 200 were randomly selected to be shown at study and the remaining 100 pictures were shown as new items, intermixed with the old items at test (following the same procedure as for Experiments 1-3). Also as in Experiments 1-3, twelve pictures were used for practice. All pictures were presented against a black background, and from a viewing distance of approximately one meter they subtended a vertical visual angle of 6.5° and a maximum horizontal visual angle of 10.9°.

Figure 4.1 Typical pictures included in Experiment 4.

The words used in Experiment 4 were selected from the MRC Psycholinguistic Database (Coltheart, 1981) and were made up from common English verbs, nounds and adjectives Mean concreteness rating[5] (Pavio, Yuille & Madigan, 1968) was 499.5 (± 99.0) and mean written frequency rating was 17.5 (± 5.7) per million (Kucera & Francis, 1967; examples are shown in Table 4.2). The number of words was matched to the number of picture stimuli described above. All words were presented on a computer monitor in 18 point Courier New font, using upper case white letters against a black background. From a viewing distance of approximately

[5] Concreteness values are integers measured in the range 100 to 700.

one meter words subtended a vertical visual angle of 0.3° and a maximal horizontal visual angle 2.3°.

Table 4.2 Typical single item words from Experiment 4.

WORD	Concreteness	Frequency
JUICE	599	11
CLUE	380	15
THEFT	361	10
GOWN	586	16

4.1.3. Experimental Paradigms

Participants were seated in front of a 15" LCD monitor connected to a desktop computer located in an adjacent room, running the experimental program on E-PRIME software (Psychology Software Tools; www.pstnet.com). A five-button response box was placed on the desk in front of the participant. Between the rooms, a two-way microphone and speaker system was set up as a mean of communication between the participant and the experimenter.

All experiments consisted of one study session, during which JOLs were made (except for Experiment 3, in which participants pressed a button to continue rather than make a JOL), followed by one memory test session. Repeated study-test cycles were avoided because some previous studies have indicated that participants' JOL accuracies changes as a function of repeated testing. For example, Koriat, Sheffer & Ma'ayan (2002) found that when participants studied the same material across several study-test cycles, they showed a tendency to become markedly underconfident in the second cycle (a phenomenon known as the underconfidence-with-practise effect). By contrast, Kelemen, Winningham & Weaver (2007) found that when participants studied different material across several study-test cycles metamemory accuracy improved. It is still unclear what factors are determining the shifts in accuracy and a single study-test cycle was therefore employed to avoid possible confounds associated with JOLs made during multiple study-test blocks.

The study phase of Experiments 1 and 2 comprised 280 trials, each involving a word pair selected randomly from the initial 420 pairs. The first word of each of the 280 pairs was re-presented at test, along with 140 new words. Word presentation order was determined randomly for each participant. Breaks were at 70 trial intervals, and initial practice sessions familiarized participants with the procedures. Each study trial began with a white fixation cross presented in the centre of a blue screen for 1000 ms. A word pair was then presented, one word above and one below the central fixation point. After 3000 ms a blue screen appeared, replaced after 500 ms by the prompt “PROBABILITY TO RECALL”. This was the instruction for participants to indicate via button press how likely they would be to recall the second word successfully if presented with the first word on a subsequent test. Participants were asked to respond on a 5-point scale: 1 (definitely forget), 2 (probably forget), 3 (unsure), 4 (probably remember), 5 (definitely remember). The need to make use of the full scale throughout the experiment was emphasized. In all experiments except from Experiments 1 and 3, the use of the rating scale was counterbalanced across participants: half the participants made ‘1’,’2’ and ‘3’ responses with their left hands (and ‘4’ and ‘5’ responses with their right hands) and the other half made ‘1’, ‘2’ and ‘3’ responses with their right hands (and ‘4’ and ‘5’ responses with their left hands). In Experiment 1, all participants made ‘1’, ‘2’ and ‘3’ responses with their left hands (and ‘4’ and ‘5’ responses with their right hands).

Participants were asked to try to remember the word pairs, but no specific memorization instructions were given. After each JOL was made, a blue screen was presented for 1000 ms before the next trial started. Experiment 3 had an identical study phase except that instead of making a JOL participants were told to press a key to continue to the next trial (“PRESS 2 TO CONTINUE”). Half the participants were instructed to press key ‘2’ with their left hands and the other half was instructed to press key ‘4’ with their right hands. No specific instructions were provided regarding use of encoding strategies.

The test phases were identical for Experiments 1-3. Each trial began with presentation of a white fixation cross in the centre of a blue screen for 1000 ms. A single word was then presented centrally and remained on the screen for 1500 ms followed by a blue screen for 2500 ms. Participants were instructed to press buttons 1 or 5 depending on whether the word was *old* (presented at study) or *new* (not presented) as soon as they had made a decision (the response could be made during either the presentation of the word or the blank screen). If a *new* response was made (or no response occurred within the 4 s response time window) the trial terminated. In Experiment 1, an *old* response was followed by the visual prompt “CAN RECALL?” and participants were asked to press buttons 1 or 5 to indicate whether they could or could not remember the word's partner at study. The prompt remained visible until a response was made. If the participant responded *no* the current trial was terminated. Following a *yes* response the prompt "RECALL WORD" appeared, and participants were instructed to verbally complete the word pair. After recording the response, the experimenter initiated the next trial. In Experiments 2 and 3, the test trial was terminated after the initial old/new discrimination. There were a total of 420 test trials, displaying 280 old words intermixed with 140 new words.

As mentioned earlier, Experiment 4 was divided into two blocks (the order of completion was counterbalanced across participants: half the participants completed the word block first and the other half completed the picture block first), however the study and test procedures were exactly the same for each of these block (only the stimuli differed). For that reason, only the procedure of the picture block will be outlined here. The study phase comprised 200 trials, each involving a picture selected randomly from the initial 300 pictures. All 200 pictures were re-presented at test, along with 100 new pictures. Picture presentation order was determined randomly for each participant. Breaks were at 100 trial intervals, and initial practice sessions familiarized participants with the procedures. Each study trial began with a white fixation cross presented in the centre of a black screen for 1000 ms. A picture was then presented and after 2000 ms a blue screen appeared, replaced after 500 ms by the prompt "PROBABILITY TO REMEMBER". This was the instruction for participants to indicate via button press how likely they would be to remember the picture successfully on a subsequent test. The scale and the instructions regarding the making of the JOL were identical to Experiments 1 and 2. After each JOL was made a blue screen was presented for 1000 ms before the next trial started.

Each test trial began with presentation of a white fixation cross in the centre of a black screen for 1000 ms. A picture was then presented centrally on the black screen. The picture remained on the screen for 2000 ms and was followed by a black screen for 2000 ms (again providing a 4 s response window). Participants were instructed to press buttons 1 or 5 depending on whether the picture was *old* (presented at study) or *new* (not presented). There were a total of 300 test trials, displaying 200 old pictures intermixed with 100 new pictures.

4.2. ERP Data Acquisition

Scalp voltages were recorded using 62 silver/silver chloride electrodes fitted in an elastic cap (QuickCap, Neuromedical Supplies; www.neuroscan.com) in accordance with an extended version of Jaspers (1958) international 10/20 system (FP1, FPZ, FP2, AF3, AF4, F7, F5, F3, F1, FZ, F2, F4, F6, F8, FT7, FC5, FC3, FC1, FCZ, FC2, FC4, FC6, FT8, T7, C5, C3, C1, CZ, C2, C4, C6, T8, TP7, CP5, CP3, CP1, CPZ, CP2, CP4, CP6, TP8, P7, P5, P3, P1, PZ, P2, P4, P6, P8, PO7, PO5, PO3, POZ, PO4, PO6, PO8, CB1, O1, OZ, O2, CB2). Electrodes were also placed on the mastoids (M1 and M2), to provide an offline reference. EOG electrodes were placed above and below the left eye (Vertical EOG), and on the outer canthi of each eye (Horizontal EOG), to monitor eye movement and blinks respectively. No specific instructions were given to participants regarding eye blinks, but they were asked to try to minimize horizontal eye movements by focussing their vision on the fixation cross that appeared prior to each experimental trial. Before initiating the experiment, participants were given some time to look at the online EEG recording on a monitor. This allowed them to directly observe the artefacts produced by eye blinks and eye movements. Electrodes were referenced to an additional electrode positioned between CZ and CPZ during recording, then re-referenced off-line to create an averaged mastoid reference. Electrode impedances were kept below 5kΩ. Recordings were made using a Synamps^2 amplifier and Neuroscan 4.3 Acquire software (Neuromedical Supplies; www.neuroscan.com). Signals were amplified with a gain of 2010, bandpass filtered at 0.1 – 40 Hz and digitized at 250 Hz (4ms/point).

EEG data were processed offline using Neuroscan 4.3 Edit software (Neuromedical Supplies; www.neuroscan.com). Based on visual inspection of the recording, segments were rejected if they were saturated or particularly noisy. The effects of eye blinks on the EEG were reduced using a regression procedure (Semlitsch, Anderer, Schuster & Presslich, 1986). Data were segmented into 2104 ms epochs, starting 104 ms prior to stimulus onset. Epochs were excluded if drift exceeded ±50μV (measured by the difference between the first and last data points in the epoch) or if the signal change exceeded ±100μV. Data were smoothed over a 5-point kernel and baseline corrected with respect to the pre-stimulus presentation period (-104 to 0 ms). Epochs were sorted according to their behavioural response categories and individual participant waveforms were averaged together to produce grand-average waveforms. To ensure a good signal-to-noise ratio, a criterion of at least 16 trials per condition was set for each participant to be included in the grand average.

4.3. Data Analyses

4.3.1. Behavioural Data

Behavioural measures at study included the response time (RT) for making JOLs and response distribution across the 5-point JOL scale. At test, behavioural measures included overall recognition accuracy, recognition accuracy across JOL and RT for making old/new discriminations (in Experiment 1, overall cued recall accuracy and cued recall accuracy across JOL were also examined). These measures were taken primarily to confirm that participants behave consistently across experiments and in a way that is comparable to standard observations in the JOL literature. Analyses were carried out using repeated measures ANOVA with a significance criterion of 0.05. Post-hoc comparisons were carried out using t-tests with Bonferroni-corrections. Metamemory accuracy was assessed by calculating both the mean Gamma correlation coefficient and d_a (see Chapter 1). Specific details of the analyses will be outlined in the relevant data chapters.

4.3.2. ERP Data

The purpose of the ERP investigations reported in this thesis was to examine JOL related neural activity at both study and at test. At study, the rationale was to compare SM effects to any possible effects associated with JOLs. Contrasts were therefore made between i) items that were and were not subsequently remembered (recalled in Experiment 1 and recognised in Experiments 2-4), and ii) items that were assigned low and high JOLs[6]. The explorative nature of the ERP research implied that no pre-experimental hypotheses were formulated regarding time windows that were submitted for analyses. Time windows were thus identified primarily on basis of visual inspection of the grand average waveforms (and varied across the four experiments).

At test, comparisons were made between old items correctly identified as old (through cued recall or recognition) and correctly rejected new items. Correctly identified old items were further subdivided into items that were assigned low and high JOLs at study. This division allowed the investigation of possible modulations of the well-characterised retrieval effects caused by JOLs. Choice of time windows submitted to analyses was primarily based on previous literature (Rugg & Curran, 2007) and corresponded well to the visual inspections of the grand average waveforms (the only exception being the picture version of Experiment 4). Time windows were as follows: 300-500 ms (mid-frontal familiarity effect), 500-800 ms (left-parietal recollection effect) and 800-1400 ms (right-frontal post-retrieval monitoring effect).

ERPs from study and test were first quantified by calculating, for each response condition, the mean activity during each latency period. The data were then submitted to repeated measures ANOVA. Typically (deviations are reported in the relevant data chapters) the initial analyses included five factors of location (frontal,

[6] An alternative approach to comparing SM effects and JOL would be to divide remembered and not remembered items into high and low JOLs, however this strategy caused a significant loss of data due to low trial numbers.

fronto-central, central, centro-parietal and parietal), two factors of hemisphere (left and right) and three factors of site (superior, medial and inferior, see Figure 4.2) in addition to a condition (response category) factor. Only main effects and interactions involving the factor of condition are reported. When interactions involving location were evident, the initial analyses were followed up by subsidiary analyses, examining each separate location (with two factors of hemisphere and three factors of site). The electrodes submitted for analyses were selected because they cover a large area of the scalp and, in most cases, seemed to capture the effects of interest (alternative electrodes were identified when effects exhibited foci on scalp locations that were not covered by the original set of electrodes). Using factors of location, hemisphere and site allows ERPs to be compared in terms of potential hemispheric and anterior-posterior differences and also give indications of the effects' proximity to the midline.

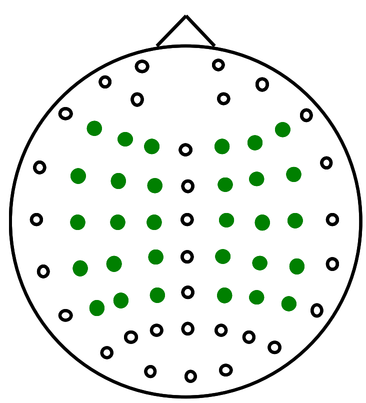

Figure 4.2 Schematic illustration of the electrodes included in initial ERP analyses.
The front of the head is pointing upwards and left side is shown at left. Each circle represents an electrode and electrodes included in the analyses are marked with green. Electrodes from frontal, fronto-central, central, centro-parietal and parietal electrode rows provided five levels of a location factor, electrodes on left and right hemisphere provided two levels of a hemisphere factor and electrodes in each quadrant provided three levels of a site factor (superior electrode sites closest to the midline, medial electrode sites and inferior electrode sites).

The ANOVA model's underlying assumption of sphericity (the requirement of homogeneity of co-variance for all factors) is usually violated in the case of ERP analyses. The consequence of this violation is an increased probability of a type 1 error and for that reason Greenhouse-Geisser corrections (Greenhouse & Geisser, 1959) are reported when necessary, to ensure a more conservative test of significance. As for the behavioural data, the significance criterion for all ERP analyses was set at 0.05.

To investigate potential qualitative differences between conditions or latency periods, topographic analyses were performed on difference waves (mean amplitudes of condition two subtracted from mean amplitudes of condition one) when robust ERP amplitude differences had been established. Prior to any topographic analyses, the data from all 62 active electrodes were normalised using the max/min method (McCarthy & Wood, 1985) described in chapter two. The analyses employed the same design as the ANOVA used to evaluate amplitude differences and only interactions involving factors of condition or latency period are reported.

4.4. Summary

The present chapter has provided an outline of the stimuli materials, experimental paradigms, EEG acquisition procedures and analyses that were employed in the research reported in the remaining chapters of this thesis. Although most experiments conform to the general methods, occasional exceptions exist and are highlighted in the relevant chapters.

Chapter 5.

Judgments of Learning and Cued Recall

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5.1. Introduction

A very important aspect of learning is the ability to predict one's future memory. For example, if a student reading for an exam is unaware of what material he has (and has not) successfully learnt, he risks wasting valuable study time revising the wrong material. If he efficiently and accurately predicts his memory, on the other hand, he knows when material is sufficiently studied and can concentrate on that which is yet to be learnt. Memory predictions of the kind described here are referred to as Judgments of Learning (JOL; described in chapter 1 and 2).

One of the most obvious situations that requires JOLs are study situations such as the one described above, however memory predictions are necessarily performed in a variety of different (possibly less apparent) real-life scenarios. For example, imagine you are preparing to do grocery shopping; before you leave the house you need to consider how likely you are to remember to buy all the items you need. If your prediction is positive (i.e. likely), you may well decide not to write a shopping list. If your prediction turns out to be inaccurate you will forget to buy some items and have to return to the shop later. Similarly, when arriving at the shop, especially on a busy day, you might consider how likely you are to remember where you parked your car. If your prediction in this case is negative (i.e. unlikely), you can use this information to engage control strategies; in this case you may decide to look for a landmark, such as a tree, that could serve as a retrieval cue when you return to collect the car later.

Because JOLs can help identify when control strategies are necessary, it is not a surprise that more accurate JOLs have been associated with increased learning (Thiede, 1999). For that reason, it is important to teach those who are less accurate at predicting their memory how to discriminate what they do know from what they do not know. What makes this mission slightly complicated, however, is that researchers know relatively little about how JOLs are made in the first place. As covered in Chapter 1, there is an ongoing debate surrounding the degree to which JOLs are based on actual memory operations (Arbuckle & Cuddy, 1969; King et al., 1980; Koriat, 1997). In short, direct/trace access theories (Arbuckle & Cuddy, 1969, King et al., 1980) postulate that JOLs are produced by reading the strength of the recently formed memory traces. Weakly encoded material will consequently be assigned a low JOL, whereas material leaving strong memory traces will receive high JOL ratings. The main problem with pure direct access theories are that they cannot adequately explain why JOL accuracy is sometimes very low (Koriat & Bjork, 2005). According to the alternative inferential views (such as the cue-utilization view proposed by Koriat, 1997), individuals do not have privileged access to memory traces and therefore need to rely on available cues that the learners believe are reliable predictors of future memory performance (see Schwartz et al., 1997).

The arguments brought forward in the direct/trace access versus inferential debate stem primarily from evidence collected from behavioural experiments. Behavioural investigations can only provide indirect measures of the relationship between JOLs and memory, however, and for that reason it is surprising how few studies have employed brain imaging techniques to investigate this issue. If JOLs are based primarily on actual memory operations, it is reasonable to expect that JOLs and memory encoding will produce overlapping ERP correlates. On the other hand, if JOLs are based on factors other than encoding, there is a possibility that JOLs will produce separate ERP correlates not present in the memory encoding contrast.

As outlined in Chapter 3, the only two JOL brain imaging studies reported to date have reached completely different conclusions. First, Sommer et al. (1995) found that successful memory encoding and JOLs produce comparable ERP correlates, suggesting that both phenomena are relying on similar brain systems (consistent with a direct/trace access hypothesis). Second, in contrast, Kao et al. (2005) found that successful encoding and JOLs gave rise to activity in both separate and overlapping areas of the brain, suggesting the existence of dissociation as well as associations between successful encoding and JOLs. One possible interpretation of the fMRI data is that JOLs are partly based on memory operations but that independent bases also exist. This interpretation implies that direct/trace access and inferential views are not mutually exclusive. The sluggish nature of the haemodynamic response that is monitored using fMRI means, however, that it is not possible to make reliable claims about the time courses of processes that differentiate between successful encoding operations and JOLs. As a result, conclusions regarding the interaction between these components are hard to reach.

Kao et al.'s (2005) results pose one important question: why did Sommer et al. (1995) fail to find separate JOL effects in their ERP study? Superficially at least, the findings from the two experiments are hard to reconcile. However, they are also problematic to compare; not only did the two experiments employ different imaging techniques (with different advantages and limitations), but they also used different kinds of stimulus materials (faces versus scenes) and rating scales (4 versus 2 point scale). There is, therefore, a clear need for further research, both to provide more opportunities for comparisons across experiments and to measure the possible impact of differences in paradigms.

The aim of the first of the series of JOL experiments reported in this thesis was to further investigate the relationship between successful memory encoding and JOLs using ERPs. The experiment was designed to resemble, as closely as possible, typical behavioural paradigms used in JOL research (e.g. Koriat & Bjork, 2005); thus word pairs were chosen as stimulus materials and memory was assessed in a later recognition memory test[7] followed by cued recall. ERPs were acquired during the study phase and separated according to whether; (i) the second word of each study pair was or was not recalled subsequently, and (ii) the study pair elicited a high or low JOL. These contrasts permit assessment of the temporal and functional correspondences between the neural signatures of successful memory encoding and JOLs. The ERP data collected at retrieval in this experiment will be reported in a separate chapter (Chapter 9).

5.2. Method

Participants were 24 students at the University of Stirling. Three participants were excluded due to equipment failure or excessive EEG artefacts, and one due to poor performance. The remaining 20 participants (12 female) had a mean age of 22 (range: 17-30).

Stimulus materials and experimental procedure conform to that outlined in Chapter 4 and the behavioural paradigm is schematically illustrated in Figure 5.1. Grand average ERP waveforms were formed for the following response categories: Recalled (items subsequently recognised as old and for which the study partner was recalled), Missed (items judged incorrectly as being new), High JOL (study pairs assigned a JOL of 4 or 5) and Low JOL (JOL of 1 or 2). Study items attracting an 'unsure' JOL (3 response) were discarded allowing the high and low JOL categories

[7] Typical behavioural JOL paradigms do not include the initial recognition test employed here. To allow examination of ERP memory retrieval effects at test, however, it was necessary to include new items to form a base line of correctly rejected new items.

to be clearly separated. Mean numbers of trials were 123, 49, 87 and 73 for the Recalled, Missed, High JOL and Low JOL categories respectively.

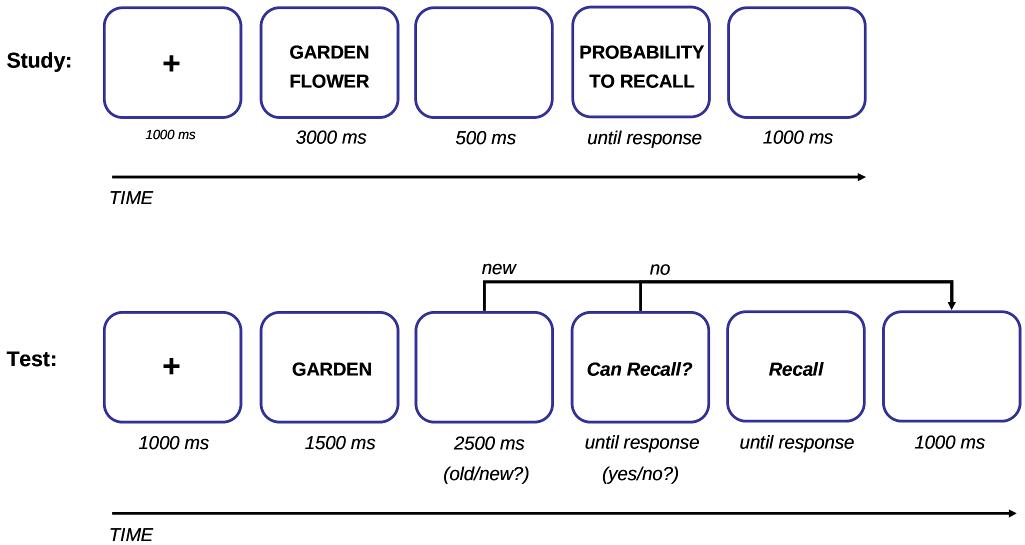

Figure 5.1 The experimental paradigm used in Experiment 1.
At study, participants saw a number of word pairs (a cue presented above a target) and made a JOL for each pair. The JOL reflected how likely the participants believed they were to remember the target word (flower) when presented with the cue word (garden) on a later test. The rating scale ranged from one (will definitely forget) to five (will definitely remember). At test, participants saw each of the upper words intermixed with a number of new word. The first task was to make an old/new recognition judgment and following each old judgment the participants were asked whether or not they could recall the target word. Following a yes response, the participants said the target word out loud and the experimenter recorded the accuracy of the response. If participants responded new on the initial task, or could not recall the target word, the trial terminated.

5.3. Behavioural Results

5.3.1. Study

Participants had a preference for assigning intermediate JOLs (Figure 5.2a). ANOVA on response rates revealed a main effect of JOL [$F(4,72) = 7.0$, $p < 0.001$], with an accompanying quadratic trend [$F(1,18) = 18.6$, $p < 0.001$], confirming the concentration of responses towards the middle of the scale. The pattern of reaction time (RT) for making JOLs at study also formed the shape of an inverted “U” when plotted against each level of JOL (Figure 5.2b). ANOVA revealed a significant main effect of JOL [$F(4,68) = 19.2$, $p < 0.001$], with both a linear [$F(1,17) = 19.5$, $p < 0.001$] and a quadratic [$F(1,17) = 31.9$, $p < 0.001$] trend.

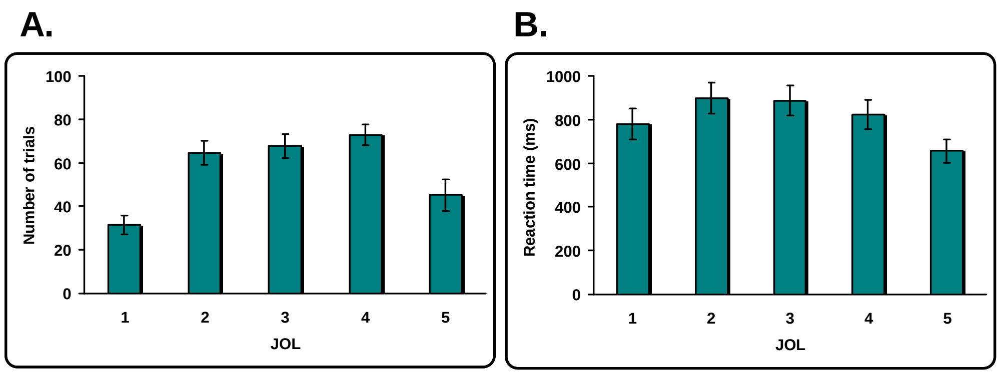

Figure 5.2 Behaviour at study.
Mean (and S.E.) number of trials assigned each JOL category at study (A) and reaction times for making each level of JOL at study (B).

5.3.2. Test

Overall recognition responses are shown in Figure 5.3a and Figure 5.3b shows the mean recall accuracy for old items distributed across the levels of JOLs assigned at study. It is evident from the graph that recall performance increased with increasing JOL and a repeated measures ANOVA confirmed that the effect of JOL was significant [$F(4,72) = 26.10$, $p < 0.001$] exhibiting a linear trend [$F(1,18) = 52.78$, $p < 0.001$]. Performance was also examined using Goodman-Kruskal Gamma (G; Nelson, 1984) and d_a (Masson & Rotello, 2009). The mean G score of 0.29 (SD = 0.16) was significantly above zero [$t(19) = 7.83$, $p < 0.001$]. Mean d_a was 0.40 (SD = 0.27) and was also signficantly above zero [$t(19) = 6.63$, $p < 0.001$]. In contrast to the reaction times measured at study, the pattern of reaction times across JOL at test showed a linear trend (Figure 5.3c). ANOVA confirmed that a main effect of JOL [$F(4,72) = 8.88$, $p < 0.001$] was accompanied with a linear trend [$F(1,18) = 13.72$, $p < 0.01$].

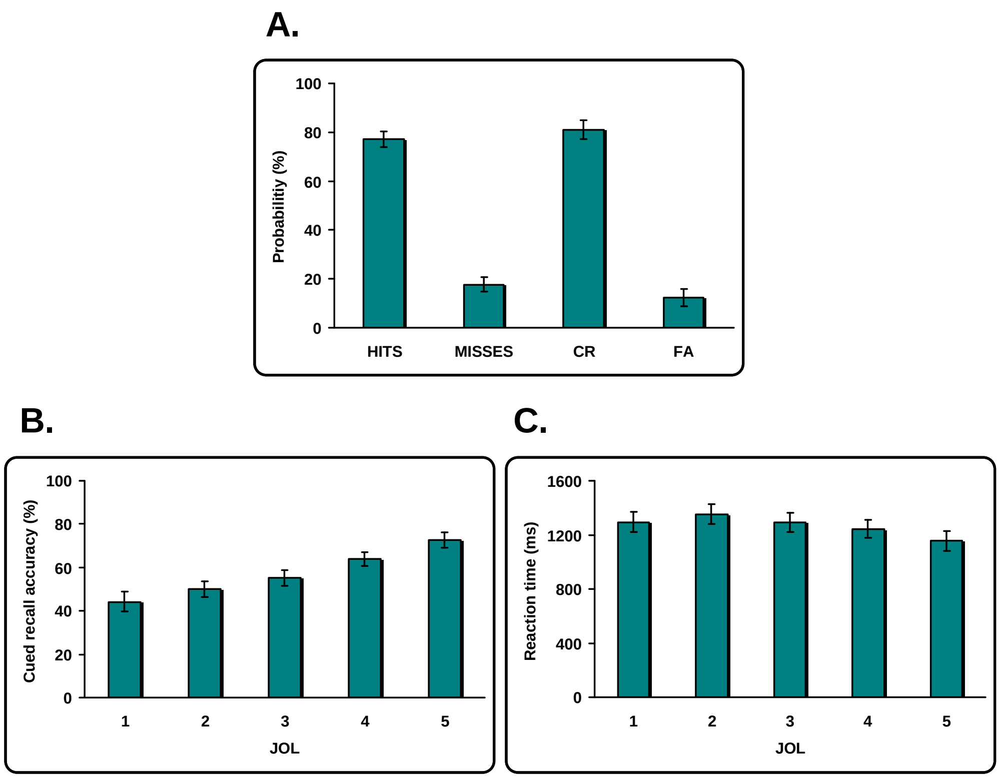

Figure 5.3 Behaviour at test.
Mean (and S.E.) recognition responses for each response category at test (A) cued recall performance across JOL at test (B) and reaction time measured at test split according to JOL (C***).***

5.4. Event-Related Potential Results

The initial ERP analyses comprised separate assessments of the study phase ERPs. First, *SM effects*: study ERPs separated according to memory accuracy at test (Recalled versus Missed; Figure 5.4)[8]. Second, *JOL effects*: ERPs associated with

[8] Items that were recognised but not recalled were not included in any analyses.

High or Low JOLs (Figure 5.5). It is not possible to contrast directly these two effects as they contain overlapping subsets of trials.

Based on visual inspections of the waveforms, two post-stimulus time windows were identified that captured the activity of interest; 550 to 1000 ms and 1300 to 1900 ms. These time windows correspond to time windows selected in Otten & Rugg (2001a). Both the SM and JOL distributions have a similar widespread positivity in the early time window, although the SM effect extends to a greater degree to anterior locations than the JOL effect. During the later time window, however, the two effects differ; the JOL contrast reveals a strong left hemisphere negative-going effect which is not present in the SM contrast. For each contrast, data were first analysed using ANOVA with factors of condition (Recalled versus Missed, High versus Low JOL), location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and electrode site (superior, mid, inferior) followed by five subsidiary analyses on each separate location when interactions involving location were evident. The outcomes of the subsidiary analyses are summarised in Table 5.1.

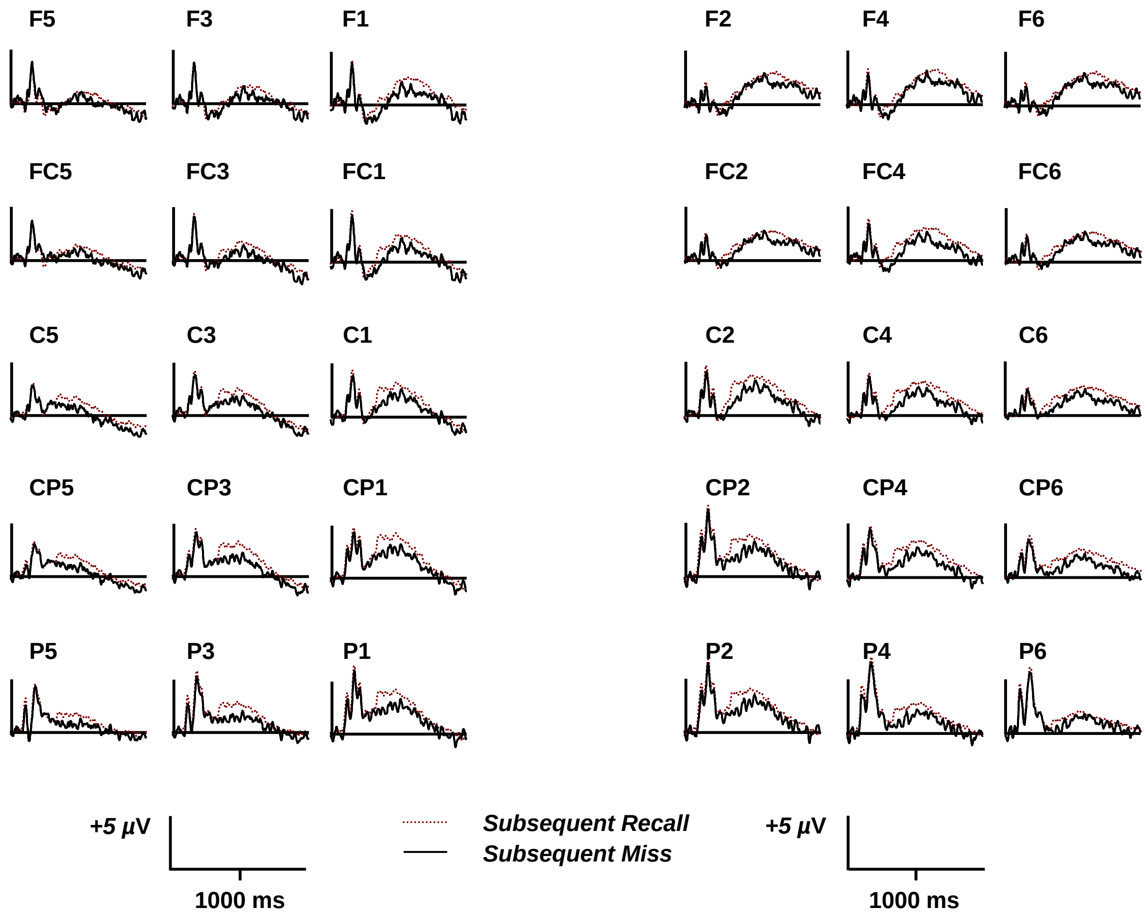

Figure 5.4 SM effects.
Grand average ERPs for subsequently missed items (black lines) and subsequently recalled items (red dotted lines).

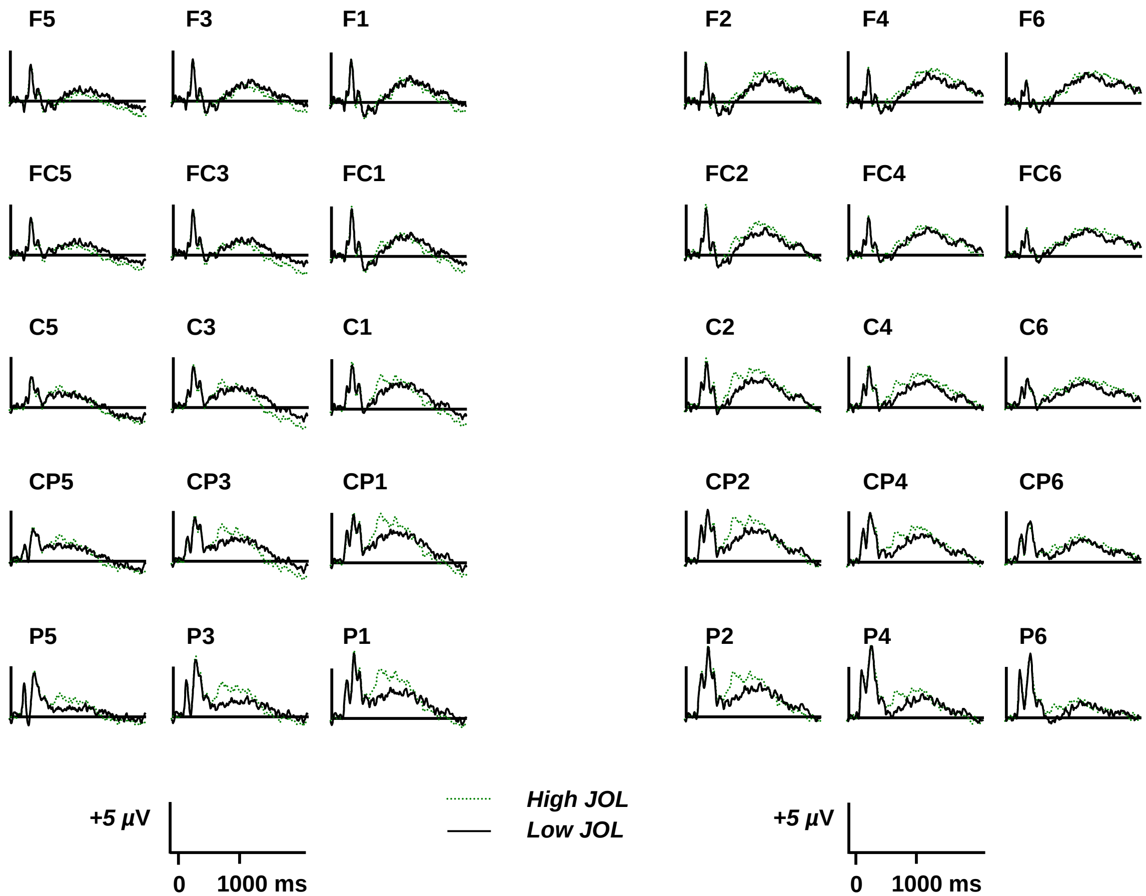

Figure 5.5 JOL effects.
Grand average ERPs for items assigned a low JOL (black lines) and items assigned a high JOL (green dotted lines).

5.4.1. SM Effects

Waveforms for subsequently recalled and subsequently missed words are shown in Figure 5.4 at electrodes included in the analyses. For the 550 to 1000 ms time window the outcome of the initial ANOVA was a main effect of condition [$F(1,19) = 8.3$, $p < 0.05$] and a significant interaction between condition and site [$F(1.1,21.5) = 13.6$, $p < 0.01$]. The analysis suggests that the SM effect is a widespread positive-going effect with a focus at posterior electrode sites (see Figure 5.6).

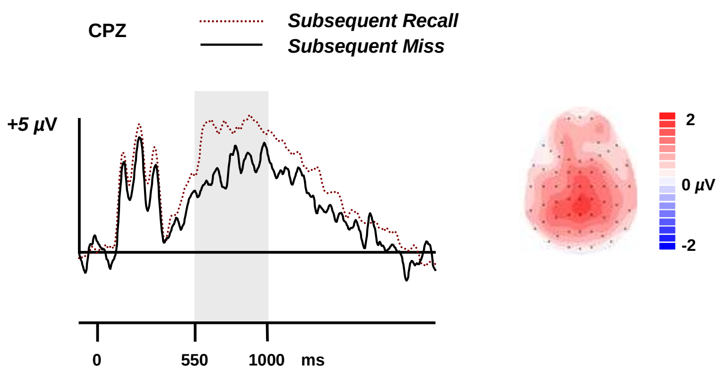

Figure 5.6 SM effect at CPZ.
Zero indicates stimulus onset. The topographic map illustrates the scalp distributions of the SM effect (subsequent recall minus subsequent miss) over the 550-1000 ms time window. The front of the head is at the top of the map and the scale bar represents the size of the effect in µV.

In the 1300-1900 ms time window the initial ANOVA revealed only a main effect of condition [$F(1,19) = 8.3$, $p < 0.05$]. As indicated in Figures 5.4 and 5.7, this effect seems to reflect a (weakened) continuation of the effect present in the preceding epoch.

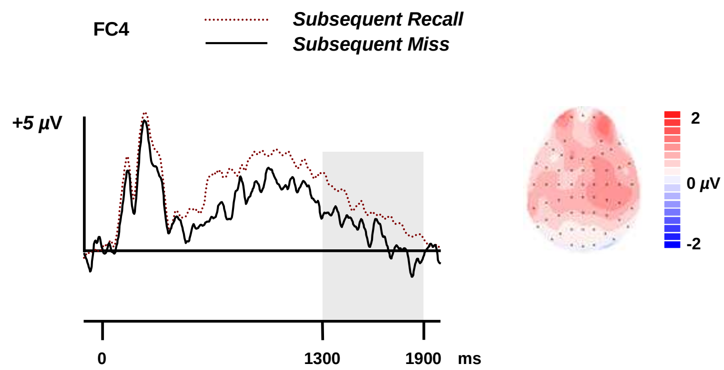

Figure 5.7 SM effect at FC4.
The topographic map illustrates the scalp distributions of the SM effect (subsequent recall minus subsequent miss) over the 1300-1900 ms time window.

5.4.2. JOL Effects

Waveforms for items assigned a low JOL and items assigned a high JOL at study are shown in Figure 5.5 at electrodes included in the analyses. For the 550 to 1000 ms time window the initial ANOVA revealed a main effect of condition [$F(1,19) = 7.1$, $p < 0.05$] along with interactions between condition and location [$F(1.7,32.2) = 11.3$, $p < 0.001$] and between condition and site [$F(1.1,20.1) = 12.2$, $p < 0.005$]. The subsidiary ANOVAs revealed interactions between condition and site from fronto-central to parietal electrode rows, confirming that the early JOL effect, as for the SM effect, reflects a relative positivity for items assigned high JOLs than for items assigned low JOLs – an effect that is largest at posterior electrode sites closest to the midline (see Figure 5.8).

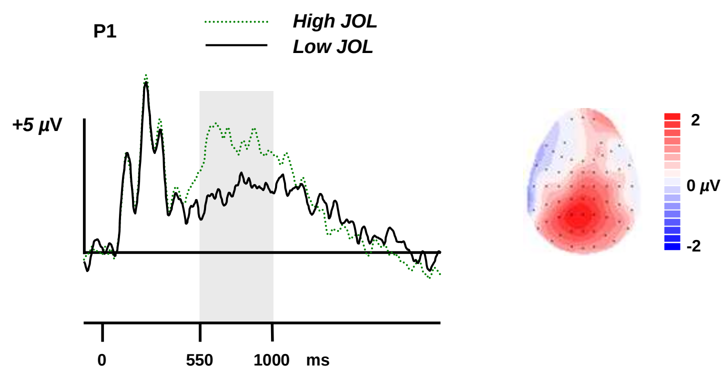

Figure 5.8 JOL effect at P1.
The topographic map illustrates the scalp distributions of the JOL effect (high JOL minus low JOL) over the 550-1000 ms time window.

For the 1300-1900 ms time window the initial ANOVA revealed significant interactions between condition and hemisphere [$F(1,19) = 41.3$, $p < 0.005$] and between condition, location and hemisphere [$F(1.6,30.6) = 4.9$, $p < 0.005$]. The subsidiary analyses revealed significant main effects of condition at centro-parietal and parietal electrode rows and significant interactions between condition and hemisphere from frontal to parietal electrode rows. As Figures 5.5 and 5.9 illustrate, ERPs elicited by items assigned high and low JOLs differ primarily at left hemisphere sites, where the high JOL ERPs are markedly more negative-going.

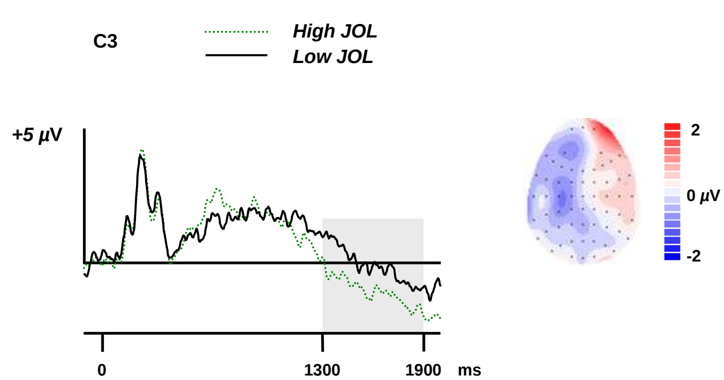

Figure 5.9 JOL effect at P1.
The topographic map illustrates the scalp distributions of the JOL effect (high JOL minus low JOL) over the 1300-1900 ms time window.

Table 5.1 Outcomes of the analysis of JOL ERP effects.
(F = Frontal; FC = Fronto-Central; C = Central; CP = Centro-Parietal; P = Parietal).

High JOL/Low JOL

550-1000ms	F	FC	C	CP	P
Condition				*F*(1,19)=9.4; *p*<0.01	*F*(1,19)=17.5; *p*<0.01
Condition x Hemisphere					
Condition x Site		*F*(1.3,24.9)=7.9; *p*<0.01	*F*(1.2,22.0)=4.8; *p*<0.05	*F*(1.1,20.7)=8.5; *p*<0.01	*F*(1.1,21.5)=11.0; *p*<0.01
Condition x Hemisphere x Site					
1300-1900ms	**F**	**FC**	**C**	**CP**	**P**
Condition					
Condition x Hemisphere	*F*(1,19)=8.6; *p*<0.01	*F*(1,19)=5.8; *p*<0.05	*F*(1,19)=10.0; *p*<0.01	*F*(1,19)=8.0; *p*<0.05	
Condition x Site					
Condition x Hemisphere x Site					

5.4.3. Analyses of Scalp Distributions

The scalp distribution analyses were conducted using ANOVA with factors of time window (early, late), location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and site (superior, mid, inferior). For the SM effects, the ANOVA revealed no significant change in distribution over time (all *Fs* < 1.9). For the JOL effects, ANOVA revealed significant interactions between time and location [$F(1.3,24.1) = 4.7$, $p < 0.05$], time and hemisphere [$F(1,19) = 8.7$, $p < 0.01$], time and site [$F(1.2,22.0) = 12.7$, $p < 0.005$] as well as between time, location and site [$F(3.2,59.3) = 3.5$, $p < 0.05$]. These interactions reflect first of all that the early effect shows an increase in positivity over midline posterior sites whereas the later effect shows a widespread increase in negativity over the left hemisphere. The reliable interactions that were revealed in the JOL analyses indicate that the early and late JOL effects are generated by at least partially non-overlapping sets of neural generators, and therefore index distinct classes of cognitive operations.

5.5. Discussion

The first of the experiments reported in this thesis investigated the relationship between JOLs and successful memory encoding using behavioural and ERP measures. The behavioural results showed a clear relationship between memory encoding and JOLs and the ERP results provided new insights into this relationship not available via the behaviour alone. These insights follow from two critical contrasts between ERPs acquired during the experiment study phase; ERPs elicited by studied items attracting correct or incorrect judgments on the subsequent memory test and ERPs elicited by items attracting high or low JOLs at study. The ERP data were analysed for two time windows: early (550-1000 ms) and late (1300-1900 ms). Findings for each window are discussed in turn.

5.5.1. Early Time Window (550-1000 ms)

The SM and JOL contrasts elicited reliable and markedly similar ERP effects between 550-1000 ms. These effects took the form of increases in positivity for subsequently recalled relative to missed items and for high JOL items relative to low JOL items. In both cases, the effects had a focus over posterior recording sites, however only the JOL effect was reliably larger at posterior sites.

If the early ERP effect indexes successful memory encoding (Paller et al., 1987), then the presence of this effect in the JOL contrast suggests that JOLs can be based upon operations that support successful encoding. Whilst attractive, this interpretation is unfortunately not without complications. First of all, because participants were relatively accurate at assigning JOLs, there is a certain amount of trials that will overlap in the two contrasts (a higher proportion of high JOL items were subsequently recalled and similarly a higher proportion of low JOL items were missed). Second, the existence of overlapping trials makes it difficult to statistically compare the two effects. For these reasons it is virtually impossible to make any strong claims about which cognitive processes are driving the early effects. One possibility is, as mentioned above, that the early effect is indicating successful memory encoding and is only present in the JOL contrast because of the behavioural correlation. Following this argument, it would be reasonable to expect that the JOL effect was noticeably smaller in comparison to the SM effect. Visual inspections of the waveforms suggest, however, that this is not the case. If anything, the JOL effect appears to be largest in magnitude, rendering the encoding interpretation of the early effect less convincing.

The second possible interpretation of the early positivity is that it is primarily driven by the JOL ratings. The presence of JOL effects in the absence of encoding effects is, perhaps, a more controversial explanation, primarily because the SM effect is an established phenomenon in the literature, whereas little evidence currently exists to suggest JOLs give rise to any independent correlates. Nevertheless, this explanation cannot be refused on those grounds alone and is therefore an option that needs exploring. If ERPs are recorded under conditions in which JOLs are not correlated with memory performance, this would provide an opportunity to investigate the ERPs without challenges of overlapping trials. If a JOL interpretation of the early effect was the correct explanation of the data, this does not imply that memory encoding has not produced any noteworthy activity. The SM effect was more smeared out compared to the JOL effect; although it showed a posterior maximum, it was not statistically larger at posterior sites and noticeable differences between the waveforms are evident at the front of the scalp. This indicates (albeit weakly) that an additional effect may be present for the encoding contrast in the early time window, which is not present for JOL. That this effect constitutes a pure ERP measure of successful encoding is at this point, however, mere speculation.

It is also important to acknowledge a third alternative interpretation of the early effect; that it is present for both encoding and JOL due to a complex interaction between the two. This interpretation does not imply that one process is driving the effect, but rather that it occurs when encoding is facilitated through the makings of JOLs. One way of portraying this possibility is that the posterior effect constitutes the neural correlates of JOL-specific encoding. This last interpretation provides a very reasonable explanation given how SM effects have been shown to change depending on the nature of the encoding tasks (Otten & Rugg, 2001a). To test whether JOL-specific encoding effects are probable is relatively easy and can be done by replicating the current experiment without JOL instructions (see Chapter 7).

5.5.2. Late Time Window (1300-1900 ms)

Regardless of the correct interpretations of the early effect, the presence of a separate JOL effect in a later time window suggests that JOLs are not based exclusively on memory operations. From 1300-1900 ms, the SM and JOL effects diverged markedly. Whereas the SM effect produced slight widespread positivity (appearing to be a continuation of the early effect), the JOL contrast produced a long-lasting negative-going effect present over the left hemisphere. Analyses of the scalp distributions of the effects revealed that only the neural activity predicting JOLs reliably changed over time suggesting that this effect is separate from the early positive effect.

Any functional interpretation of the late negative-going JOL effect would be premature on the basis of the current experiment alone, however several possibilities are available to explore. It is critical that the effect occurred after effects that are shared between successful memory encoding and JOLs. This temporal information strongly suggest that the JOL-specific effect reflects metacognitive assessment processes which operate downstream of the operations that actually determine memorability. This claim could not have been made on the basis of the previous brain imaging (fMRI) study of memory encoding and JOLs (Kao et al, 2005) because of the low temporal resolution of haemodynamic indices of neural activity. Sommer et al. (1995), on the other hand, employed ERPs and did not reveal a JOL-specific effect. Notably, however, they only examined the ERPs up to 1000 ms post-stimulus, thereby precluding identification of late-onsetting JOL effects (see Figure 5.10).

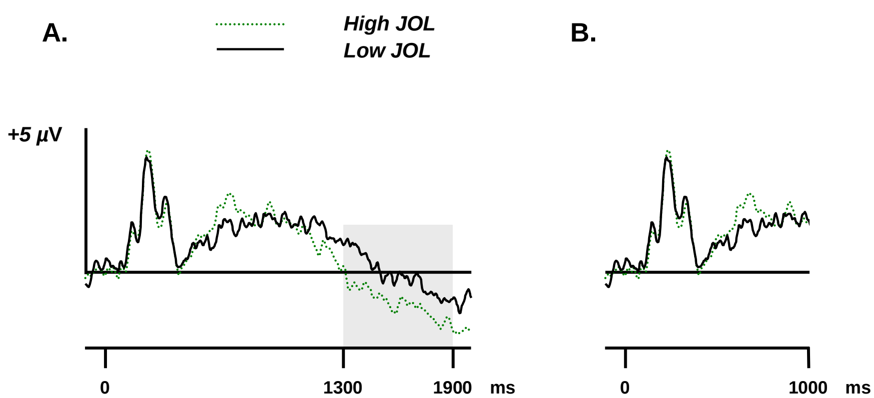

Figure 5.10 The time course of the late JOL effect.
A shows the late JOL effect with the full recording epoch (2000 ms post-stimulus) used in this experiment. B shows the same effect but with an epoch shortened to 1000 ms post-stimulus to match the recording epoch used by Sommer et al. (1995).

The fact that there is no spill-over of the late JOL effect to the SM contrast suggests that participants have an imperfect understanding of some of the factors that influence memorability. In other words, they could assign importance to factors that do not in fact contribute substantively to effective encoding.

5.6. Summary and Conclusion

This experiment investigated the correspondence between the neural correlates of successful memory encoding and of JOLs revealing an early effect shared by the two and a later effect only present in the JOL contrast. These findings suggest that there are associations as well as dissociations between the neural systems that mediate successful memory encoding and JOLs.

The specific results are not completely consistent with the results of either Sommer et al. (1995) or Kao et al. (2005). As mentioned previously, the null results of Sommer et al. (1995) is likely a consequence of the relatively short recording epoch and therefore it is not feasible to directly compare their findings to those of the current experiment. Kao et al.’s (2005) experiment made use of an entirely different imaging technique and comparisons are, due to that reason alone, quite problematic. Nevertheless, Kao et al. (2005) found that both successful memory encoding and JOLs were associated with separate effects in addition to an overlapping effect. The current experiments identified two ERP effects that correspond to these fMRI effects, but failed to find a separate effect indicative of memory encoding alone. It is worth noting, however, that although the SM effect was remarkably similar to the early JOL effect, it was more smeared out and longer lasting (extending into the second time window, see Figure 5.7), which could signify that additional activity, not shared by JOLs, was indeed present but not statistically robust. At the strongest, the current results suggest a reliable relationship between memory encoding and JOLs, however the nature of this relationship is yet to be determined. Critically, because JOLs also gave rise to a separate and later-onsetting effect, the current findings provide evidence that memory operations are not the sole basis of JOL decisions.

Irrespective of the accuracy of the functional accounts summarised in this section, however, the behavioural and ERP findings from this study indicate that (i) the processes differentiating high and low JOLs do not reduce to those that support successful memory encoding, and (ii) the JOL-specific processes operate downstream of those that are shared between encoding operations and judgments about the subsequent memorability of studied material.

Chapter 6.

Judgments of Learning and Recognition Memory

6.1. Introduction

The primary purpose of Experiment 1 was to establish whether the ERP correlates of Judgments of Learning are the same as, or differ from, the ERP correlates of successful memory encoding. The results showed that whilst both JOLs and encoding elicited an early positive-going effect with a posterior maximum, JOLs gave rise to an additional negative-going effect over the left hemisphere. These findings strongly suggest that although the cognitive processes supporting JOLs and successful encoding are intimately related during the early stages of processing, the two dissociate at a later stage.

At a superficial level, the findings summarised above are consistent with the observations from a prior fMRI experiment by Kao et al. (2005) and in line with predictions put forward by inferential theories of JOL (Koriat, 1997). Nevertheless, the electrophysiological findings raise a number of unanswered questions that need addressing. For example, what is the exact relationship between the early encoding effect and the early JOL effect? Are they elicited independently in the two contrasts, or is one effect ‘driven’ primarily by one single condition? Finally, how does the early JOL effect differ from the later-onsetting JOL effect and are the two effects equally sensitive to experimental manipulations? Before any strong claims can be brought forward regarding the functional significances of the effects observed in Experiment 1, the above questions need to be explored.

The principal aim of Experiment 2 was to further examine the ERP correlates of JOLs and successful memory encoding by altering instructions at test; rather than having to recall the second word of the word pairs following an old/new judgment, participants were only required to distinguish old items from new items (using a standard recognition memory test). Participants were kept unaware of the details of the test format, and it was therefore expected that their approaches to the study task would not differ across Experiments 1 and 2. Rather, this change in paradigm causes a change in the criteria for trials included in the SM contrast. The alteration of test instructions should theoretically have no consequences for JOLs because the trials included to form this contrast are not backsorted based on performance at test (see Chapter 3). Thus, Experiment 2 was designed to affect SM effects exclusively, whilst keeping JOLs constant.

Naturally, the logic of the experimental manipulation rests upon the assumption that the SM effect will be successfully altered by changes in task demands at test. ERP results by Yovel & Paller (2004) suggest that this assumption is reasonable; they presented participants with a number of faces paired with names of occupations. At test, participants were required to make old/new judgments and following each old judgments they were asked to provide one of three responses: i) that they remembered the occupation that was paired with the face originally ii) that they remembered any other specifics about the initial study episode (for example that the face showed a resemblance to a friend) or iii) that they did not remember any specific context of the study episode. Recollection was defined as the ability to correctly retrieve the occupation or other specific information. Familiarity, on the other hand, was defined as the inability to retrieve any such details. Yovel & Paller (2004) found that right-hemispheric activity was predictive of subsequent face familiarity, whereas bilateral activity predicted subsequent face recollection.

As outlined in Chapter 3, the majority of evidence for and against specific SM effects for recollection and familiarity comes from experiments using the R/K paradigm (Tulving, 1985). R/K experiments have, however, reached different conclusions regarding this issue; some researchers have found that the ERP correlates of subsequent *remember* and *know* responses are the same (Smith, 1993), whereas others have found that only *remember* responses elicit noticeable effects (Friedman & Trott, 2000). Yet another experiment has revealed evidence of qualitatively different effects associated with *remember* and *know* responses (Duarte et al., 2004). Notably, the current experiment does not use an R/K test paradigm, but the change from cued recall to recognition will potentially include more test trials recognised on basis of familiarity, which is the process believed to support K judgments in R/K decisions.

The inconsistencies of findings in the encoding literature clearly offer no guarantee that the present paradigm will produce SM effects that are observably different from those observed in Experiment 1. A supplementary aim of altering test instructions in Experiment 2 was therefore to boost overall memory performance; using recognition rather than cued recall would almost certainly increase the number of trials falling into the category of correctly identified items. More trials would therefore potentially be included in the successful memory encoding condition and cleaner ERP data be acquired. The fact that participants were no longer instructed to speak out loud was also expected to cause a reduction of unnecessary muscular tension during the test phase, potentially causing fewer trials to be lost during artefact rejection. The possibilities of investigating retrieval related ERPs, and in particular any potential modulations of retrieval effects by JOL, served as an additional incentive.

6.2. Method

Participants were 32 students at the University of Stirling. Five participants were excluded due to equipment failure or excessive EEG artefacts, and three due to poor performance. The remaining 24 participants (16 female) had a mean age of 21 (range: 18-27).

Stimulus materials and experimental procedure conform to those outlined in Chapter 4 and the behavioural paradigm is schematically illustrated in Figure 6.1. Grand average ERP waveforms were formed for the following response categories: Hits (items subsequently recognised as old), Misses (items judged incorrectly as being new), High JOL (study pairs assigned a JOL of 4 or 5) and Low JOL (JOL of 1 or 2). As explained in greater detail below, study items attracting an ‘unsure’ JOL (3 response) were included in additional analyses reported following the standard High JOL versus Low JOL analyses. Mean numbers of trials were 205, 53, 119, 75 and 63 for the Hits, Misses, High JOL, Low JOL and Medium JOL categories respectively.

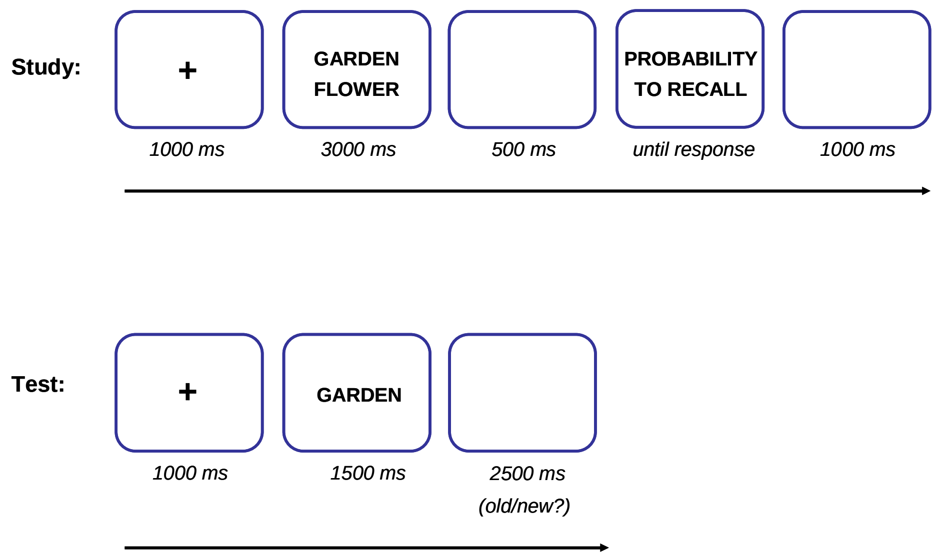

Figure 6.1 The experimental paradigm used in Experiment 2.
At study, participants saw a number of word pairs (a cue presented above a target) and made a JOL for each pair. The JOL reflected how likely the participants believed they were to remember the target word (flower) when presented with the cue word (garden) on a later test. The rating scale ranged from one (will definitely forget) to five (will definitely remember). At test, participants saw each of the upper words intermixed with a number of new words and were required to make an old/new recognition judgment.

6.3. Behavioural Results

6.3.1. Study

Participants had a preference for assigning intermediate JOLs (Figure 6.2a). ANOVA on response rates revealed a main effect of JOL [$F(4,92) = 17.0$, $p <$

0.001], with accompanying linear [$F(1,23) = 16.5$, $p < 0.001$] and quadratic trends [$F(1,23) = 25.2$, $p < 0.001$]. The pattern of reaction time (RT) for making JOLs at study also formed the shape of an inverted "U" when plotted against each level of JOL (Figure 6.2b). ANOVA revealed a significant main effect of JOL [$F(4,92) = 5.7$, $p < 0.001$], exhibiting linear [$F(1,23) = 6.6$, $p < 0.001$] and quadratic trends [$F(1,23) = 12.4$, $p < 0.01$].

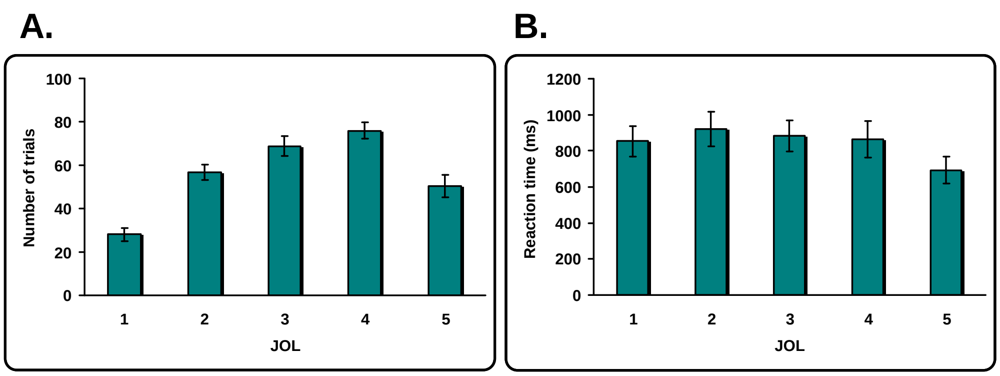

Figure 6.2 Behaviour at study.
Mean (and S.E.) number of trials assigned each JOL category at study (A) and reaction times for making each level of JOL at study (B).

6.3.2. Test

Overall recognition responses are shown in Figure 6.3a. Figure 6.3b shows the mean recognition accuracy for old items distributed across the levels of JOLs assigned at study. It is evident from the graph that recognition performance increased with increasing JOL and a repeated measures ANOVA confirmed that the effect of JOL was significant [$F(4,92) = 23.7$, $p < 0.001$], exhibiting linear [$F(1,23) = 49.7$, $p < 0.001$] and quadratic trends [$F(1,23) = 7.3$, $p < 0.05$]. The mean G score of 0.26 (SD = 0.15) was significantly above zero [$t(23) = 8.06$, $p < 0.001$]. Mean d_a was 0.37 (SD = 0.25) and was also signficantly above zero [$t(23) = 7.42$, $p < 0.001$]. In contrast to the reaction times measured at study, the pattern of reaction times across JOL at test showed a linear development (Figure 6.3c). ANOVA confirmed a main effect of JOL [$F(4,92) = 11.2$, $p < 0.001$], reflecting a linear trend [$F(1,23) = 28.0$, $p < 0.001$].

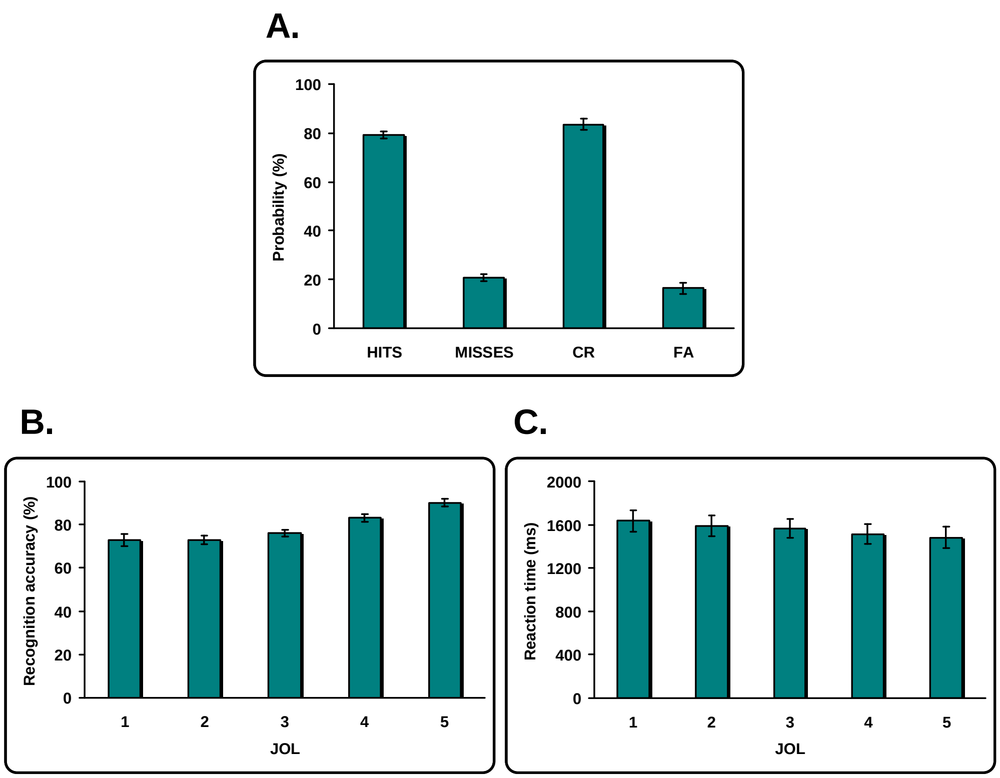

Figure 6.3 Behaviour at test.
Mean (and S.E.) recognition responses for each response category at test (A) recognition performance across JOL at test (B) and reaction time measured at test split according to JOL (C).

6.4. Event-Related Potential Results

As in Experiment 1, the initial ERP analyses comprised separate assessments of the study phase ERPs. First, *SM effects*: study ERPs separated according to memory accuracy at test (Hits versus Missed; Figure 6.4). Second, *JOL effects*: ERPs associated with High or Low JOLs (Figure 6.5). Again, it is not possible to contrast directly these two effects as they contain overlapping subsets of trials. The first set of analyses that were carried out followed the same structure as for Experiment 1. The ERP results section in the present experiment has, however, an additional set of JOL analyses reported at the end that were not possible in Experiment 1 (due to insufficient trial numbers). Two of these analyses involve comparisons of the data from Medium JOL (JOL responses of 3). The aim of these analyses was to establish whether the differences in JOL ERPs reflect gradual changes in amplitude as a function of the JOL responses.

Based on visual inspections of the waveforms it was confirmed that the two time windows used in Experiment 1 captured the activity of interest (550-1000 ms and 1300-1900 ms post-stimulus presentation). The SM and JOL distributions exhibit a similar widespread positivity in the early time window. During the later time window, however, the two effects differ; the JOL contrast reveals a strong posterior negative-going effect which is not present in the SM contrast. A third effect was also observed in this data set. This effect was present in both contrasts with a relatively early onset (300-500 ms post-stimulus) and a parietal distribution. In the SM contrast, the effect was characterised by an increase in positivity for missed items relative to recognised items. Similarly, in the JOL contrast, the effect was characterised by an increase in positivity for Low JOL items. These early effects are not the primary focus of this investigation, but have for completeness been summarised in Appendix A.

For each contrast, data were first analysed using ANOVA with factors of category (Hits versus Missed, High versus Low JOL), location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and electrode site (superior, mid, inferior) followed by five subsidiary analyses on each separate location when interactions involving location were evident. The outcomes of the subsidiary analyses for the early and late time windows are summarised in Tables 6.1 and 6.2.

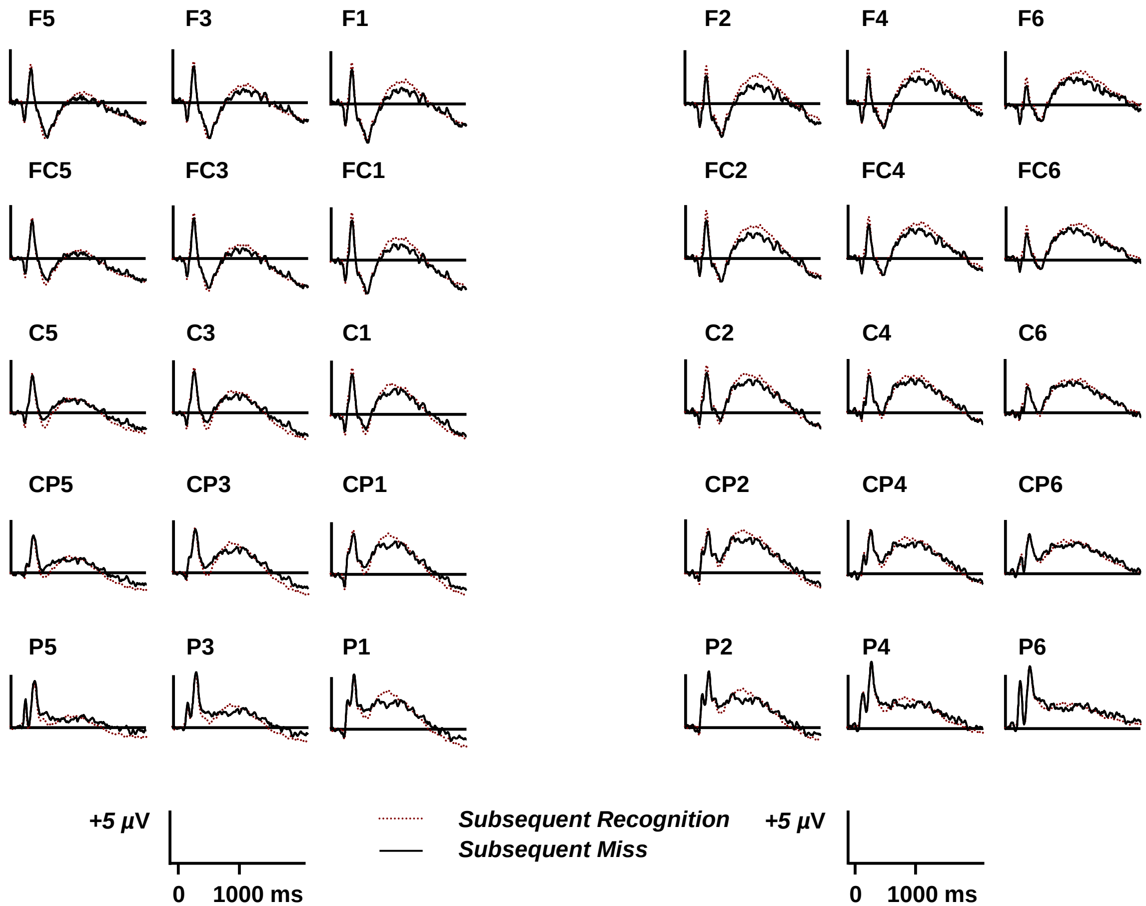

Figure 6.4 SM effects.
Grand average ERPs for subsequently missed items (black lines) and subsequently recognised items (red dotted lines).

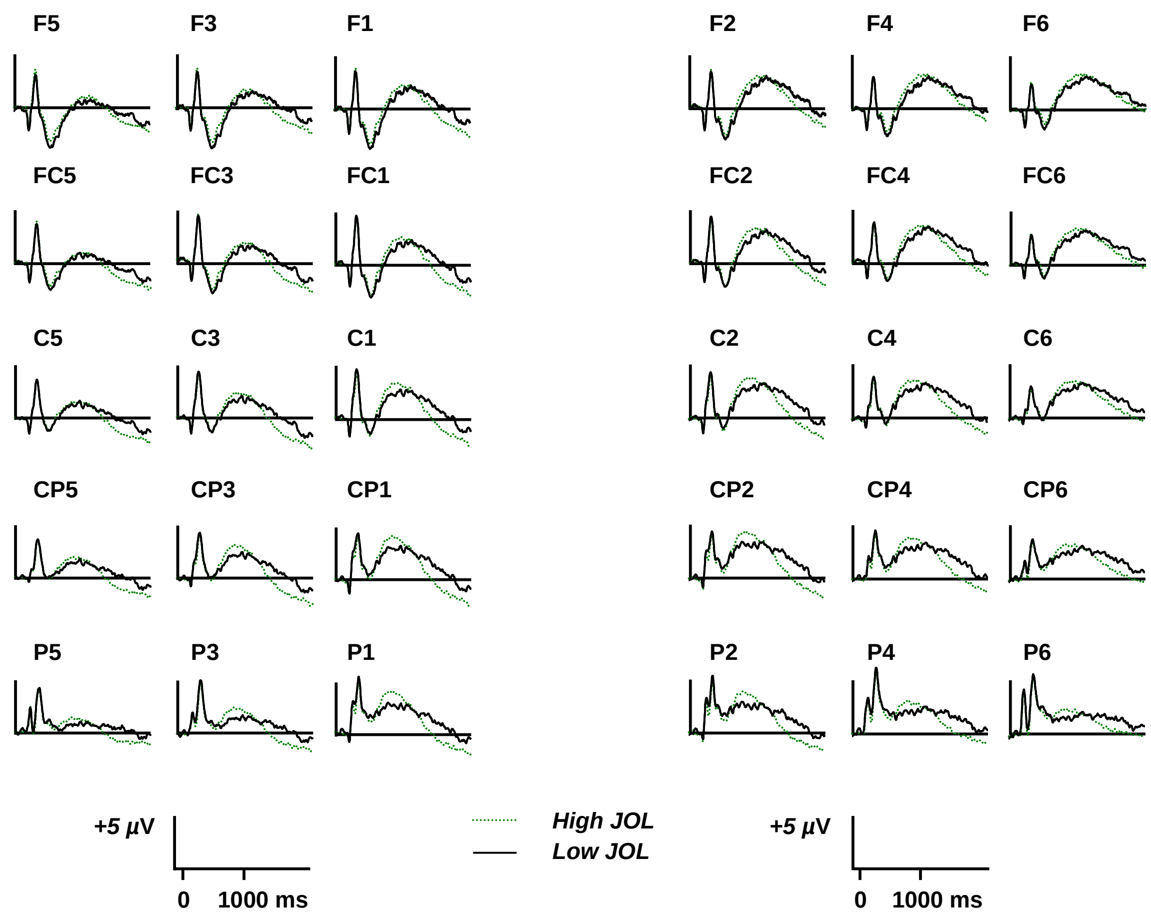

Figure 6.5 JOL effects.
Grand average ERPs for items assigned a low JOL (black lines) and items assigned a high JOL (green dotted lines).

6.4.1. SM Effects

Waveforms for subsequent Hits and subsequent Misses are shown in Figure 6.4 at electrodes included in the analyses. For the 550 to 1000 ms time window the outcome of the initial ANOVA was a significant interaction between condition and site [$F(1.1,26.2) = 15.8$, $p < 0.001$] reflecting that the SM effect is a broadly distributed positive-going effect which is largest at sites closest to the midline (see Figure 6.6).

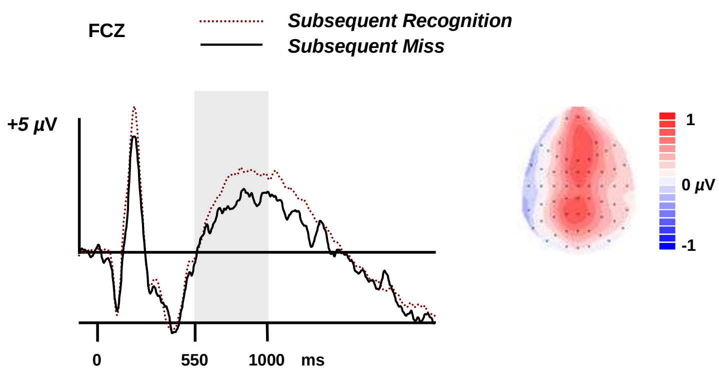

Figure 6.6 SM effect at FCZ.
The topographic map illustrates the scalp distributions of the SM effect (subsequent Hits minus subsequent Misses) over the 550-1000 ms time window.

For the 1300-1900 ms time window the initial ANOVA revealed no significant main effects or interactions (all *Fs* < 3.0).

6.4.2. JOL Effects

Waveforms for study item assigned a Low JOL and items assigned a High JOL are shown in Figure 6.5 at electrodes included in the analyses. For the 550-1000 ms time window the outcome of the initial ANOVA was a main effect of condition

[$F(1,23) = 10.0$, $p < 0.01$] along with interactions between condition and site [$F(1.1,25.2) = 11.6$, $p < 0.01$] and between condition, hemisphere and site [$F(1.3,29.9) = 4.0$, $p < 0.05$]. The analyses confirm that the early JOL effect reflects a relative positivity for items assigned High JOLs than for items assigned Low JOLs that is largest at posterior electrode sites closest to the midline (the effect also seems to be slightly skewed towards the right hemisphere over fronto-central and central electrodes and slightly skewed to the left over parietal electrodes; see Figure 6.7).

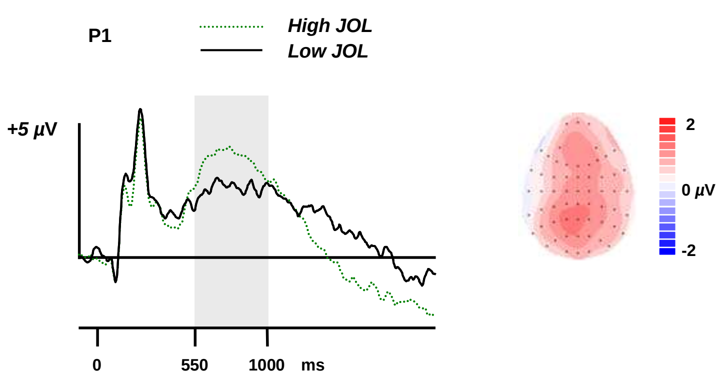

Figure 6.7 JOL effect at P1.
The topographic map illustrates the scalp distributions of the JOL effect (High JOL minus Low JOL) over the 550-1000 ms time window.

For the 1300-1900 ms time window the outcome of the initial ANOVA was a significant main effect of condition [$F(1,23) = 15.9$, $p < 0.01$], along with significant interactions between condition and location [$F(1.3,29.7) = 4.7$, $p < 0.05$] and between condition and site [$F(1.2,27.0) = 17.2$, $p < 0.001$]. The subsidiary analyses revealed significant main effects of condition and significant interactions between condition and site across all five electrode rows. As Figures 6.5 and 6.8 illustrate, ERPs elicited by items assigned High and Low JOLs differ primarily on electrode sites that are closest to the midline, where the High JOL ERPs are markedly more negative-going relative to Low JOL ERPs.

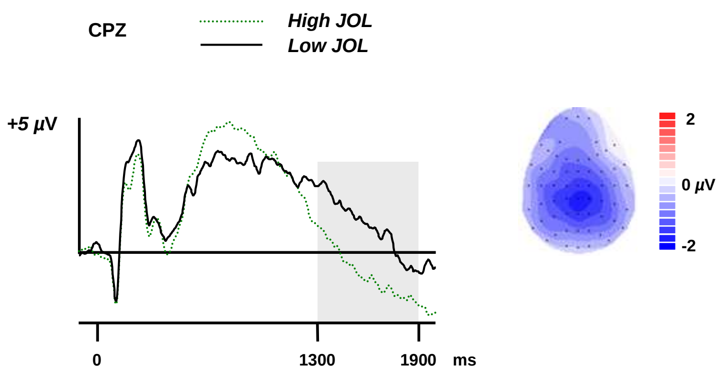

Figure 6.8 JOL effect at CPZ.
The topographic map illustrates the scalp distributions of the JOL effect (High JOL minus Low JOL) over the 1300-1900 ms time window.

Table 6.1 Outcomes of the analysis of the JOL ERP effects.
(F = Frontal; FC = Fronto-Central; C = Central; CP = Centro-Parietal; P = Parietal).

High JOL/Low JOL

1300-1900ms	F	FC	C	CP	P
Condition	$F(1,23)=5.1; p<0.05$	$F(1,23)=8.9; p<0.01$	$F(1,23)=16.9; p<0.001$	$F(1,23)=27.1; p<0.001$	$F(1,23)=27.1; p<0.001$
Condition x Hemisphere					
Condition x Site	$F(1.2,27.4)=11.1; p<0.01$	$F(1.3,30.2)=9.1; p<0.01$	$F(1.2,28.4)=9.1; p<0.01$	$F(1.2,28.1)=17.8; p<0.001$	$F(1.2,26.7)=11.3; p<0.01$
Condition x Hemisphere x Site					

6.4.3. Analyses of Scalp Distributions

The scalp distribution analyses were conducted using ANOVA with factors of time window (early, late), location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and site (superior, mid, inferior). The analyses were not carried out for the SM effects since there was no evidence of activity separating Hits and Misses in the late time window. For the JOL effects, ANOVA revealed significant interactions between time and location [$F(1.3,31.6) = 4.8$, $p < 0.05$] and between time and site [$F(1.1,25.5) = 42.4$, $p < 0.001$]. The interaction between condition and location reflect how both the early and late JOL effects exhibit parietal maxima but with opposite polarity. Similarly, the interaction between condition and site reflect how both effects of opposite polarities are focussed over medial electrode sites. The reliable interactions that were revealed in the JOL analyses indicate that the early and late JOL effects in Experiment 2 are also produced by different sets of neural generators.

6.4.4. Additional Analyses of the Early JOL Effect

In the present study, enough trials were obtained for items assigned a Medium JOL (JOL response of 3) and for that reason, comparisons between Low JOL, Medium JOL and High JOL were possible (scalp maps are provided in Figures 6.9 and waveforms in Figure 6.10). To investigate these data initial ANOVAs with factors of condition (High JOL, Medium JOL, Low JOL), location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and site (superior, mid, inferior) were carried out for each time window (550-1000 ms and 1300-1900 ms) and are reported below.

For the early time window, the initial ANOVA revealed a significant main effect of condition [$F(1.8,41.2) = 4.2$, $p < 0.05$], along with interactions between condition and site [$F(1.8,41.7) = 3.7$, $p < 0.05$] and between condition, location and site [$F(4.4,100.7) = 3.3$, $p < 0.05$]. Two additional ANOVAs were then carried out to investigate in more detail how the three conditions differ from each other; High JOL versus Medium JOL and Medium JOL versus Low JOL. High JOL versus Low JOL were reported above in the original analyses. The ANOVAs were followed up by five subsidiary analyses on each electrode row when appropriate (the outcomes of which are summarised in Table 6.2).

The first of the comparisons (High JOL versus Medium JOL) revealed a significant main effect of condition [$F(1,23) = 5.3$, $p < 0.05$] and a significant interaction between condition, location and site [$F(2.3,53.3) = 3.7$, $p < 0.05$]. The five subsidiary analyses revealed significant main effects of condition on centro-parietal and parietal electrode rows and a significant interaction between condition and site on the frontal electrode row. The interaction between condition and site on frontal electrode rows seem to reflect how High JOL items are more positive-going relative to Medium JOL items on sites closest to the midline. The second comparison (Medium JOL versus Low JOL) revealed only a significant interaction between condition, location and site [$F(2.3,59.4) = 5.1$, $p < 0.01$]. The five subsidiary analyses revealed significant interactions between condition and site on centro-parietal and parietal electrode rows. As reported previously, the original comparison between High JOL and Low JOL revealed a significant main effect of condition, a significant interaction between condition and site and between condition, hemisphere and site. Altogether, therefore, these analyses confirm that i) Medium JOL produce ERPs that are more positive-going relative to Low JOL items (an effect which is predominantly present on posterior electrode sites closest to the midline), ii) High JOL items produce ERPs that are more positive-going relative to Medium JOL items (an effect which is widespread across the scalp), and finally iii) High JOL items produce ERPs that are more positive-going compared to Low JOL items (and effect which is relatively widespread but with a focus on sites closest to the midline). In sum, the ERPs associated with JOLs making appear to become more positive the higher the JOL ratings. The statistical outcomes are consistent with the impression provided in Figure 6.9 and 6.10.

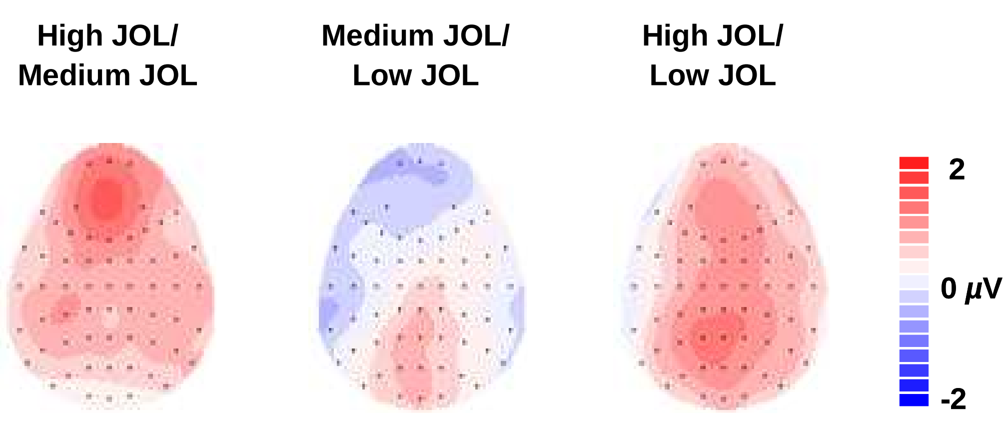

Figure 6.9 Distributions of early JOL effects.
The topographic map illustrates the scalp distributions of the High JOL versus Medium JOL, Medium JOL versus Low JOL and High JOL versus Low JOL effects during the early time window.

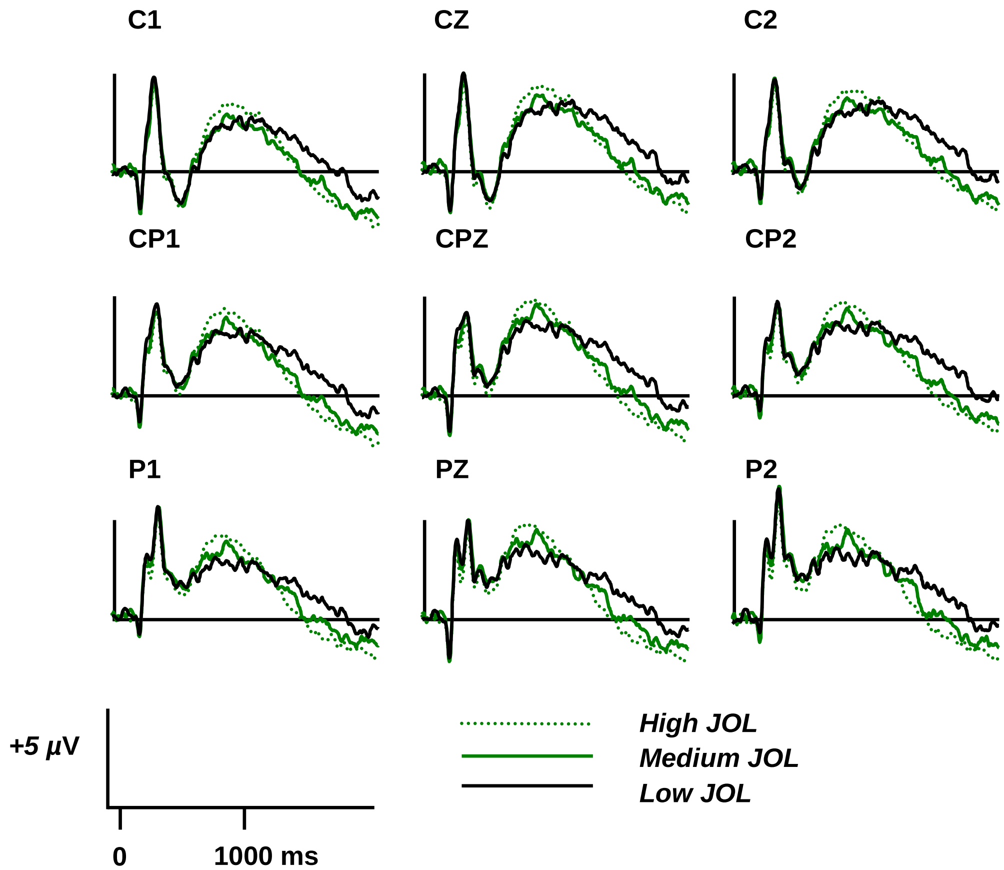

Figure 6.10 JOL effects (including Medium JOL) at representative electrodes.
Grand average ERPs for items assigned a Low JOL (black lines), items assigned a Medium JOL (green lines) and items assigned a High JOL (green dotted lines).

Table 6.2 Outcomes of the analyses of the JOL ERP effects.
(F = Frontal; FC = Fronto-Central; C = Central; CP = Centro-Parietal; P = Parietal).

High JOL/Medium JOL

550-1000ms	F	FC	C	CP	P
Condition				$F(1,23)=6.7$; $p<0.05$	$F(1,23)=6.1$; $p<0.05$
Condition x Hemisphere					
Condition x Site	$F(1.2,28.4)=5.5$; $p<0.05$				
Condition x Hemisphere x Site					

Low JOL/Medium JOL

550-1000ms	F	FC	C	CP	P
Condition					
Condition x Hemisphere					
Condition x Site				$F(1.1,25.6)=6.1$; $p<0.05$	$F(1.1,25.8)=7.5$; $p<0.01$
Condition x Hemisphere x Site					

6.4.5. Additional Analyses of the Late JOL Effect

For the late time window, the initial ANOVA revealed a significant main effect of condition [$F(1.8,41.2) = 6.8$, $p < 0.01$], along with interactions between condition and site [$F(1.9,43.5) = 5.5$, $p < 0.01$]. Two additional ANOVAs were then carried out to investigate in more detail how the three conditions differ from each other; High JOL versus Medium JOL and Medium JOL versus Low JOL (waveforms are provided in Figure 6.10 and scalp maps in Figure 6.11). High JOL versus Low JOL were reported above in the original analyses.

The first of the comparisons (High JOL versus Medium JOL) revealed no significant main effect or interactions (all Fs < 1.5). The second comparison (Medium JOL versus Low JOL) revealed only a significant main effect of condition [$F(1,23) = 6.7$, $p < 0.05$]. As reported previously, the original comparison between High JOL and Low JOL revealed a significant main effect of condition and significant interactions between condition and location and between condition and site. Altogether, the additional analyses suggest that i) there are no differences between ERPs elicited by Medium and High JOLs, and ii) the ERP elicited by Low JOLs is significantly more positive-going compared to both Medium and High JOLs. The statistical outcomes are consistent with the impression provided in Figures 6.10 and 6.11.

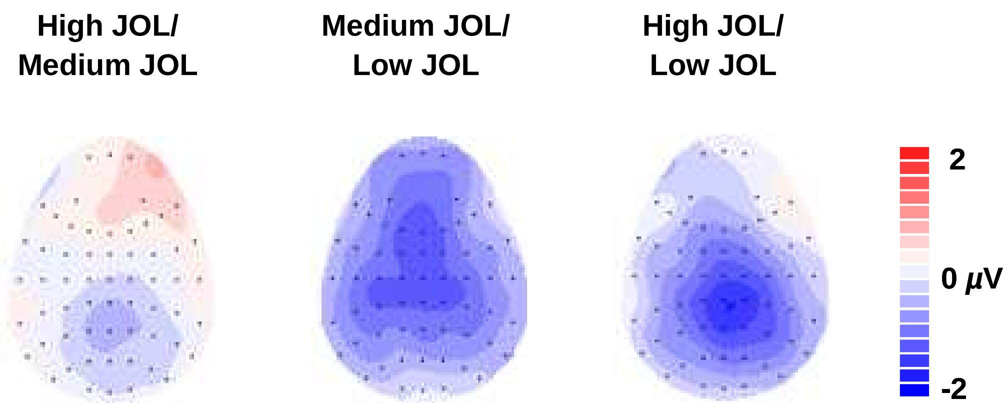

Figure 6.11 Distributions of late JOL effects.
The topographic map illustrates the scalp distributions of the High JOL versus Medium JOL, Medium JOL versus Low JOL and High JOL versus Low JOL effects during the late time window.

The late negative-going JOL effect observed in Experiment 1 showed a clear left-hemispheric distribution, however the effect in Experiment 2 showed no such hemispheric differences. Except from this disparity, the effects were remarkably similar with comparable morphologies and time courses. One inconsistency across the experimental procedures might possibly explain this difference; while the rating scale used in Experiment 2 was counterbalanced, the scale used in the preceding experiment was not (see Chapter 4). To investigate if the late JOL effect is sensitive to the choice of response hand, the late JOL effect from Experiment 2 was plotted separately for the participants who used a standard scale (as in Experiment 1) and for the participants who used a reversed version of the scale (see Figure 6.12).

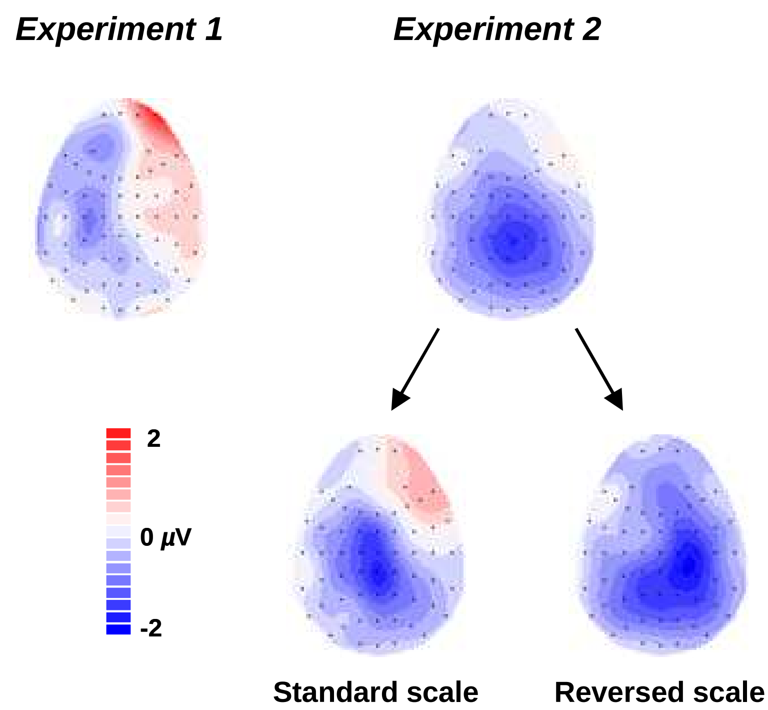

Figure 6.12 The late JOL effect for standard and reversed scales.
The illustration shows the effect from Experiment 1 (upper left) and Experiment 2 (upper right). The topographical maps below show the effect from Experiment 2 separately for the group of participants (N = 12) who used standard scale (left) and the group of participants (N = 12) who used a reversed scale (left).

Subtraction data (High JOL minus Low JOL) from the two groups were analysed using ANOVA with a between-participant factor of group (standard scale versus reversed scale) and within-participant factors of location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and electrode site (superior, mid, inferior). The ANOVA revealed significant interactions between group and hemisphere [$F(1,22.0) = 18.1$, $p < 0.001$] confirming the impression in Figure 6.12 that the two groups produce significantly different late JOL effect; whereas the group using the standard scale produce effects that are slightly skewed to the left (and maximal towards the midline), the group using a reversed scale produce effects that are slightly skewed to the right (and maximal at more lateral electrodes).

To confirm that the differences in distribution are real, scalp distribution analyses were carried out after rescaling the data, revealing significant interactions between group and hemisphere [$F(1,22.0) = 18.1$, $p < 0.001$] and between group, location and hemisphere [$F(1.6,36.3) = 5.8$, $p < 0.01$]. These analyses confirm that the distribution of the late JOL effect is dependent on the choice of response hand for making the JOL ratings; when a standard scale is used, the effect is most prominent over the right hemisphere, whereas when a reversed scale is used, the effect is most prominent over the left hemisphere.

The fact that the late JOL effect is sensitive to choice of response hand could be indicating that the effect is reflecting differential activity associated with the motoric preparation of making JOL ratings. Motoric activity is associated with one of the first observed ERP deflections, the *Contingent Negative Variation* (CNV). This effect was first demonstrated by Walter, Cooper, Aldridge, McCallum & Winter (1964; see Luck, 2005), who presented participants with a warning signal followed by a target stimulus and instructed them to press a button when they detected the target. In the time period between the presentation of the warning signal and the target, Walter et al. (1964) observed a negative voltage at frontal recording sites that appeared to reflect participants preparing to respond to the upcoming stimulus. The time course of the negative-going late JOL effect observed in Experiments 1 and 2 could be interpreted as reflecting a CNV potential, however this interpretation is dependent on the pattern of reaction times at study matching the pattern of the effect; the largest differences in the CNV potential should be present between conditions which show the greatest differences in reaction times. Looking at the reaction times across Low, Medium and High JOL (Figure 6.13), however, it is clear that the difference is largest between Medium JOL and High JOL. An ANOVA comparing the reaction times for all three conditions revealed a significant main effect of JOL [$F(2,46) = 4.2$, $p < 0.05$]. Post hoc comparisons revealed a marginally significant difference between High and Medium JOL ($p = 0.05$). By contrast, looking at the ERPs for the same three conditions (see Figure 6.10 above), the biggest difference in this case is between Low JOL and the two remaining conditions. This observation makes a CNV interpretation of the late JOL effect very unlikely.

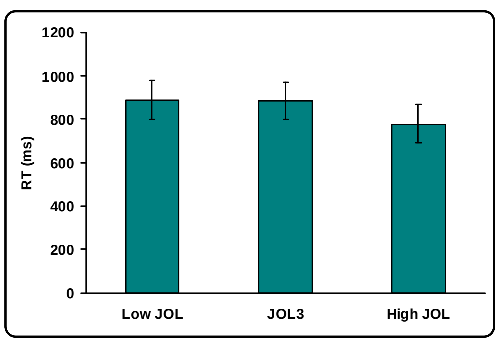

Figure 6.13 Reaction times across JOL.
Mean (and S.E.) reaction times for making Low, Medium and High JOLs at study.

6.4.6. JOL ERP Effects without Memory Confounds

As previously stated, the statistical comparison between subsequent memory and JOL effects is inherently confounded due to some overlap in the trials which contribute to each ERP contrast. To be able to investigate JOL effects in the absence of memory, we extracted ERPs elicited by high and low JOL responses from a subset of trials that exclusively included subsequent hits. If the JOL effects characterised above are still evident in this subset, this provide reason to conclude that the effects are reasonable representation of the neural activity associated with JOL ratings that are not obscured by collapsing trials that were both subsequently remembered and forgotten[9].

The topographic maps displaying the JOL effects are provided in Figure 6.14. The early JOL effect is characterised by an increase in positivity for high JOL items relative to low JOL items and this difference is widespread but with a focus over posterior electrode sites closest to the midline. The late JOL effect, by contrast, is associated with an increase in negativity for high JOL items relative to low JOL items and this difference is also largest on posterior electrode sites closest to the midline. Overall, this pattern of effects appears to correspond well to the JOL effects described in the above sections.

For the 550 to 1000 ms time window ANOVA revealed a significant main effect of condition [$F(1,23) = 13.2$, $p < 0.01$] and an interaction between condition and site [$F(1.2,26.9) = 13.9$, $p < 0.01$]. The analyses confirm that the early JOL effect is largest at electrode sites closest to the midline. For the JOL effect present in the 1300-1900 ms ANOVA revealed a significant main effect of condition [$F(1,23) = 10.5$, $p < 0.01$] and a significant interaction between condition and site [$F(1.2,26.5) = 12.9$, $p < 0.01$]. These analyses confirm that the ERPs elicited by items assigned

[9] Ideally a comparable analysis of SM effect should be carried out within either Low or High JOL items to allow an examination of SM effect without JOL confounds, however this analysis was not possible due to insufficient trial numbers in the subsequent missed condition.

High and Low JOLs differ primarily on electrode sites that are closest to the midline. The JOL effects without memory confounds are remarkably similar to the original effects that included both subsequently missed and remembered items.

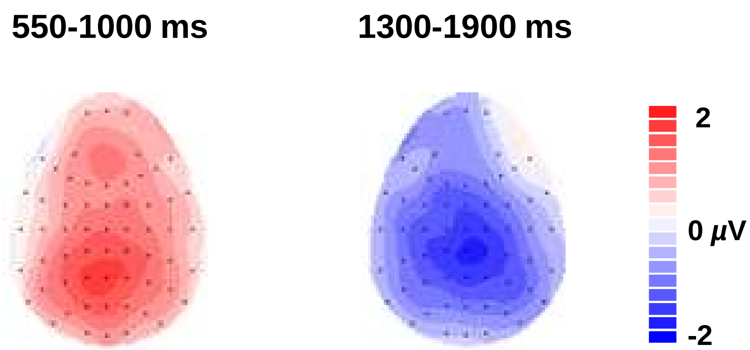

Figure 6.144 Distribution of the JOL effects without memory confounds.

6.5. Discussion

The second of the experiments reported in this thesis examined the relationship between JOLs and memory encoding in a similar way to Experiment 1, however rather than sorting the trials included in the memory encoding contrast based on subsequent cued recall, the trials were sorted based on subsequent recognition. Altering the test requirements did not produce noticeably different ERP correlates of subsequent memory, but the experimental manipulation did, however ensure an increase in the trials that contributed to the SM contrast and the ERPs are considerably cleaner in comparison to those from Experiment 1. In addition, the JOL effect could be analysed within trials that only included subsequent hits allowing the examination of JOL effects without memory confounds. These analyses revealed a similar pattern of effect to the original effect that included both subsequently missed and remembered items suggesting that the observed JOL effects are genuine. The ERP data in Experiment 2 were analysed using the same two time windows as the data from Experiment 1: early (550-1000 ms) and late (1300-1900 ms). Findings for each time window are discussed in turn.

6.5.1. Early Time Window (550-1000 ms)

Similar to the findings from Experiment 1, the SM effect in Experiment 2 is characterised by an increase in positivity for subsequently recognised relative to subsequently missed items. In experiment 2, however, the effect did not have as clear a posterior focus, but rather seemed to exhibit two peaks – one at midline frontal electrode sites and one at midline parietal electrode sites. Although it is possible that this pattern reflects the existence of two separate effects, statistical analyses did not, however, verify the presence of two peaks. Backsorting study trials based on subsequent recognition rather than cued recall therefore seems not to have produced qualitatively different SM effects across Experiment 1 and 2.

The early JOL effect found in Experiment 2 also strongly resembles the pattern of activity observed in Experiment 1; items assigned high JOLs showed a clear increase in positivity relative to items assigned low JOLs. Unlike the SM effect, the maximum amplitude was recorded at posterior electrode sites, but statistical analyses did not establish a reliable interaction between condition and location (as in Experiment 1).

In the discussion section of Chapter 5 three possible interpretations of the early effects were outlined: i) the effects reflect a ‘pure’ measure of successful memory encoding, ii) the effects reflect a ‘pure’ measure of JOL, and finally iii) the effect is a product of a interaction between JOL and encoding (i.e. JOL-specific encoding strategies). Given the similar pattern of results, Experiment 2 does not provide much additional evidence in favour of any one of the theories. The present data do, however, provide a more fine-grained analysis, demonstrating that the ERP for Medium JOL responses lies between the High and Low JOL ERPs, revealing a clear correlation between the JOL rating and the magnitude of the early JOL effect.

In both Experiments 1 and 2 there are clear increases in memory performance as JOL ratings get higher. For that reason it remains impossible to determine whether the modulation of the JOL effect is a direct consequence of the JOL ratings or simply reflect an increase in the proportion of recognised trials. Again, however, if the JOL effect is primarily driven by successful encoding operations, it is reasonable to expect it to be smaller in comparison to the SM effect. As in Experiment 1, however, a visual inspection of the SM and JOL effects from Experiment 2 gives the impression that the JOL effect is larger in magnitude than the SM effect. Although visual inspection does not provide strong evidence that the early effect is at last partly related to JOL processes, the consistency of this observation across two experiments makes it hard to argue that successful encoding processes exclusively give rise to the early positivity.

One way to further investigate the functional significance of the early effect is to replicate the present experiment without JOL instructions; if successful encoding in the absence of the explicit requirement to make JOLs produces effects that are comparable to those observed in Experiments 1 and 2, it would imply that JOLs themselves are not necessarily causing the early effects seen in Experiments 1 and 2. On the other hand, if the SM effect turns out to be qualitatively different, this would imply that JOLs were at least partly responsible for the effects.

6.5.2. Late Time Window (1300-1900 ms)

Experiment 2 replicated the findings of Experiment 1; there were no significant SM effects in the late time window, but there was clear evidence of a negative-going JOL effect with a centro-parietal maximum. Unlike the late JOL effect in Experiment 1, however, this effect was not left-sided, but focussed instead on midline electrodes. Follow-up analyses of the data suggest that this difference in topography is the result of counterbalancing the rating scale. Since the distribution of the late JOL effect seems to be dependent on the choice of response hand, this raised the concern that the effect reflects response preparation (i.e. CNV) rather than JOL-related processes per se. When ERPs elicited by Medium JOL items plotted against Low and High JOL items, it was clear that High JOL and Medium JOL ERPs overlapped and differed significantly in amplitude from Low JOL items. By contrast, the largest difference in reaction time was between Low and Medium JOL items compared to High JOL items. It is therefore very unlikely that the late JOL effect is caused solely by response preparation processes.

The fact that the waveforms associated with Medium JOLs overlap with High JOLs in the late time windows is itself an interesting observation. The early JOL effect showed a graded increase; the higher the JOL rating the larger the amplitude of the effect. Why then does the late JOL effect not display a similar pattern? One possibility is that the early effect reflects processes involved in determining JOL responses, whereas the late JOL effect reflects processes that work on the product of the JOL decision. These components of processing correspond to what Nelson & Narens (1990) refer to as *monitoring* and *control* in their theoretical framework for metacognition (see Chapter 1). Although this interpretation does not provide a simple answer to why low JOL items should be processed differently from High JOL and Medium JOL items, one speculation is that when memorability is judged as low (as opposed to high or ‘uncertain’) participants engage in specific control strategies to compensate for poor learning. Although examinations of Medium JOL activity do not provide comprehensive insights into the functional significance of the early and late JOL effects, their outcomes are consistent with the view that these effects are functionally distinct (because only the early effect is clearly graded). This claim could not have been supported with the same degree of confidence based on the data from Experiment 1 alone.

6.6. Summary and Conclusion

Experiment 2 further investigated the correspondence between the neural correlates of successful memory encoding and JOLs by altering task instructions at test. As in Experiment 1, a positive-going effect shared by SM and JOL was evident in an early time window. This effect seemed to be modulated by the JOL ratings; higher

JOL resulted in an increase in positivity. The primary purpose of altering test instructions at test was to provide an alternative basis upon which encoding trials could be sorted. Successful encoding defined as successful recognition did not, however, produce effects that differed noticeably from successful encoding defined as successful cued recall. In a later time window there was only evidence for a negative-going JOL effect distinguishing High and Medium JOL items from Low JOL items. Overall, the findings from Experiment 2 replicate and extend the findings from Experiment 1, which suggested that there are associations as well as dissociations between the neural systems that mediate successful memory encoding and JOLs.

Chapter 7.

Learning without Judgments of Learning

7.1. Introduction

Experiments 1 and 2 established that Judgments of Learning are associated with neural correlates that are partly overlapping and partly distinct from that of successful memory encoding. The overlapping deflection, a relatively early effect occurring between 550 and 1000 ms post-stimulus presentation, is characterised by an increase in positivity for high JOL items relative to low JOL items and for recognised items relative to missed items. Why this effect is present in both the JOL and memory contrast is unclear. It is possible that the effect is driven primarily by processes supporting successful memory encoding and is therefore only visible in the JOL contrast due to the inevitable correlation between JOLs and SM performance. It is equally possible, however, that the effect is purely JOL related and this interpretation is supported by the observation that the JOL effects have been visibly larger than the SM effect across the two preceding experiments. A third possibility is that the early positive-going effect arises when JOLs and encoding co-occur.

This latter interpretation is resting upon the assumption that JOLs directly influence processes which determine the probability of future remembering of the material under study. Explicitly, the question concerns the existence of JOL-specific SM effects. A number of studies have established that the neural correlates of successful memory encoding are influenced by the choice of encoding task. For example, Otten & Rugg (2001a; see Chapter 3) found qualitatively different SM effects for animacy and alphabetic encoding tasks. Otten & Rugg (2001a) identified three time windows that were submitted for analyses: 0-350 ms, 550-1000 ms and 1300-1900 ms post-stimulus. For the animacy task, the first time window revealed a left frontal focus, the second a fronto-central focus and the third time window showed again a left frontal focus. All effects were characterised by an increase in positivity for recognised relative to missed items. For the alphabetic task, the focus of the effects was restricted to centro-parietal recording sites and this effect was characterised by an increase in negativity for recognised relative to missed items.

Although it is unclear what the different topographies of SM effects reflect, it has been speculated whether frontal effects are associated with ‘deep’ encoding and posterior effects with ‘shallow’ encoding. Fernandez et al. (1998) found effects with centro-parietal focus when their participants were instructed to avoid elaborate encoding strategies. Comparably, encouraging participants to engage in elaborative encoding strategies have been found to suppress the centro-parietal effects in Von Restorff paradigms and generated frontal effects instead (Fabiani et al., 1990; Karis et al., 1984; see Chapter 3).

The ERP findings outlined above are accompanied by several findings of task-specific SM effects from fMRI experiments (Baker, Sanders, Maccotta & Buckner 2001; Fletcher, Stephenson, Carpenter, Donovan & Bullmore, 2003; Otten, Henson & Rugg, 2002; Otten & Rugg, 2001b; Park, Uncapher & Rugg, 2008). Given this growing body of evidence, the conception of JOL-specific encoding effects is not unlikely. One way of investigating this possibility is to examine the neural correlates of successful encoding of the stimuli set from Experiments 1 and 2 having removed any requirements to make JOLs. This is the primary aim of Experiment 3. If the SM effects that arise under no-JOL conditions are the same as the effects that arise when JOLs are being made, this observation would support the encoding interpretation of the early effect. If, on the other hand, the effects from Experiment 3 are qualitatively different from those from Experiments 2[10], this suggests that JOLs are at least partly responsible for the overlapping deflection.

7.2. Method

Participants included 29 students at the University of Stirling. Two participants were excluded due to equipment failure or excessive EEG artefacts, and three due to poor performance. The remaining 24 participants (19 female) had a mean age of 21 (range: 17-34).

Stimulus materials and experimental procedure conform to that outlined in Chapter 4 and the behavioural paradigm is schematically illustrated in Figure 7.1. Grand

[10] The experimental paradigm in Experiment 3 is identical to that of Experiment 2 (except from the removal of the JOL instruction). For that reason the results from Experiment 3 will mainly be compared to that of Experiment 2 rather than Experiment 1 which employed a cued recall task at test.

average ERP waveforms were formed for the following response categories: Hits (items subsequently recognised as old) and Missed (items judged incorrectly as being new). Mean numbers of trials were 156 and 80 for Hits and Missed categories respectively.

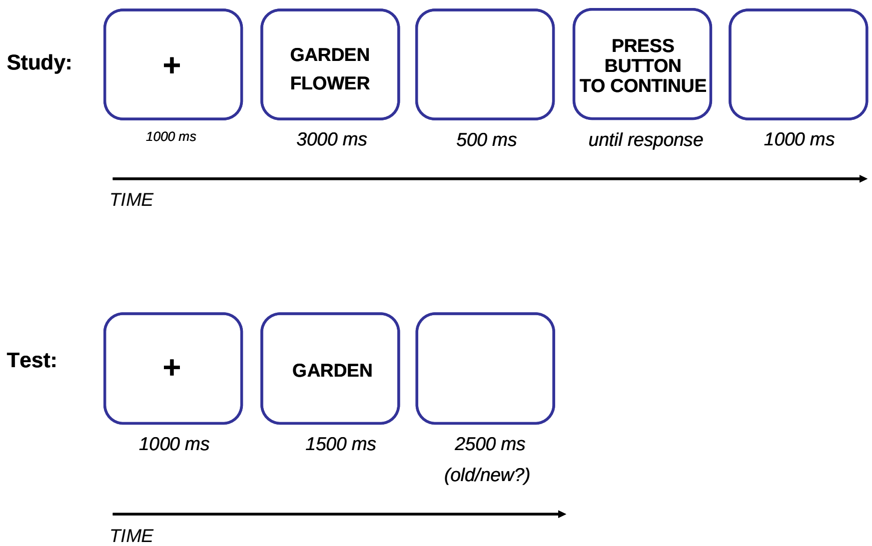

Figure 7.1 The experimental paradigm used in Experiment 3.
At study, participants saw a number of word pairs (a cue presented above a target). Rather than making a JOL, they were instructed to press a button (either 2 or 4) to initiate the next trial. At test, participants saw each of the upper words intermixed with a number of new words and were required to make an old/new recognition judgment.

7.3. Behavioural Results

7.3.1. Test

Overall recognition responses are shown in Figure 7.2. Although participants in Experiment 3 are still correctly rejecting new items at a rate comparable to Experiments 1 and 2, the overall hit rate is considerably lower.

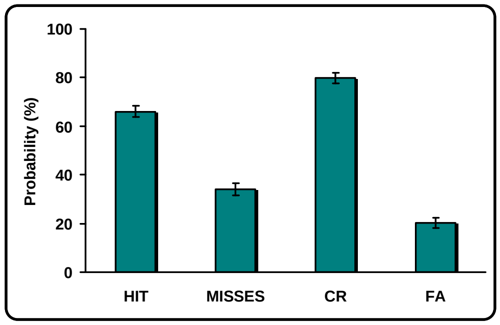

Figure 7.2 Behaviour at test.
Mean (and S.E.) recognition responses for each response category at test.

7.4. Event-Related Potential Results

The initial ERP analyses comprised assessments of the study phase ERPs; SM *effects*: study ERPs separated according to memory accuracy at test (Hits versus Missed; Figure 7.3).

For comparison purposes, the same time windows that were chosen in Experiment 1 and 2 (550 to 1000 ms post-stimulus presentation and 1300 to 1900 ms post-stimulus presentation) were used for analyses of the SM effects in the present experiment. Additional analyses are reported at the end of the result section using an alternative time window that appears to better fit the time course of the effect. The SM effect in Experiment 3 is rather characterised by widespread frontal positivity that is relatively long-lasting. As in Experiment 1 and 2, data were analysed using ANOVA with factors of category (Hits versus Missed), location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and electrode site (superior, mid, inferior).

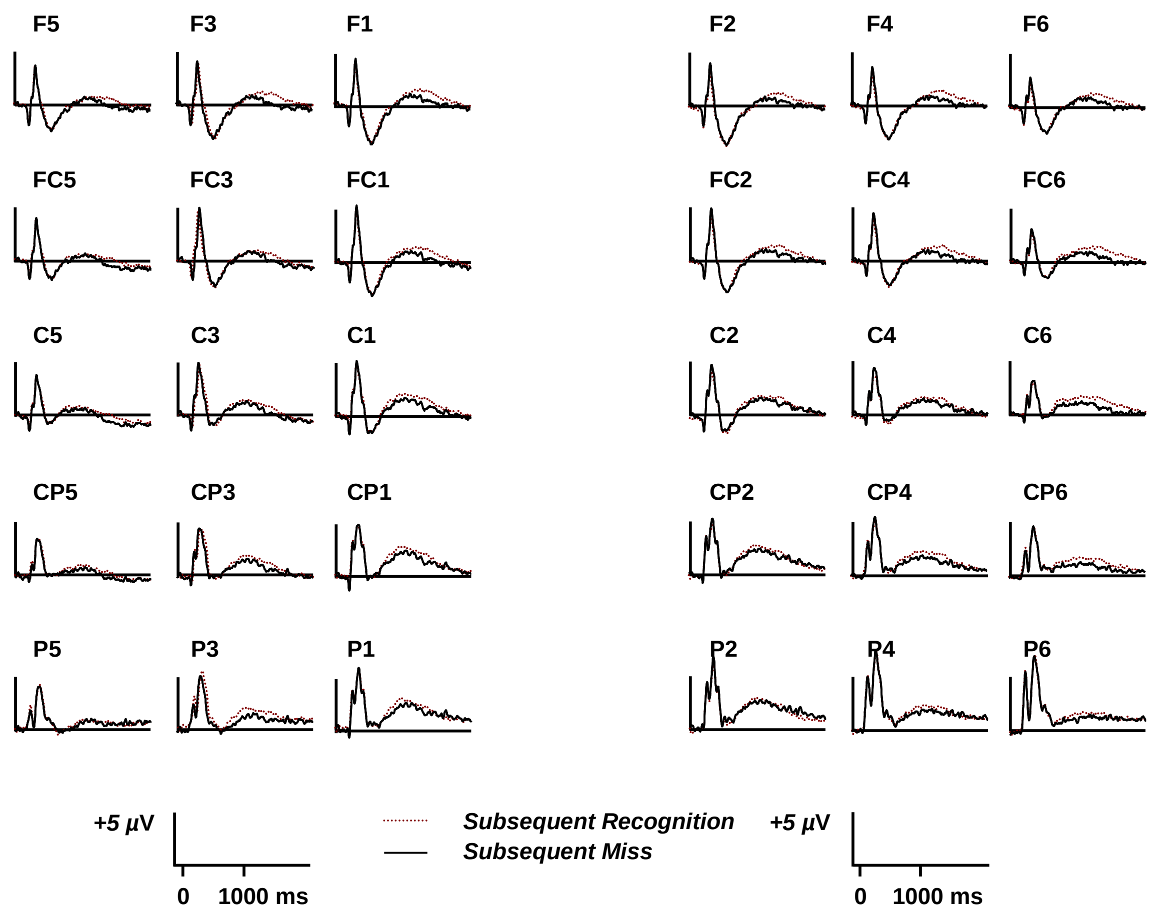

Figure 7.3 SM effects.
Grand average ERPs for subsequently Missed (black lines) and subsequently recognised items (red dotted lines).

7.4.1. SM Effects

Waveforms for subsequent Hits and subsequent Misses are shown in Figure 7.3 at electrodes included in the analyses. For both the the 550 to 1000 ms and 1300-1900 ms time windows the ANOVAs did not reveal any significant main effects or interactions (all Fs < 2.0).

7.4.2. Additional Analyses of the SM Effects

Visual inspection of the waveforms suggest that the time windows chosen for analyses in Experiment 1 and 2 do not correspond to the time course of the SM effects observed in the current experiment. Closer examination of the effects gives the impression that the effects comprise of one long-lasting and relatively widespread effect rather than two separate effects. Complementary analyses were therefore carried out using a 1000-2000 ms time window. The outcome of these additional analyses is reported below.

For the 1000-2000 ms time window the initial ANOVA revealed only a significant main effect of condition [$F(1,23) = 5.7$, $p < 0.05$] indicating that the effect is broadly distributed with a focus over right-frontal electrode sites (see Figure 7.4).

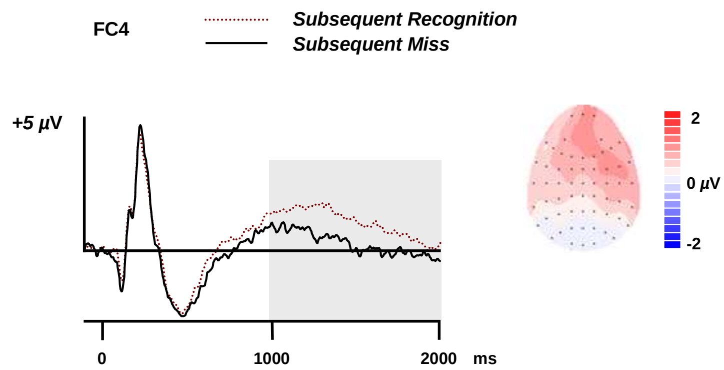

Figure 7.4 SM effect at FC4.
The topographic map illustrates the scalp distributions of the SM effect (subsequent recognition minus subsequent Miss) over the 1000-2000 ms time window.

7.4.3. Analyses of Scalp Distributions: comparing SM effects from Experiments 2 and 3

Scalp distribution analyses were carried out to establish whether or not the SM effects from Experiments 2 (550-1000 ms) and 3 (1000-2000 ms) are topographically distinct using ANOVA with factors of Experiment (2,3), location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and site (superior, mid, inferior). ANOVA revealed a significant interaction between Experiment and site [$F(1.2,53.2) = 7.1$, $p < 0.01$], reflecting that the early SM effect from Experiment 2 was largest on the midline electrodes, whereas this was not the case for the later SM effect from Experiment 3. The reliable interaction that was revealed in the analyses indicates that the two SM effects are produced by different sets of neural generators.

One concern regarding the different time courses and distribution of the SM effects across Experiment 2 and 3 was how performance was considerably lower in the latter case. To investigate whether poorer discrimination could be the primary cause for the differences in activity, ERPs were formed for a subset of participants (N = 8) for whom performance was matched to that of Experiment 2 (Figure 7.5). If the difference in SM effects across Experiments 2 and 3 is performance related, then the performance matched subset from Experiment 3 should show SM effects that are similar to those observed in Experiment 2. Due to the low sample size, no statistical analyses on behavioural or ERP data were carried out.

As can be seen from the waveforms and scalp maps provided in Figure 7.6, there is no indication of an early posterior SM effect. In the later time window, on the other hand, there is an indication of a positive effect present over right-frontal electrode sites. This effect seems to resemble the effect that is present for the full sample and shown in figure 7.3 above.

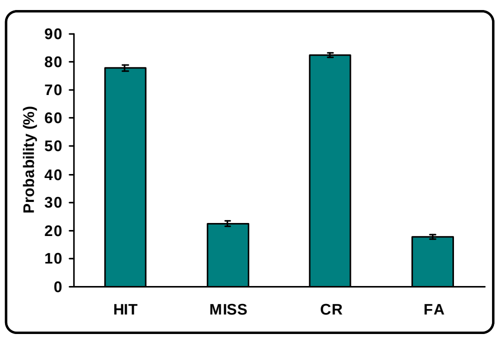

Figure 7.5 Behaviour at test for subset of participants.
Mean (and S.E.) recognition responses for each response category at test for subset of participants (N=8) performance matched to Experiment 2.

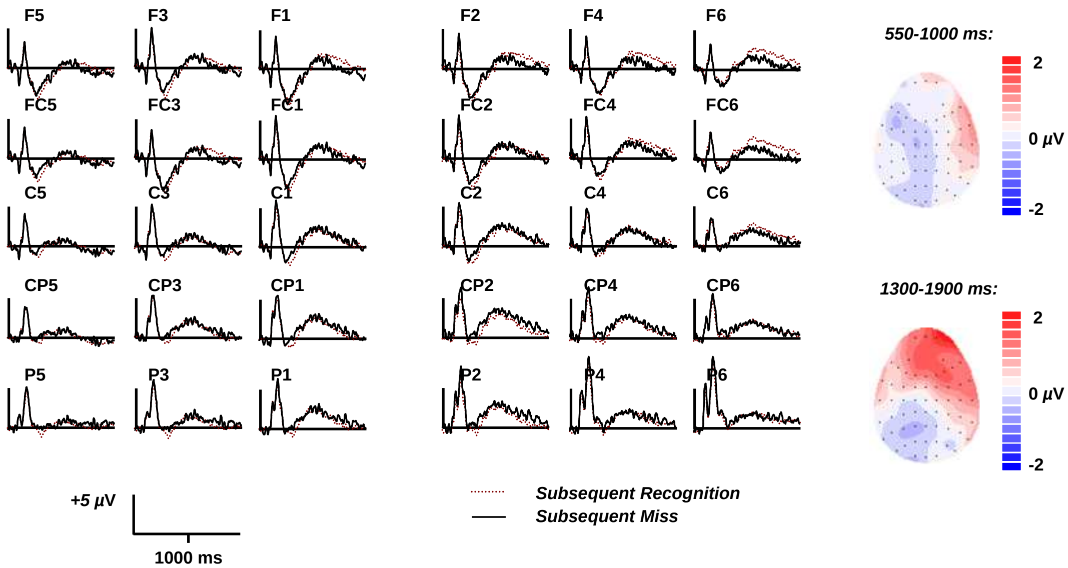

Figure 7.6 SM effects for a subsample of 8 participants.
The waveforms represent subsequently Missed (black lines) and subsequently Recognised items (red dotted lines). The topographic maps illustrate the scalp distributions of the effects (subsequent recognition minus subsequent Miss) over the 550-1000 ms (upper map) and 1300-1900 ms (lower map) time windows.

7.5. Discussion

Experiment 3 investigated the characteristics of SM effects elicited when JOLs are not required. Except from the JOL instructions provided at study, all experimental parameters were kept the same as for Experiment 2. When no JOLs were required, overall memory performance was considerably lower and ERP effects were widespread but most prominent over right-frontal recording sites. Although the SM effects from Experiment 2 were also relatively widespread, the focus was on midline electrodes and the effect was largest on fronto-central electrode sites. The time-course of the SM effect from Experiment 3 also differed from those of Experiment 2; no effects were present in the 550-1000 ms and 1300-1900 ms time windows that were chosen for analyses in Experiments 1 and 2. Instead, a long-lasting effect was present from 1000 ms which lasted throughout the remaining

1000 ms of the recording epoch. This effect was topographically distinct from the effect observed in Experiment 2.

Comparing ERP effects across experiments for which performance is not matched is not without complications because it is possible that the difference in SM effects is simply reflecting poorer discrimination in one experiment relative to the other. However, it is reasonable to assume that the neural correlates of successful memory encoding should be weaker in the experiment with worst performance because relatively fewer trials are likely to reflect veridical subsequent recollection (Park, Uncapher & Rugg, 2008). Since the effects from Experiment 3 do not seem to be weaker versions of the effects from Experiment 2, it is likely that the apparent discrepancies are caused by qualitative differences in cognition. The data points for the subset of participants with higher performance scores support this understanding as they showed the same pattern of ERP effects as the full sample from the same experiment. Hence, removing JOL instructions at study seems to have resulted in qualitatively different SM effects. This is a finding which adds to the growing body of evidence suggesting that successful memory encoding is supported by multiple neuronal systems (Rugg, Otten & Henson, 2002).

SM effects have been found to vary across experiments and they are frequently divided into two subtypes: frontal and centro-parietal effects. It is unclear what the differences in topography signify, but some researchers have speculated whether frontal effects are associated with elaborative encoding strategies whereas centro-parietal effects are reflecting rote learning strategies (Fabiani et al., 1990; Fernandez et al., 1998; Fernandez & Tendolkar, 2001; Karis et al., 1984). Although the SM effects from the preceding JOL experiments were relatively widespread, Experiment 1 nevertheless had a posterior maximum. The case of Experiment 2 is slightly more complicated as it seemed to exhibit two separate maxima. Although the frontal ‘peak’ was slightly greater than the posterior ‘peak’, this difference was minimal and therefore it is difficult to determine which category of SM effects this effect belongs to.

Assuming that frontal SM effects do in fact reflect elaborative encoding and that posterior effects reflect rote memorisation, the pattern of effects across Experiment 1, 2 and 3 becomes difficult to interpret. Assessing memorability of study items presumably involves some level of sophisticated processing (which was reflected in the enhanced memory performance of Experiments 1 and 2 relative to Experiment 3). It is well established that elaborative strategies (deep encoding) are associated with increased memory performance relative to rote learning (shallow encoding; see Craik & Lockhart, 1972) and therefore the experiment exhibiting frontal effects should also produce the highest memory score. Instead, memory performance in Experiment 3 is dramatically lower compared to Experiments 1 and 2, which both exhibit SM effects extending to posterior electrode sites. Similarly, it is difficult to comprehend why making JOLs should encourage rote memorisation strategies. One possibility is that the functional distinction between frontal and posterior effects needs to be reconsidered. Alternatively, the frontal deflections of the SM effects from Experiments 1 and 2 are reflecting elaborative encoding while the posterior deflection is JOL-specific and unrelated to previously observed SM effects with posterior maxima (Besson & Kutas, 1993; Fernandez et al., 1998; Neville et al. 1986; Paller et al., 1987; Sanquist et al., 1980; Van Petten & Senkfor, 1996).

One interesting observation in relation to the discrepant performance scores across Experiments 2 and 3 is that even the performance on the lowest JOL items from Experiment 2 are overall better remembered compared to items from Experiment 3 (Figure 7.7). Making JOLs, therefore, seem to successfully boost *overall* recognition rates, and this observation undeniably highlights the effectiveness of JOLs as encoding task.

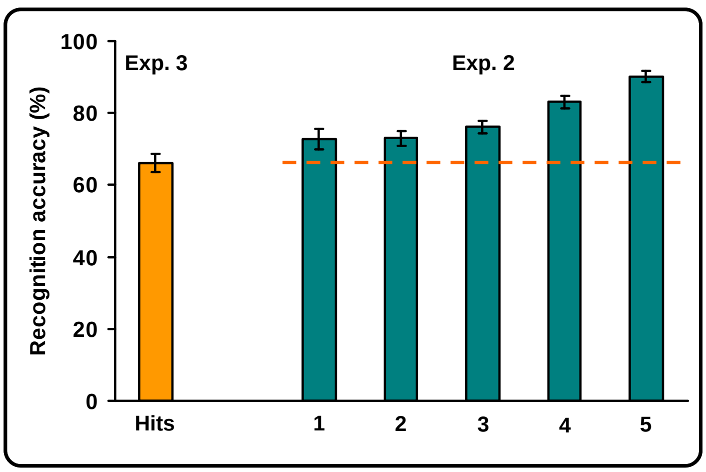

Figure 7.7 Comparison of behavioural performance from Experiments 2 and 3.

Concerning the relatively low memory score from Experiment 3, it is important to note that Experiment 2 and 3 differ in one additional important aspect; whereas making JOLs could be considered the encoding task of Experiment 2, this task has been removed in Experiment 3, and consequently one is comparing conditions in which a specific encoding strategy was and was not encouraged. The second step in establishing the existence of JOL-specific encoding effects is therefore to compare the results from Experiments 2 and 3 to an experiment in which JOL instructions have been replaced with alternative encoding instructions. This would be an interesting next step to take to investigate the interaction between actual and predicted encoding success (however not a topic covered further in this thesis).

7.6. Summary and Conclusion

The primary aim of Experiment 3 was to investigate the nature of SM effects when JOLs are not required. Both Experiments 1 and 2, which required JOLs to be made at study, produced similar SM effects characterised by an increase in positivity for remembered relative to forgotten items during 550 and 1000 ms post-stimulus presentation. The effects were widespread but with a focus on midline electrode sites. When the prompt to make JOLs was replaced by a prompt to press a button to continue, a long-lasting SM effect was present from 1000 ms post-stimulus until the end of the recording epoch. This effect was also positive-going, but exhibited a right-frontal focus. The different time course and scalp distribution of the SM effect from Experiment 3 indicate that removing the requirement to make a JOL result in qualitatively different correlates of successful memory encoding.

Chapter 8.

Judgments of Learning and Material Specificity

8.1. Introduction

The previous JOL experiments reported in this thesis (Chapters 5 and 6) employed an identical study paradigm and only differed in the memory assessments made at test. For that reason, it is perhaps unsurprising that the effects are remarkably similar. To comprehensively investigate the robustness and generality of SM and JOL effects it is therefore necessary to examine their appearances under a range of different circumstances. The purpose of Experiment 4 is to investigate whether or not the consistent JOL-specific effects that have been observed across two experiments using verbal material will remain present when the material is pictorial.

Kao et al. (2005) have provided fMRI evidence suggesting that JOL-specific activity is present when participants make JOLs for pictures of indoor and outdoor scenes, however their findings do not guarantee observable ERP effects for the same set of stimuli (as discussed in Chapter 2). Also, the previous fMRI study does not provide any information regarding the nature of this effect compared to the effects from Experiments 1 and 2. The only way to assess material specificity is to employ the same imaging technique whilst investigating JOLs to both kinds of stimuli. Experiment 4 therefore uses the pictures employed by Kao et al. (2005) in addition to single item words (in a separate block) to allow a comparison of ERP JOL effects elicited by verbal and pictorial material.

Experiment 4 comprised two separate within-subject design blocks, employing single pictures and words as stimuli respectively. In addition, the JOL made in Experiment 4 differed from that in Experiments 1 and 2. By necessity, JOLs made for single item stimuli must indicate the probability of future recognition rather than cued recall (which was the case in Experiments 1 and 2). Although the primary aim of the present investigations was to compare single item words and pictures, a secondary aim was to compare the consequences of using single item words as opposed to pairs of words (as used in Experiments 1 and 2). Differences between experiments using pairs and single item words are likely to reflect differences in strategic processing since encoding of one item, rather than two, limits the use of certain encoding operations (e.g. conceptual binding) and the ERP correlates of encoding may be sensitive to this experimental manipulation.

Changing from pairs to single items also has potential consequences for the ERP correlates of the JOLs; since the JOLs in Experiment 4 reflect the likelihood of future *recognition* rather than *cued recall* (as the JOLs in Experiments 1 and 2) this could influence the choice of strategy underlying the JOL decision. Importantly, however, the limited brain imaging literature in this field means this change of strategies is much less certain. Whatever the outcomes of Experiment 4, the findings are likely to shed some light on the sensitivities (or lack thereof) of the effects reported in previous chapters. In sum, Experiment 4 has two main objectives: (i) to investigate potential differences in processing between single item words and single item pictures and (ii) to investigate potential differences in processing between the single item words and pairs of words (as revealed in Experiments 1 and 2).

8.2. Method

Participants were 38 students at the University of Stirling. Five participants were excluded due to equipment failure or excessive EEG artefacts, five due to ceiling performance in the word block, two due to insufficient trial numbers and two for not following instructions. The remaining 24 participants (14 female) had a mean age of 20 (range: 17-31).

Stimulus materials and experimental procedure conform to those outlined in Chapter 4 and the behavioural paradigm is schematically illustrated in Figure 8.1. Grand average ERP waveforms were formed for the following response categories for each experiment: Hits (items subsequently recognised as old), Misses (items judged incorrectly as being new), High JOL (study pairs assigned a JOL of 4 or 5) and Low JOL (JOL of 1 or 2). Study items attracting an ‘unsure’ JOL (3 response) were discarded due to insufficient trial numbers. Mean numbers of trials in the word block were 129, 41, 65 and 73 for the Hits, Misses, High JOL and Low JOL categories respectively and 94, 65, 54 and 75 in the picture block.

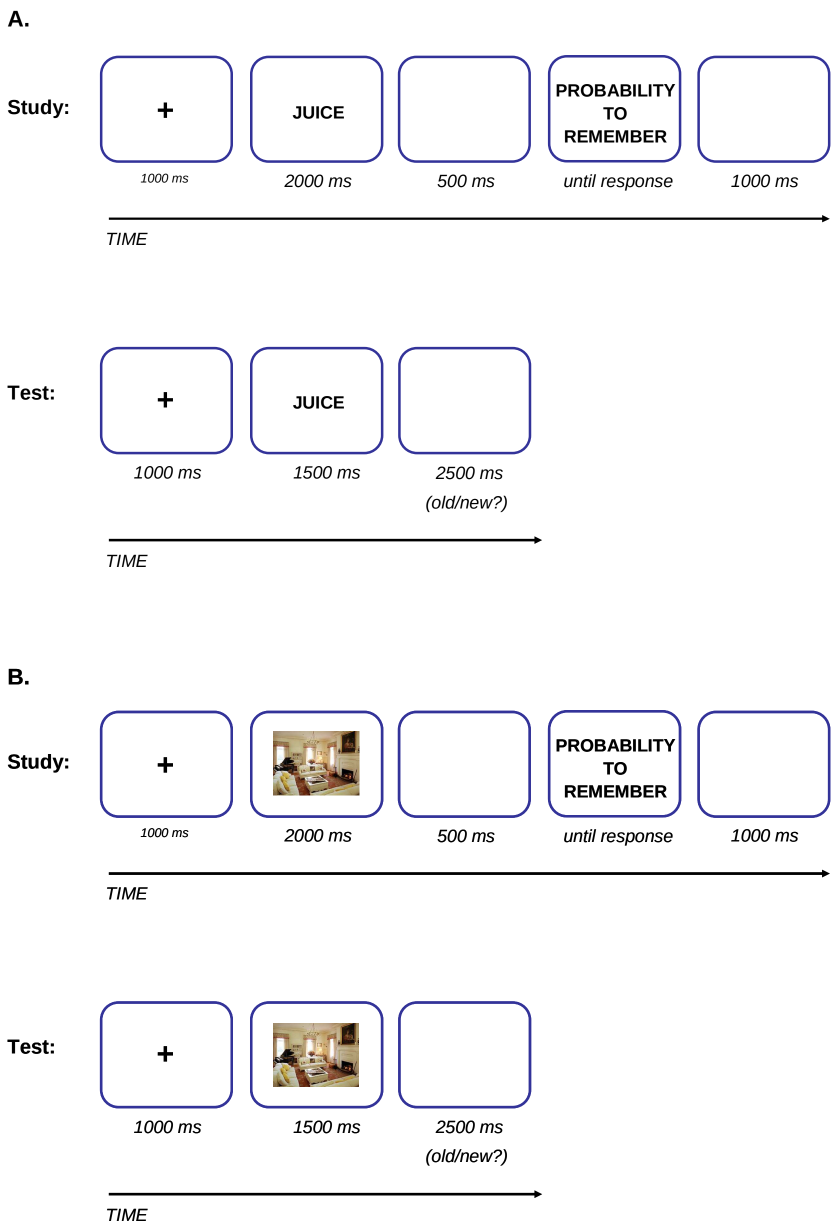

Figure 8.1 The experimental paradigms used in Experiment 4.
For the word block (panel A) participants saw a number of words and made a JOL for each. The JOL reflected how likely the participants believed they were to remember the word on a later test. The rating scale ranged from one (will definitely forget) to five (will definitely remember). At test, participants saw each word intermixed with a number of new words and were required to make an old/new recognition judgment. For the picture block (panel B), the procedure was identical except that participants viewed pictures of indoor scenes rather than words.

8.3. Behavioural Results

8.3.1. Word Block: Study

Response rates at study are shown in Figure 8.2a. ANOVA revealed a main effect of JOL [$F(4,88) = 20.3$, $p < 0.001$], with accompanying linear [$F(1,22) = 5.1$, $p < 0.05$] and quadratic trends [$F(1,22) = 27.9$, $p < 0.001$]. The pattern of reaction time (RT) for making JOLs at study formed the shape of an inverted "U" when plotted against each level of JOL (Figure 8.2b). ANOVA revealed a significant main effect of JOL [$F(4,88) = 3.0$, $p < 0.05$], exhibiting a quadratic trend [$F(1,22) = 14.6$, $p < 0.01$].

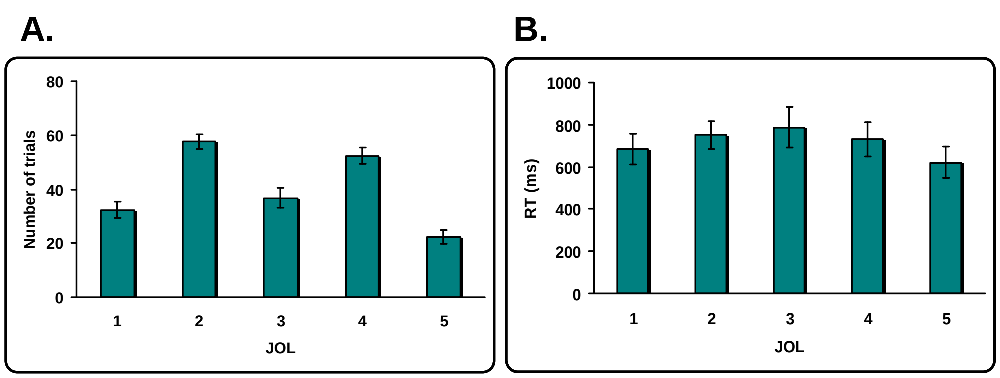

Figure 8.2 Behaviour at study.
Mean (and S.E.) number of trials assigned each JOL category at study (A) and mean (and S.E.) reaction times for making each level of JOL at study (B).

8.3.2. Word Block: Test

Overall recognition responses are shown in Figure 8.3a. Figure 8.3b shows the mean recognition accuracy for old items distributed across the levels of JOLs assigned at study. It is evident from the graph that recognition performance increased with increasing JOL and a repeated measures ANOVA confirmed that the effect of JOL was significant [$F(4,88) = 15.2$, $p < 0.001$], exhibiting a linear trend [$F(1,22) = 22.9$, $p < 0.001$]. The mean G score of 0.36 (SD = 0.12) was significantly above zero [$t(23) = 14.56$, $p < 0.001$]. Mean d_a was 0.53 (SD = 0.21) and was also signficantly above zero [$t(23) = 12.17$, $p < 0.001$]. Reaction times at test across JOL are shown in Figure 8.3c. ANOVA confirmed a main effect of JOL [$F(4,88) = 8.2$, $p < 0.001$], exhibiting linear [$F(1,22) = 16.8$, $p < 0.001$] and quadratic trends [$F(1,22) = 6.0$, $p < 0.05$].

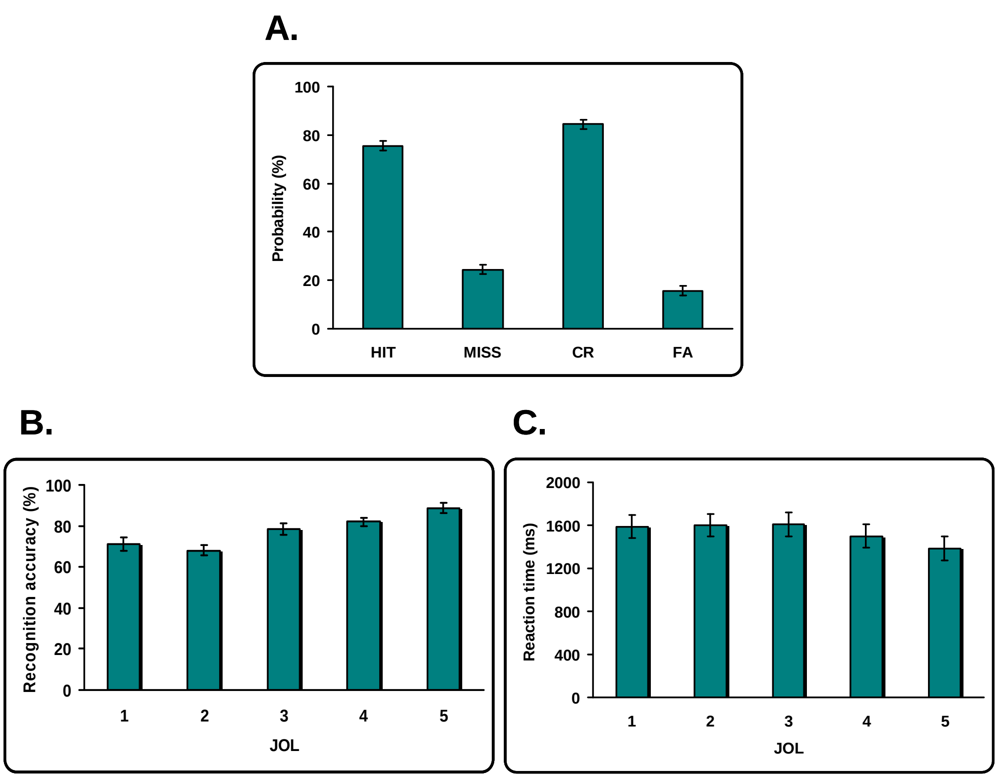

Figure 8.3 Behaviour at test.
Mean (and S.E.) recognition responses for each response category at test (A), recognition performance across JOL at test (B) and reaction time measured at test split according to JOL (C).

8.3.3. Picture Block: Study

Response rates at study are shown in Figure 8.4a. ANOVA revealed a main effect of JOL [$F(4,88) = 34.2$, $p < 0.001$], with accompanying linear [$F(1,22) = 22.0$, $p < 0.001$] and quadratic trends [$F(1,22) = 40.1$, $p < 0.001$]. Although the pattern of reaction time (RT) for making JOLs at study, measured across JOL, formed the shape of an inverted "U" as in the word block, (see Figure 8.4b) the ANOVA did not reveal a significant main effect of JOL ($F = 0.22$).

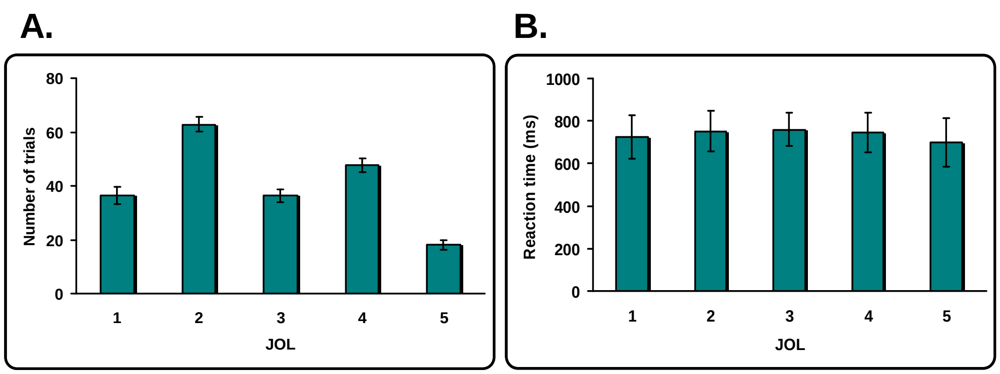

Figure 8.4 Behaviour at study.
Mean (and S.E.) number of trials assigned each JOL category at study (A) and reaction times for making each level of JOL at study (B).

8.3.4. Picture Block: Test

Overall recognition responses are shown in Figure 8.5a. Figure 8.5b shows the mean recognition accuracy for old items distributed across the levels of JOLs assigned at study. It is evident from the graph that recognition performance increased with increasing JOL and a repeated measures ANOVA confirmed that the effect of JOL was significant [$F(4,88) = 18.9$, $p < 0.001$], exhibiting linear [$F(1,22) = 21.3$, $p < 0.001$] and quadratic trends [$F(1,22) = 9.3$, $p < 0.01$]. The mean G score of 0.38 (SD = 0.12) was significantly above zero [$t(23) = 15.36$, $p < 0.001$]. Mean d_a was 0.56 (SD = 0.19) and was also signficantly above zero [$t(23) = 14.78$, $p < 0.001$]. The pattern of reaction times across JOL at test showed a linear development (Figure 8.5c). ANOVA confirmed that a main effect of JOL [$F(4,88) = 11.3$, $p < 0.001$] was accompanied by a linear trend [$F(1,22) = 14.4$, $p < 0.01$].

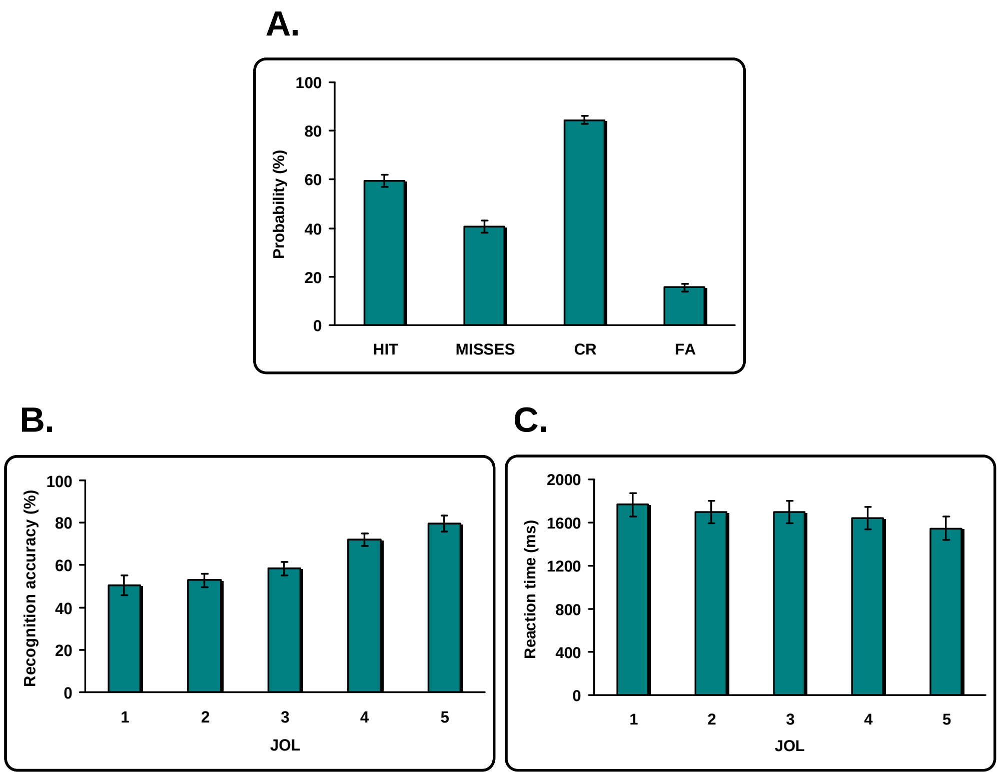

Figure 8.5 Behaviour at test.
Mean (and S.E.) recognition responses for each response category at test (A), recognition performance across JOL at test (B) and reaction time measured at test split according to JOL (C).

8.4. Event-Related Potential Results

As for Experiments 1 and 2, the initial ERP analyses comprised separate assessments of the study phase ERPs. First, *SM effects*: study ERPs separated according to memory accuracy at test (Hits versus Misses; Figures 8.6 and 8.8).

Second, *JOL effects*: ERPs associated with High or Low JOLs (Figures 8.7 and 8.9). Again, it is not possible to directly contrast these two effects as they contain overlapping subsets of trials.

Data were submitted to analyses for the same two time windows used in Experiments 1 and 2; 550 to 1000 ms post-stimulus presentation and 1300 to 1900 ms post-stimulus presentation. However, visual inspections of the waveforms strongly suggest that the timing of the effects in the current experiment does not fully match the timing of the effects in Experiments 1 and 2. For that reason alternative time windows were identified and additional analyses carried out. These are reported in a separate section of the current chapter (for the word block) and in Appendix B (for the picture block).

For each contrast, data were first analysed using ANOVA with factors of category (Hits versus Misses, High versus Low JOL), location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and electrode site (superior, mid, inferior) followed by five subsidiary analyses on each separate location when interactions involving location were evident. The outcomes of the subsidiary analyses for the early and late time windows are summarised in Tables 8.1-8.3. Analyses are reported separately for each experiment.

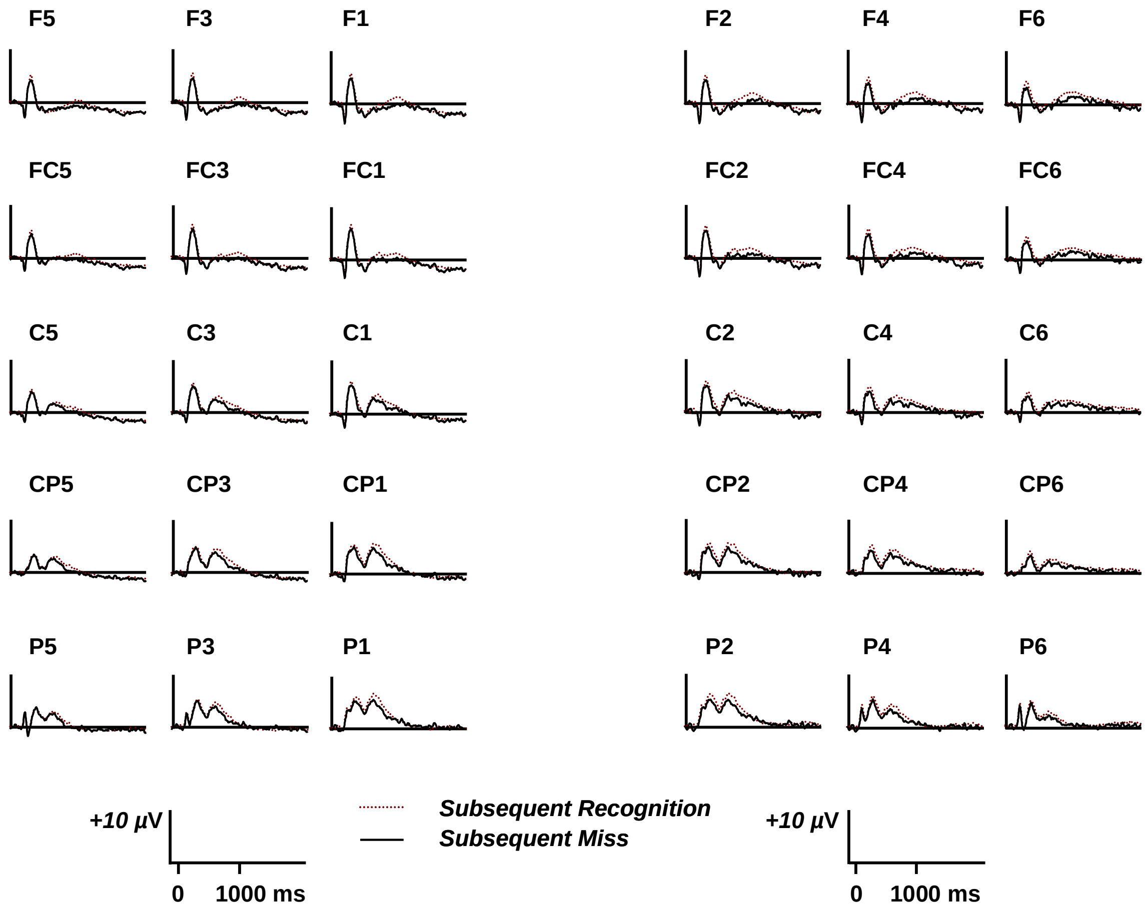

Figure 8.6 SM effects from the word block.
Grand average ERPs for subsequently missed items (black lines) and subsequently recognised items (Hits; red dotted lines).

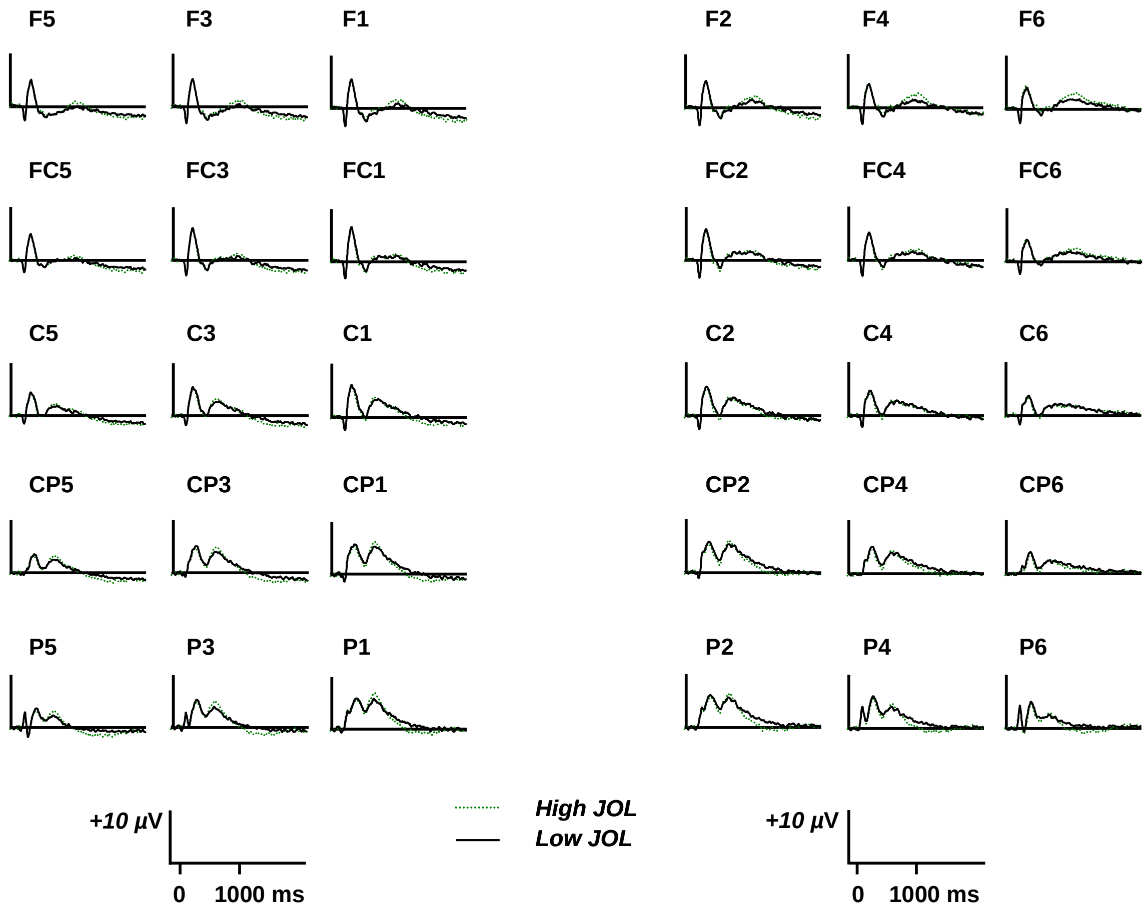

Figure 8.7 JOL effects from the word block.
Grand average ERPs for items assigned a low JOL (black lines) and items assigned a high JOL (green dotted lines).

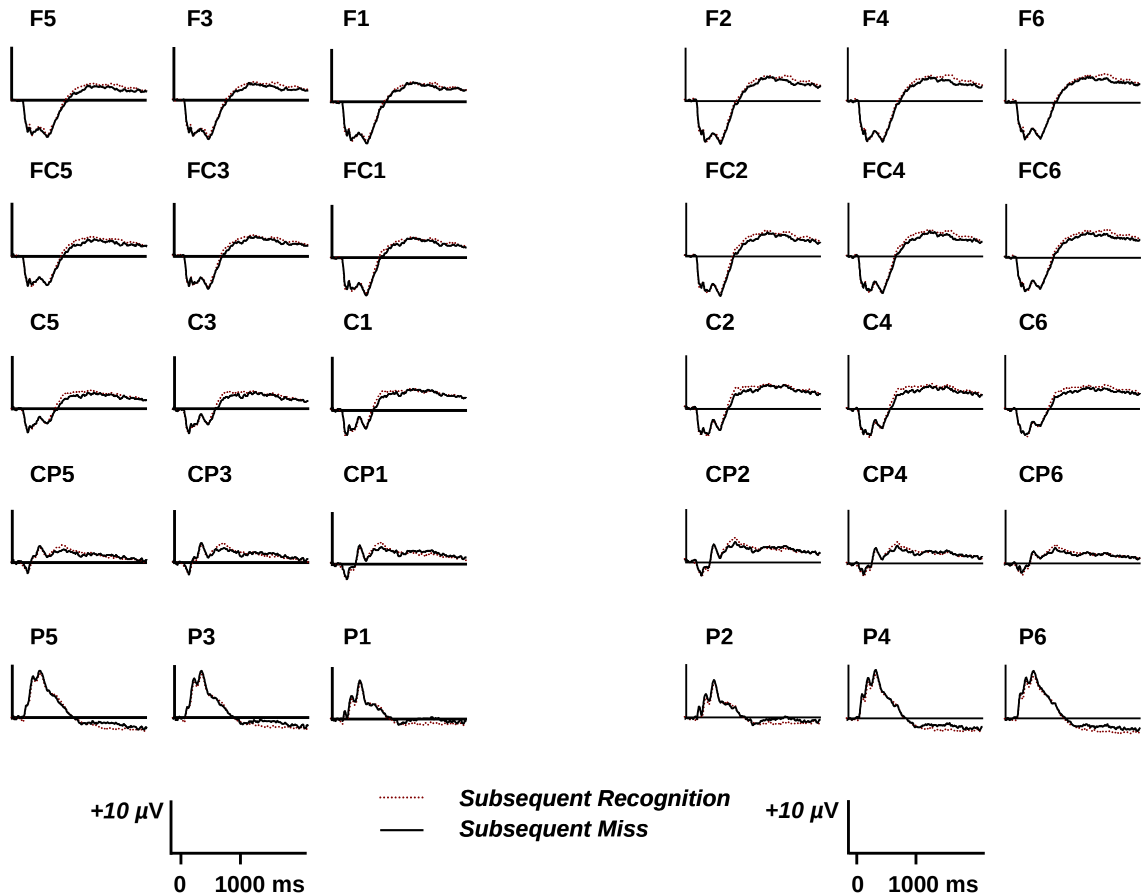

Figure 8.8 SM effects from the picture block.
Grand average ERPs for subsequently missed items (black lines) and subsequently recognised items (Hits; red dotted lines).

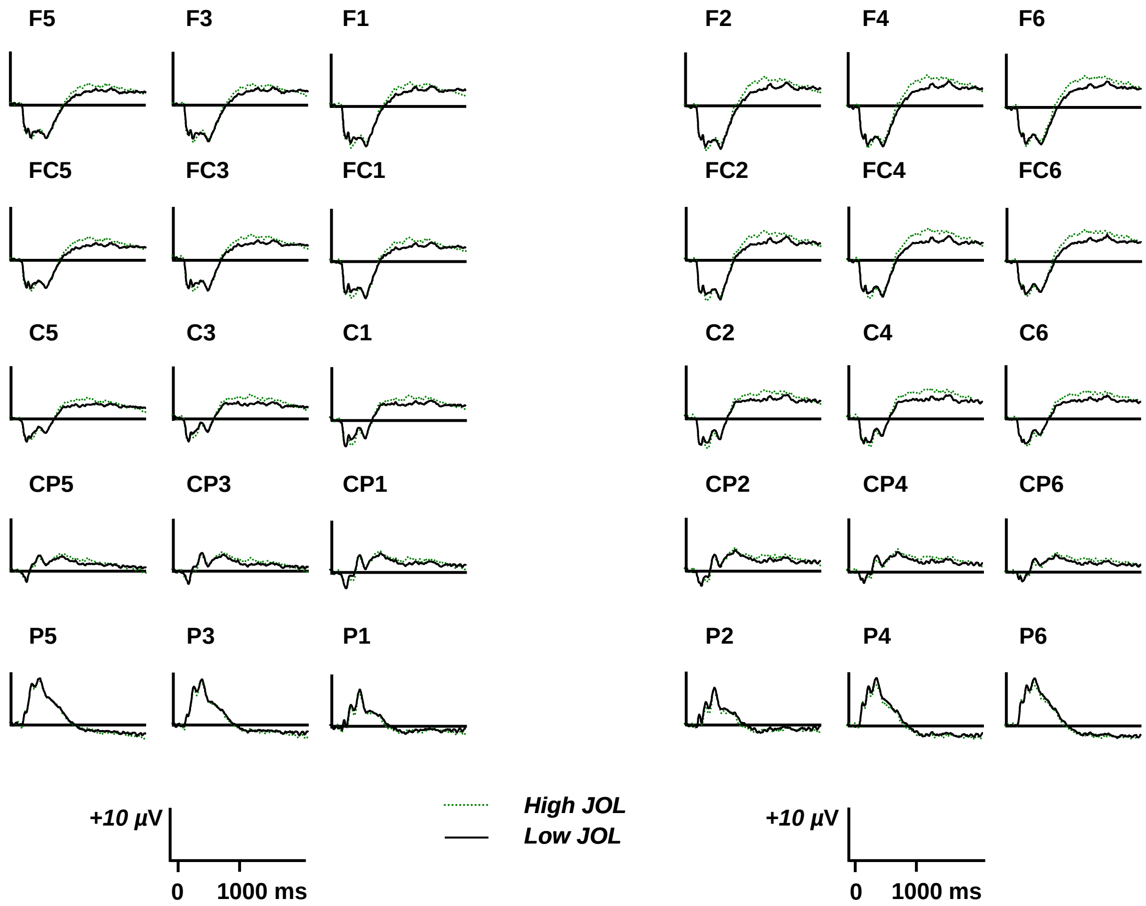

Figure 8.9 JOL effects from the picture block.
Grand average ERPs for items assigned a low JOL (black lines) and items assigned a high JOL (green dotted lines).

8.4.1. Word Block: SM Effects

Waveforms for subsequent Hits and subsequent Misses are shown in Figure 8.6 at electrodes included in the analyses. For the 550 to 1000 ms time window the outcome of the initial ANOVA was a significant main effect of condition [$F(1,23) = 8.3$, $p < 0.01$] reflecting a widespread increase in positivity for remembered relative to missed items with a focus over frontal electrode sites (see Figure 8.10).

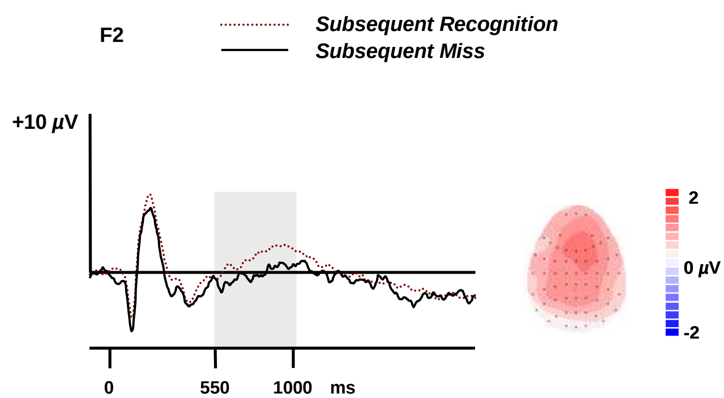

Figure 8.10 SM effect at F2.
The topographic map illustrates the scalp distributions of the SM effect (subsequent Hits minus subsequent Miss) over the 550-1000 ms time window.

For the 1300-1900 ms time window the initial ANOVA revealed a significant interaction between condition and hemisphere [$F(1,23) = 5.6$, $p < 0.05$]. The analysis seem to reflect the fact that there is a small, but significant, SM effect in the 1300-1900 ms time window, characterised by an increase in positivity on the right relative to the left hemisphere (see Figure 8.11).

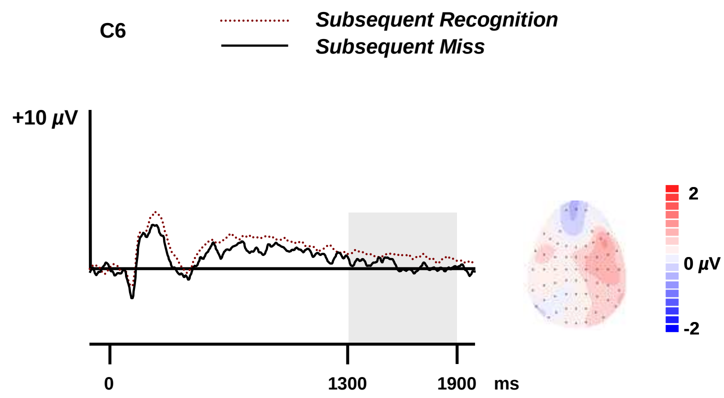

Figure 8.11 SM effect at C6.
The topographic map illustrates the scalp distributions of the SM effect (subsequent Hits minus subsequent Miss) over the 1300-1900 ms time window.

8.4.2. Word Block: JOL Effects

Waveforms for study items assigned Low JOLs and items assigned High JOLs are shown in Figure 8.7 at electrodes included in the analyses. For the 550 to 1000 ms time window the outcome of the initial ANOVA was an interaction between condition, location and hemisphere [$F(1.8,41.4) = 5.2$, $p < 0.05$]. The subsidiary ANOVAs revealed interactions between condition and hemisphere for the parietal electrode row and between condition, hemisphere and site for centro-parietal and parietal electrode rows. The subsidiary analyses seem to reflect a slight increase in negativity on the right hemisphere with a slight increase in positivity on inferior electrode sites on the left hemisphere. These interactions therefore appear to be unrelated to the positivity visible at anterior electrode sites (where the effect is maximal). Since this frontal positivity seem primarily present on electrode sites not included in the first set of analyses, additional analyses were carried out on electrode sites at anterior locations (FP1, FP2, AF3 and AF4)[11]. Data were analysed using ANOVA with factors of category (High JOL versus Low JOL), location (fronto-polar, anterior-frontal) and hemisphere (left, right). The analyses revealed a significant main effect of condition [$F(1,23) = 6.8$, $p < 0.05$] and a significant interaction between condition and location [$F(1,23) = 5.6$, $p < 0.05$] confirming the presence of a positive-going anterior effect which is larger at fronto-polar relative to anterior-frontal locations (see Figure 8.12).

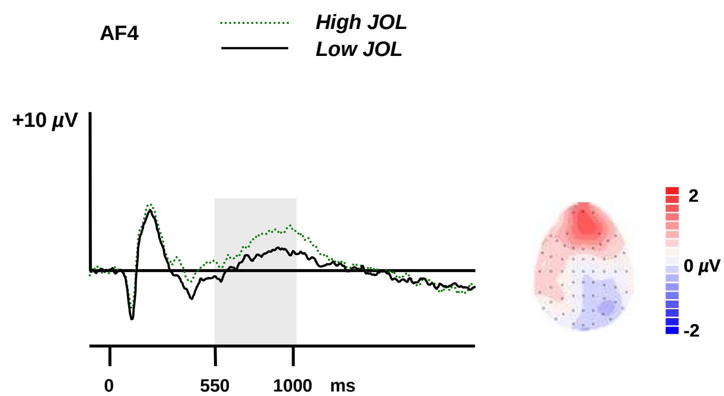

Figure 8.12 JOL effect at AF4.
The topographic map illustrates the scalp distributions of the JOL effect (High JOL minus Low JOL) over the 550-1000 ms time window.

For the 1300-1900 ms time window the outcome of the initial ANOVA revealed significant interactions between condition and hemisphere [$F(1,23) = 4.7$, $p < 0.05$], condition, location and hemisphere [$F(2.3,52.9) = 3.1$, $p < 0.05$] and between condition, hemisphere and site [$F(1.5,34.4) = 4.3$, $p < 0.05$]. The subsidiary analyses revealed significant interactions between condition and hemisphere at frontal and fronto-central electrode rows, condition and site at the frontal electrode row and

[11] To ascertain that the prefrontal JOL effect is specific to the word block of Experiment 4, analyses of the prefrontal electrodes were also carried out on the JOL contrast in Experiments 1 and 2. The results of these analyses are reported in Appendix C.

between condition, hemisphere and site on fronto-central electrode rows. Overall, the analyses appear to reflect that the JOL effect in the 1300-1900 ms time window is a negative-going effect with a focus over left frontal electrode sites (see Figure 8.13).

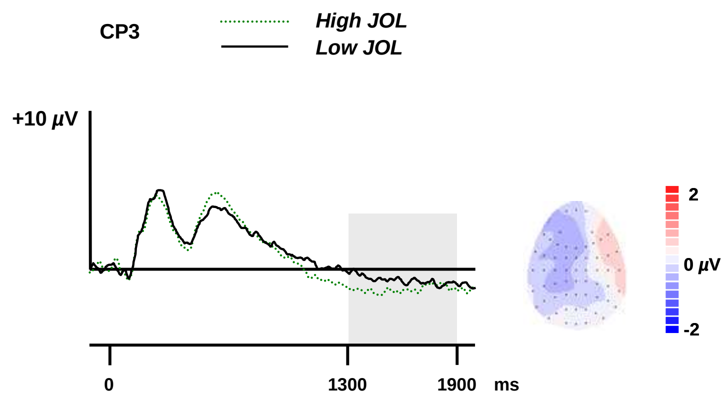

Figure 8.13 JOL effect at CP3.
Zero indicates stimulus onset. The topographic map illustrates the scalp distributions of the JOL effect (High JOL minus Low JOL) over the 1300-1900 ms time window. The front of the head is at the top of the map and the scale bar represents the size of the effect in µV.

Table 8.1 Outcomes of the analysis of the JOL ERP effects.
(F = Frontal; FC = Fronto-Central; C = Central; CP = Centro-Parietal; P = Parietal).

High JOL/Low JOL

550-1000ms	F	FC	C	CP	P
Condition					
Condition x Hemisphere					$F(1,23)=8.4$; $p<0.001$
Condition x Site					
Condition x Hemisphere x Site				$F(1.3,30.2)=4.7$; $p<0.05$	$F(1.7,39.4)=4.6$; $p<0.05$
1300-1900ms	**F**	**FC**	**C**	**CP**	**P**
Condition					
Condition x Hemisphere	$F(1,23)=6.2$; $p<0.05$	$F(1,23)=7.4$; $p<0.05$			
Condition x Site	$F(1.4,31.5)=4.9$; $p<0.05$				
Condition x Hemisphere x Site		$F(1.8,41.9)=6.6$; $p<0.01$			

8.4.3. Picture Block: SM Effects

Waveforms for subsequent Hits and subsequent Misses are shown in Figure 8.8 at electrodes included in the analyses. For the 550 to 1000 ms time window the outcome of the initial ANOVA was a significant interaction between condition, hemisphere and site [$F(1.3,28.9) = 4.1$, $p < 0.05$]. The analysis seems to reflect a widespread positivity with a focus over central electrode sites (with a slight additional negativity present on inferior electrode sites on the right hemisphere; see Figure 8.14).

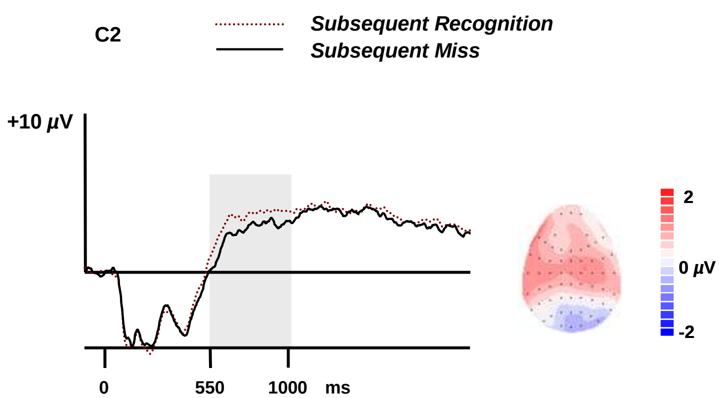

Figure 8.14 SM effect at C2.
The topographic map illustrates the scalp distributions of the SM effect (subsequent Hits minus subsequent Miss) over the 550-1000 ms time window.

For the 1300-1900 ms time window the initial ANOVA revealed a significant interaction between condition and location [$F(1.2,27.0) = 8.9$, $p < 0.01$]. The subsidiary analyses revealed only a significant main effect of condition at the parietal electrode row. This main effect reflects negative-going activity present over posterior electrode sites (see Figure 8.15).

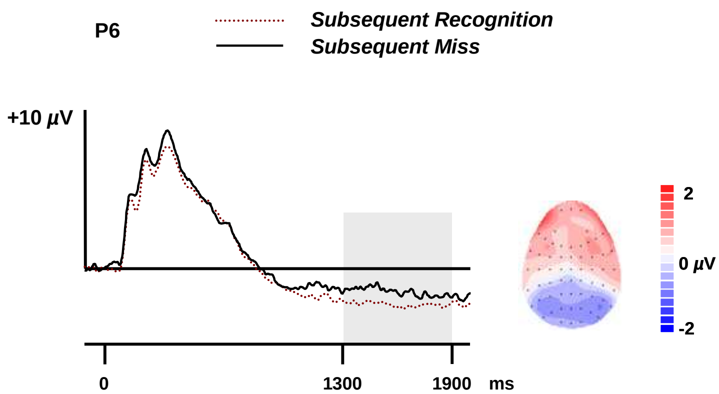

Figure 8.15 SM effect at P6.
The topographic map illustrates the scalp distributions of the SM effect (subsequent Hits minus subsequent Miss) over the 1300-1900 ms time window.

8.4.4. Picture Block: JOL Effects

Waveforms for study items assigned Low JOLs and items assigned High JOLs are shown in Figure 8.9 at electrodes included in the analyses. For the 550 to 1000 ms time window the outcome of the initial ANOVA was significant interactions between condition and location [$F(1.3,29.3) = 4.6$, $p < 0.05$] and between condition, location and hemisphere [$F(1.4,32.1) = 5.1$, $p < 0.05$]. The subsidiary ANOVAs revealed main effects of condition from frontal to central electrode rows. Overall, the analyses reflect a relatively widespread positivity that is largest at anterior electrode sites slightly skewed to the right (see Figure 8.16).

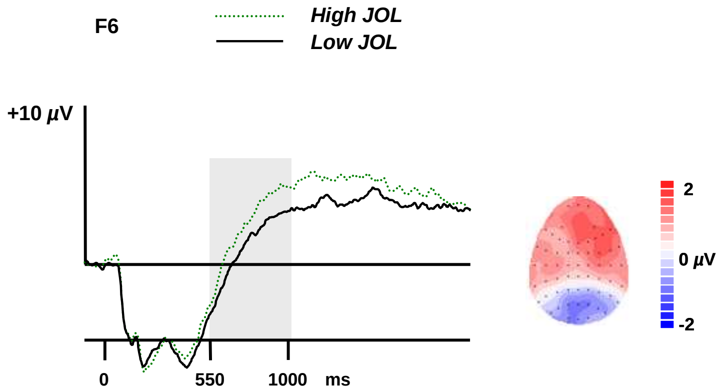

Figure 8.16 JOL effect at F6.
The topographic map illustrates the scalp distributions of the JOL effect (High JOL minus Low JOL) over the 550-1000 ms time window.

For the 1300-1900 ms time window the outcome of the initial ANOVA was a significant interaction between condition, location and site [$F(3.1,71.0) = 2.8$, $p < 0.05$]. The subsidiary analyses revealed only a significant interaction between condition, hemisphere and site at the centro-parietal electrode row. The analyses seem to reflect that the JOL effect in the 1300-1900 ms time window is positive-going and maximal at centro-parietal inferior electrode sites on the right hemisphere (see Figure 8.17).

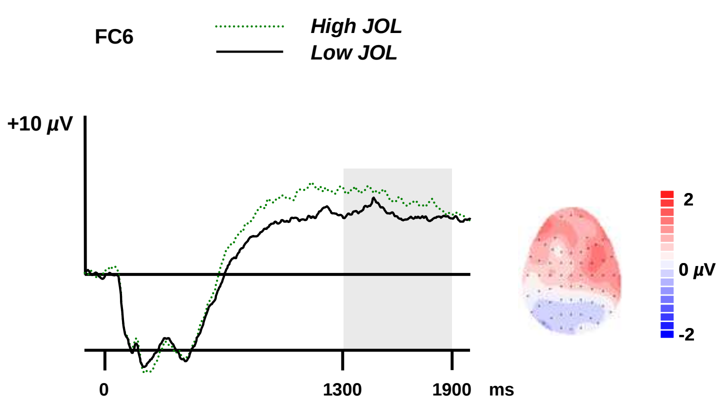

Figure 8.17 JOL effect at FC6.
The topographic map illustrates the scalp distributions of the JOL effect (High JOL minus Low JOL) over the 1300-1900 ms time window.

Table 8.2 Outcomes of the analysis of the SM effects.
(F = Frontal; FC = Fronto-Central; C = Central; CP = Centro-Parietal; P = Parietal).

Recognition/Miss

1300-1900ms	F	FC	C	CP	P
Condition					$F(1,23)=5.4$; $p<0.05$
Condition x Hemisphere					
Condition x Site					
Condition x Hemisphere x Site					

Table 8.3 Outcomes of the analysis of the JOL effects.
(F = Frontal; FC = Fronto-Central; C = Central; CP = Centro-Parietal; P = Parietal).

High JOL/Low JOL

550-1000ms	F	FC	C	CP	P
Condition	$F(1,23)=4.8$; $p<0.05$	$F(1,23)=5.0$; $p<0.05$	$F(1,23)=4.4$; $p<0.05$		
Condition x Hemisphere					
Condition x Site					
Condition x Hemisphere x Site					
1300-1900ms	**F**	**FC**	**C**	**CP**	**P**
Condition					
Condition x Hemisphere					
Condition x Site					
Condition x Hemisphere x Site				$F(1.8,42.4)=4.7$; $p<0.05$	

8.4.5. Word Block: Analyses of Scalp Distribution

The scalp distribution analyses were conducted using ANOVA with factors of time window (early, late), location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and site (superior, mid, inferior). For the SM effects, ANOVA revealed significant interactions between time and site [$F(1.1,25.5) = 8.7$, $p < 0.01$], reflecting that the early effect exhibits a focus over inferior electrode sites whereas the late effect exhibits a focus over superior electrode sites. For the JOL effects, ANOVA revealed significant interactions between time and hemisphere [$F(1,23) = 16.4$, $p < 0.01$], time, location and site [$F(3.1,71.5) = 4.6$, $p < 0.01$] and finally time, hemisphere and site [$F(1.5,34.9) = 13.8$, $p < 0.001$]. The analysis reflects that the early effect is characterised by widespread positivity most prominent at frontal electrode sites, whereas the late effect exhibits negativity on the left hemisphere. The reliable interactions that were revealed in the analyses indicate that the early and late SM and the early and late JOL effects are generated by at least partially non-overlapping sets of neural generators, and therefore reflect distinct classes of cognitive operations.

8.4.6. Picture Block: Analyses of Scalp Distribution

For the SM effects, the ANOVA revealed no significant change in distribution over time (all $Fs < 3.4$). For the JOL effects, ANOVA revealed significant interactions between time, location and site [$F(3.2,74.7) = 5.8$, $p < 0.05$] and between time, location, hemisphere and site [$F(3.7,84.4) = 2.8$, $p < 0.05$]. The interactions reflect a reduction of the spread of the effect from the early to the late time window, from widespread fronto-central positivity in the early time window to a more restricted (and left-sided) centro-parietal maximum in the late time window. The scalp distribution analysis suggest that the early and late JOL effects from the picture block are produced by at least partially distinct sets of neural generators.

8.4.7. Analyses of Scalp Distributions across Stimulus Contents

Scalp distribution analyses were carried out to compare the topographies of the word and picture effects in the early and late time windows, however the analyses revealed no significant interactions (all Fs < 2.3).

8.4.8. Word Block: SM Effects (Re-analyses)

The time windows from Experiments 1 and 2 did not seem to appropriately capture the effects in the present experiments. There are many possible factors which can explain why this is the case; firstly, in Experiments 1 and 2 pairs of words were presented at study whereas the stimuli used in Experiment 4 were single items. The time it takes for the initial stages of sensory and perceptual processing to occur for paired associates as opposed to single items will necessarily vary and this in itself could create differences in timings of the effects. Secondly, the picture block of Experiment 4 used images that were deliberately compiled to discourage verbalisation during encoding and for that reason participants could have been forced to rely on study strategies that differ from those used in Experiments 1 and 2 and the word block of Experiment 4. Thirdly, the presentation time of the stimuli were shortened from 3 seconds to 2 seconds in Experiment 4. The change of presentation duration was to avoid the total running time of the full experiment (words *and* pictures) exceeding two hours. It was also expected that 3 seconds would be too long for single-item stimuli potentially causing participants to lose focus.

Through visual inspection of the waveforms an alternative sets of time windows was identified and the data were submitted to a second series of analyses. The time windows identified were: 300-800 ms post-stimulus and 800-1200 ms post-stimulus for the word block and 600-1500 ms post-stimulus for the picture block. The analyses follow the same general logic as the preceding experiments reported in this thesis (with any exceptions clearly emphasised) and results from subsidiary analyses are reported in Tables 8.4 and 8.5. The outcome of the second set of analyses performed on data from the picture block did not deviate considerably from the first set of analyses and is for that reason reported in Appendix B rather in the main text.

For the 300-800 ms time window the outcome of the initial ANOVA was a significant main effect of condition [$F(1,23) = 6.3$, $p < 0.05$] reflecting the presence of a positive-going SM effect that is relatively widespread and focussed over posterior electrode sites (see Figure 8.18).

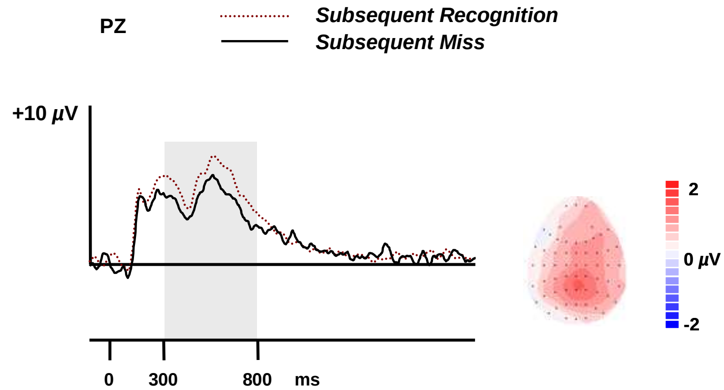

Figure 8.18 SM effect at PZ.
The topographic map illustrates the scalp distributions of the SM effect (subsequent Hits minus subsequent Miss) over the 300-800 ms time window.

For the 800-1200 ms time window the outcome of the initial ANOVA was a significant interaction between condition and location [$F(1.5,34.6) = 4.3$, $p < 0.05$]. The subsidiary analyses revealed significant main effects of condition only at frontal and fronto-central electrode rows. The analyses reflect a positive-going SM effect present at frontal electrode sites (see Figure 8.19).

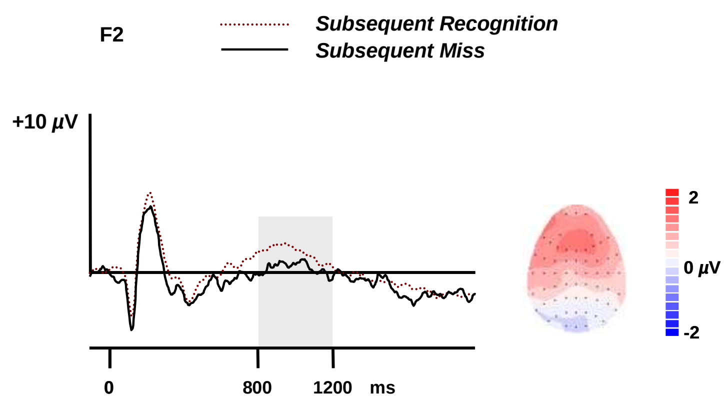

Figure 8.19 SM effect at F2.
The topographic map illustrates the scalp distributions of the SM effect (subsequent Hits minus subsequent Miss) over the 800-1200 ms time window.

8.4.9. Word Block: JOL Effects (Re-analyses)

For the 300-800 ms time window the outcome of the ANOVA was a significant interaction between condition, location and hemisphere [$F(2.0,46.5) = 5.0$, $p < 0.05$]. The subsidiary analyses revealed a significant interaction between condition and hemisphere on the parietal electrode row. The subsidiary analyses seem to reflect a slight increase in positivity on the left hemisphere with a slight increase in negativity on inferior electrode sites on the left hemisphere. As for the original time windows, the interactions seem unrelated to the positivity present at anterior electrode sites (where the effect is maximal). Since the frontal positivity seems primarily present on electrode sites not included in the original analyses, additional analyses were carried out on electrode sites at anterior locations (FP1, FP2, AF3 and AF4). Data were analysed using ANOVA with factors of category (High JOL versus Low JOL), location (fronto-polar, anterior-frontal) and hemisphere (left, right). The analyses revealed a significant main effect of condition [$F(1,23) = 5.1$, $p < 0.05$] confirming a positive-going effect at anterior locations (see Figure 8.20).

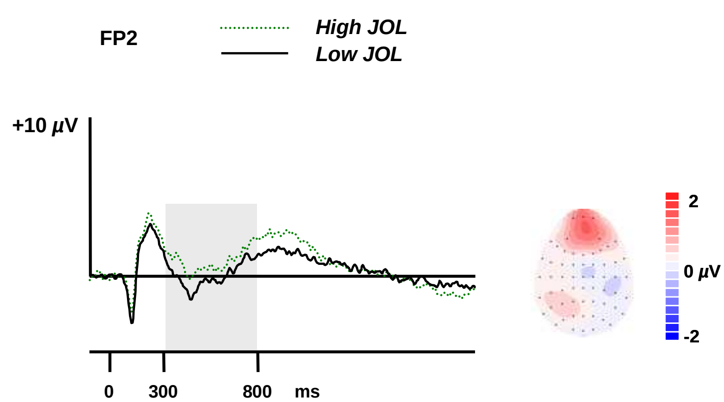

Figure 8.20 JOL effect at FP2.
The topographic map illustrates the scalp distributions of the JOL effect (High JOL minus Low JOL) over the 300-800 ms time window.

For the 800 to 1200 ms time window, the outcome of the initial ANOVA was significant interactions between condition and location [$F(1.2,28.3) = 8.7$, $p < 0.01$] and between condition, location and hemisphere [$F(1.8,42.0) = 4.8$, $p < 0.05$]. The subsidiary analyses revealed significant main effects of condition at frontal and parietal electrode rows and an interaction between condition and site at the centro-parietal electrode row. Overall, the analyses reflect a combination of positivity at frontal electrode sites with simultaneous negativity at posterior electrode sites (see Figure 8.21).

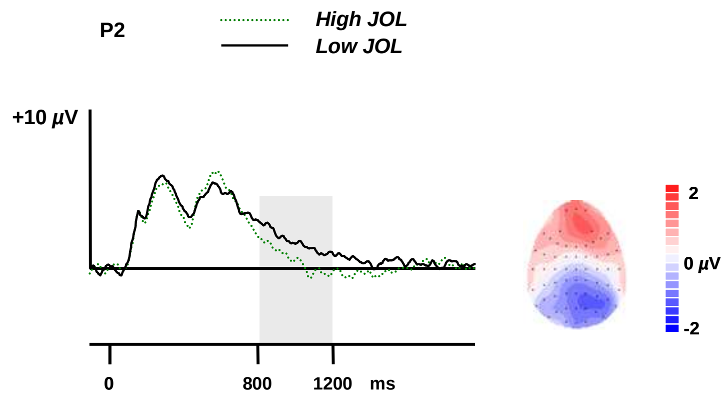

Figure 8.21 JOL effect at P2.
The topographic map illustrates the scalp distributions of the JOL effect (High JOL minus Low JOL) over the 800-1200 ms time window.

Table 8.4 Outcomes of the analysis of the SM effects.
(F = Frontal; FC = Fronto-Central; C = Central; CP = Centro-Parietal; P = Parietal).

Recognition/Miss

800-1200ms	F	FC	C	CP	P
Condition	$F(1,23)=7.7$; $p<0.05$	$F(1,23)=5.2$; $p<0.05$			
Condition x Hemisphere					
Condition x Site					
Condition x Hemisphere x Site					

Table 8.5 Outcomes of the analysis of the JOL effects.
(F = Frontal; FC = Fronto-Central; C = Central; CP = Centro-Parietal; P = Parietal).

High JOL/Low JOL

300-800ms	F	FC	C	CP	P
Condition					
Condition x Hemisphere					$F(1,23)=4.9$; $p<0.05$
Condition x Site					
Condition x Hemisphere x Site					
800-1200ms	**F**	**FC**	**C**	**CP**	**P**
Condition	$F(1,23)=4.9$; $p<0.05$				$F(1,23)=6.6$; $p<0.05$
Condition x Hemisphere					
Condition x Site				$F(1.2,24.3)=4.6$; $p<0.05$	
Condition x Hemisphere x Site					

8.5. Discussion

The aim of Experiment 4 was to investigate whether or not the JOL effects that were observed in Experiments 1 and 2 are material specific. Participants completed two sets of blocks; a single item word block and a single item picture block. The results from the word block showed some similarities but also some differences with the previous JOL studies reported in this thesis. The results from the picture block appeared to be differed from both the previous studies and the word block, which would suggest that JOL effects do vary depending on the nature of the stimulus materials, however, analyses of scalp distribution did not confirm this difference. Results were first analysed using the original time windows from Experiments 1 and 2 and re-analysed using alternative time windows. The results from each experiment are discussed in turn.

8.5.1. Word Block

The word block gave rise to early widespread and positive-going SM effects, whereas the analyses of the later time window revealed an additional positive-going effect on the right hemisphere. Ideally, the time windows identified previously should form the basis for investigations of subsequent experiments, however in the case of Experiment 4, there are many factors that could have influenced the timing of the effects (such as presentation time, complexity of stimuli, etc) and thus it was considered reasonable to carry out alternative analyses. When data were re-analysed, the distributions of the effects were slightly different; during the 300-800 ms the positive effect shows a posterior focus resembling the SM effects from

Experiments 1 and 2. By contrast, during 800-1200 ms the second positive effect showed a frontal focus, a SM effect that has not been described previously in this thesis.

JOL effects in the original early time window were characterised by prefrontal positivity whereas the later time window revealed a negative-going effect on the left-frontal hemisphere. The anterior effect is clearly different from the early JOL effects seen in Experiments 1 and 2, but the late negativity seems to resemble the previously observed late JOL effects. Notably, the negative-going effect was lateralised as in Experiment 1, which is surprising given that the scale was counterbalanced (see Chapter 6). It is possible, however, that the unexpected distribution was partly caused by using a poorly matched time window; re-analyses of the data revealed a central and posterior scalp distribution similar to that observed in Experiment 2. The anterior effect seemed unaffected by the changing time windows.

8.5.2. Picture Block

The picture block gave rise to an early positive-going SM effect restricted to central electrode locations. Although analyses of the late time window indicated a presence of positivity at fronto-central and central locations, the maximum amplitude was nevertheless found at parietal electrode locations where the effect was negative-going. When the effect was analysed using an alternative time window of 600-1500 ms, the parietal negativity failed to reach significance. Thus, the SM effects were small and poorly focused, possibly due to the relatively low behavioural performance score. It is unclear whether the posterior negativity is related to the negativity associated with JOLs for verbal stimuli, but this seems unlikely given that it is not visible in the JOL contrast.

JOL effects were more prominent than the SM effect and were characterised by long-lasting frontal positivity followed by right hemisphere positivity at central electrode locations. Closer examination of the waveforms led to the impression that the early and late JOL effects in the picture block were better characterised as one continuous effect. The alternative analyses revealed significant frontal to central positivity, slightly skewed to the right at frontal sites. Neither the SM nor JOL effects from the picture block resemble effects from any of the word experiments.

Although the separate statistical characterisations of the word and picture effects suggest that different stimulus contents give rise to different neural correlates of memory and metamemory, no statistical support for this claim was provided from the comparisons of scalp distributions. It is likely, however, that the lack of significant site interactions, in this case, is a reflection of low statistical power. Furthermore, the time courses of the effects appeared to be inadequately captured by the original time windows, resulting in the effects being poorly localised. Future studies should therefore aim to investigate the material specificity of JOLs by further using designs that will ensure more statistical power.

It is important to note that the word and the picture blocks differed in one essential aspect besides the apparent nature of the stimulus material; memory performance was considerably worse for pictures than what it was for words. Clearly, participants had more difficulties remembering material in the form of pictures, and it is possible that the homogeneity of the indoor scenes was the main underlying cause of this problem. Since performance was not matched across the two blocks, it is impossible to rule out the possibility that SM effects, in particular, would be different was discrimination higher for pictures.

8.6. Summary and Conclusion

The primary aim of Experiment 4 was to investigate whether the JOL specific effects observed in Experiments 1 and 2 were content specific. A secondary aim was also to investigate the consequences of switching form paired associates to single item words as study material. This was deemed necessary for comparison purposes since the pictures presented were also single items. It was found that single item words elicited an early SM effect and a late JOL effect that both seemed to resemble the effects found in Experiments 1 and 2, although the time courses were slightly different (300-800 ms versus 550-1000 ms and 800-1200 ms versus 1300-1900 ms). Past experiments reported in this thesis have not demonstrated any separate *late* SM effects, however the present experiment revealed a clear frontally distributed positivity. The early JOL effect was also novel; it was distributed at anterior rather than posterior electrode sites. Given the pattern of ERP effects, it seems likely that participants engaged in some of the same cognitive strategies when encoding and assessing single item words and paired associates, however some strategies also seemed to deviate, which is not surprising given the important differences between the word stimuli.

SM and JOL effects to pictures each seem best characterised as one positive-going and long lasting effect, which was widespread in the case of SM and focused on right-frontal electrode sites in the case of JOLs. Both these effects appear different in time course and distribution to the effects seen for single-item words, which suggest that the underlying processes were slightly sensitive to the change of stimulus material. On a functional level, this observation is compatible with an inferential theory of JOL: when the nature of the stimuli changes, different sets of cues are available to form the basis of the JOL. The present findings therefore strongly suggest that metacognitive assessments seem to rely on multiple neural and functional processes in much the same manner as memory encoding (Otten & Rugg, 2001a).

Chapter 9.

Judgments of Learning and the ERP Correlates of Memory Retrieval

9.1. Introduction

Experiments 1 and 2 revealed a combination of shared and independent neural activity contributing to successful memory encoding and JOL, suggesting that JOLs may be based partly on memory encoding operations. To further investigate the basis upon which JOLs are made, it is possible to examine the Event-Related Potentials recorded during the subsequent retrieval task assessing whether the measures of familiarity, recollection and post-retrieval monitoring are modulated by JOL. The rationale behind this strategy is that the consequences JOL assessments have for the pattern of processes engaged during later attempts to retrieve can offer additional insights into the processes that are employed during encoding. Before the underlying principle of the current experiments is fully outlined, a brief reminder of the characteristics of the ERP retrieval effects will be provided.

A vast body of literature has established that ERPs to successfully remembered items are generally more positive-going than those to correctly rejected new items; a pattern of activity referred to as ‘old/new effects’ (see Chapter 3). At least three distinct old/new effects can be identified and dissociated at retrieval: the mid-frontal, left-parietal and right-frontal old/new effects, all of which have different functional interpretations (for a recent review see Rugg & Curran, 2007).

The mid-frontal effect typically occurs between approximately 300 and 500 ms post-stimulus, with a focus over mid-frontal electrode sites. The effect has been mainly associated with the successful recognition of old items, but has sometimes also been observed for false alarms (new items mistaken for being old; e.g. Curran, 2000; Curran & Cleary, 2003; Nessler et al., 2001; Wolk et al., 2006). For this reason, amongst others (see Chapter 3), the mid-frontal effect is widely believed to reflect familiarity, which is the sense of having encountered an item previously without retrieval of additional contextual information (Rugg & Curran, 2007, but also see Paller et al., 2007; Yovel & Paller, 2004).

The left-parietal effect onsets shortly after the mid-frontal effect dissipates. This effect typically occurs between 500 and 800 ms post-stimulus, with a focus over left-parietal electrode sites. Consistent evidence (see Chapter 3) suggests that the left-parietal effect constitutes the ERP correlate of recollection-based recognition (see Rugg & Curran, 2007). The functional interpretation stems partly from the observation that the effect is larger for hits compared to false alarms (Curran et al., 2001) and for items judged to have been *remembered* rather than *known* to be old (Curran, 2004; Duzel et al., 1997; Rugg et al., 1998; but see Spencer et al., 2000) as well as the fact that the magnitude of the effect increases with the amount of contextual information that has been recovered (Wilding & Rugg, 1996).

Lastly, the right-frontal effect has been found to onset shortly after the left-parietal effect (approximately 800 ms post-stimulus) and often lasts until the end of the recording epoch, with a focus over right-frontal recording sites. Of all three old/new effects, there seem to be least certainty about the functional interpretation of the right-frontal effect. Although relatively early studies suggested that the effect reflected recollection in much the same manner as the left-parietal effect, more recent evidence has led to the understanding that the right-frontal activity reflects post-retrieval monitoring processes acting on the product of retrieval, possibly related to decision-making processes (Hayama et al., 2008).

To date, there is very limited research literature on differential involvement of retrieval processes as a function of JOL and the only studies that exist have used different operationalisations of familiarity compared to dual process theorists. Whereas memory researchers refer to familiarity as one of two possible routes to recognition, metamemory researchers generally refer to familiarity in the sense of *perceptual fluency* or *ease of processing* (Koriat & Levy-Sadot, 1999; for an exception see Daniels, Toth & Hertzog, 2009). These differences partly reflect inconsistencies in experimental paradigms; most behavioural JOL paradigms do not assess memory by means of old/new recognition judgments but rather with cued recall procedures. In cued recall paradigms all presented cues are old and the level of familiarity is therefore primarily viewed as differentiating between items that have been frequently (or recently) encountered in the past. By contrast, in ERP memory retrieval experiments it is advantageous to include new items and incorporate an old/new recognition task at test because memory retrieval effects are characterised in the literature as the difference in activity between correctly identified old items and correctly rejected new items. Thus, under these circumstances, familiarity refers to participants' feeling of having encountered an item in the specific study episode preceding the test phase. Familiarity and ease of processing/perceptual fluency are therefore typically regarded as distinguishable phenomena (although one might argue that ease of processing or perceptual fluency could falsely lead to positive memory judgments associated with familiarity).

The assumptions underlying the paradigm employed here is that the measures of familiarity, recollection and post-retrieval monitoring, when separated according to JOL at study, will provide an indication of the degree to which processes consequential to these measures were employed when the JOLs were made. Differences in terminology mean it is unfeasible to compare most previous behavioural JOL studies of retrieval processes (e.g. Metcalfe & Finn, 2008). The only other known study to investigate judgments of learning from a dual process theory perspective was carried out by Daniels et al. (2009). Daniels et al. (2009) presented participants with a number of single-item words and instructed them to make immediate JOLs to each word on a 0-100 scale. At test, half of the participants were presented with all old words intermixed with a number of new words. For this group the initial task was to make an old/new judgment and following each old judgment participants were asked to indicate whether their decision had been based on familiarity, recollection or no memory. The remaining half of the participants were presented with word stems and asked to complete each stem using words from the study list. If participants had no memory of a word appropriate for the stem, they were asked to write down first words that came to mind. For this group, after each stem completion, participants were asked to indicate whether the production of each word was based on familiarity, recollection or no memory. Daniels et al. (2009) found that words which were recollected, regardless of group, received significantly higher average JOLs compared to items that were recognised based on familiarity or no memory at all. It was concluded that recollection plays a more essential role in the assignment of JOLs compared to familiarity, because contextual cues available at the time of study both form a basis for making JOLs and aid recollection at test.

Considering the results presented by Daniels et al. (2006), one likely outcome of Experiment 2 is a modulation of the ERP index of recollection as a function of JOL; the higher the JOL the larger the amplitude of the left-parietal effect. If familiarity does not contribute to the JOL assignment, the mid-frontal effect should be the same across levels of JOL. The anticipated results of Experiment 1, on the other hand, are different to that of Experiment 2; since participants were required to recall the second word of the word pair, rather than just make an old/new judgment, it is anticipated that all the recalled items will be fully recollected and no modulation of the mid-frontal or left-parietal effects should be evident.

It is less clear whether JOLs will have any consequences for the amplitude of the right-frontal effect. Although the current understanding of the right-frontal effect is that it reflects post-retrieval monitoring, the exact nature of this account is rather vague. Until recently the effect was believed to relate to episodic memory processes, however recently Hayama et al. (2008) showed that right-frontal effects are also present when participants are required to make semantic decisions about new items. One possibility is that words receiving varying levels of JOLs at study will require different degrees of monitoring following retrieval. Despite the difficulties of forming specific hypotheses regarding the right-frontal effect in the present experiments, the time window in which this effect is typically present was submitted to analysis for exploratory purposes.

9.2. Method

The retrieval data sets from Experiments 1 and 2 are derived from a subset of participants who contributed to the study phase data sets of the same experiments. Participant details therefore deviate slightly from those reported in Chapters 5 and 6 and are outlined below.

9.2.1. Experiment 1

Of the 20 participants who contributed to the study phase data of Experiment 1, 14 of these performed sufficiently to contribute to the test phase data. This subset of participants (10 female) had a mean age of 22 (range: 17-27).

Stimulus materials and experimental procedure conform to those outlined in Chapter 4 and is also schematically illustrated in Figure 5.1 in Chapter 5. Grand average ERP waveforms were formed for the following response categories: High JOL Recall (items assigned a high JOL at study, recognised as old and for which the study partner was recalled), Low JOL Recall (items assigned a low JOL at study, recognised as old and for which the study partner was recalled) and Correct Rejections (CR; correctly identified new items). Mean numbers of trials were 55, 40 and 85, for High JOL Recall, Low JOL Recall and CR categories respectively.

9.2.2. Experiment 2

Of the 24 participants who contributed to the study phase data of Experiment 2, 21 performed sufficiently to contribute to the test phase data. This subset of participants (8 female) had a mean age of 20 (range: 17-30).

Stimulus materials and experimental procedure conform to those outlined in Chapter 4 and is also schematically illustrated in Figure 6.1 in Chapter 6. Grand average ERP waveforms were formed for the following response categories: High JOL Hit (items assigned a high JOL at study and which were recognised as old), Medium JOL Hit (items assigned a medium JOL at study and which were recognised as old), Low JOL Hit (items assigned a low JOL at study and which were recognised as old) and Correct Rejections (CR; correctly identified new items). Mean numbers of trials were 95, 45, 53 and 97, for High JOL Hit, Medium JOL Hit, Low JOL Hit and CR categories respectively.

9.3. Behavioural Results

The behavioural results from the sample of participants contributing to the test phases of Experiments 1 and 2 do not differ considerably from the behavioural results of the full sample contributing to the study phases. The behavioural results are for that reason not re-reported in this section, but for completeness, these data are summarised in Appendix D.

9.4. Event-Related Potential Results

9.4.1. Experiment 1

The initial ERP analyses comprised assessments of the test phase ERPs sorted according to the behavioural response categories: Low JOL Recall, High JOL Recall and CR. Each of the JOL conditions was statistically compared against CR to confirm the presence of potential memory retrieval effects.

The ERP data were analysed using the traditional time windows that have been identified in the literature (Allan et al., 1998; Rugg, 1995; Rugg & Curran, 2007); 300-500 ms (mid-frontal old/new effect), 500-800 ms (left-parietal old/new effect) and 1000-1600 ms (right-frontal old/new effect) post-stimulus. Each contrast was first analysed using ANOVA, with factors of category (Low JOL Recall versus CR and High JOL Recall versus CR), location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and electrode site (superior, mid, inferior) followed by five subsidiary analyses on each separate location when appropriate. Waveforms for the retrieval effects are shown in Figure 9.1 at all electrodes included in the analyses. The outcomes of the subsidiary analyses producing significant results are summarised in Table 9.1.

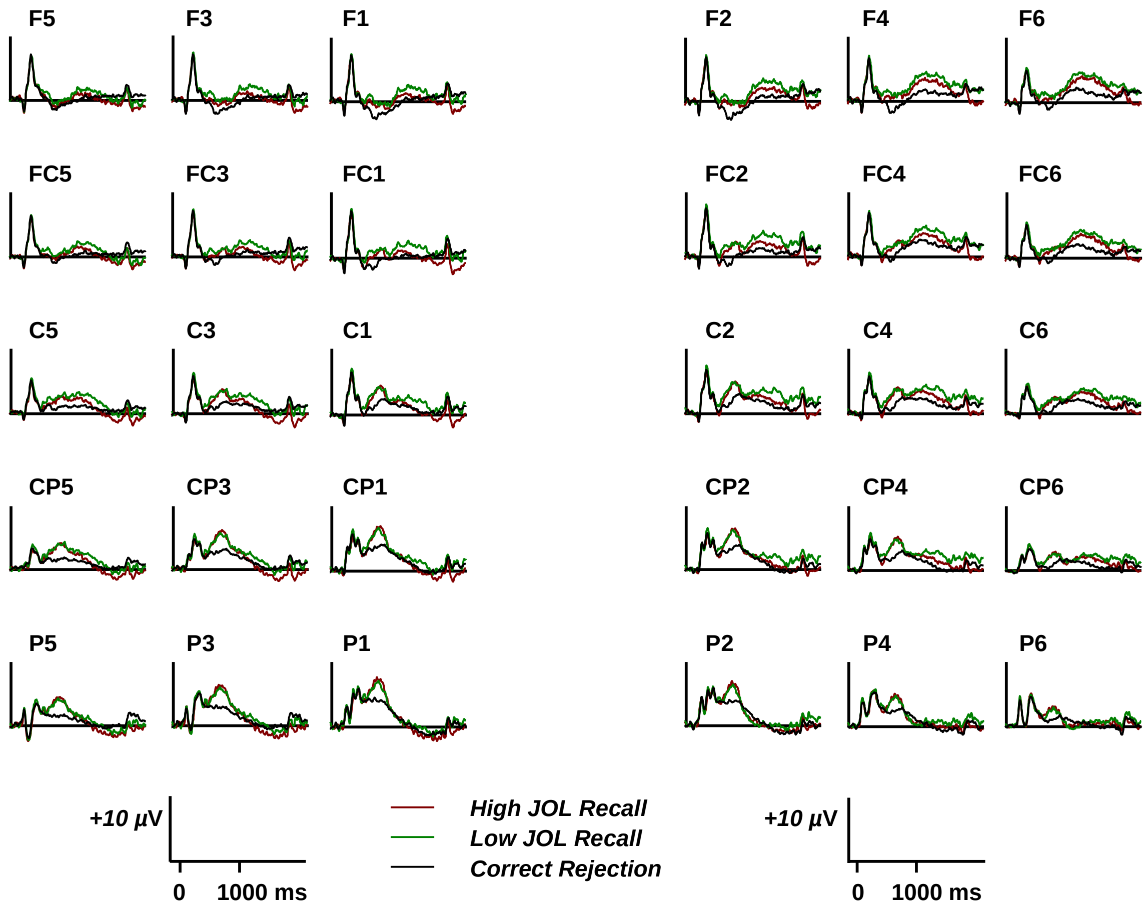

Figure 9.1 Memory retrieval effects.
Grand average ERPs for CR (black lines), High JOL Recall (red lines) and Low JOL Recall (green lines).

9.4.2. Low JOL Recall Effects

For the 300-500 ms time window the initial ANOVA revealed no significant main effects or interactions (all *Fs* < 2.0). By contrast, in the 500-800 ms time window the initial ANOVA revealed a significant main effect of condition [$F(1,13) = 12.2$, $p < 0.01$] along with interactions between condition, location and hemisphere [$F(1.6,20.6) = 6.1$, $p < 0.05$], condition and site [$F(1.2,15.0) = 5.8$, $p < 0.05$] and condition, location, hemisphere and site [$F(3.8,48.8) = 4.6$, $p < 0.01$]. The subsidiary analyses revealed significant main effects of condition across all five electrode rows, significant interactions between condition and site at frontal and fronto-central electrode rows and a significant interaction between condition and hemisphere at parietal electrode rows. The outcomes of the analyses reflect that the Low JOL Recall effect in the 500-800 ms time window is a relatively widespread positive-going effect with a focus over left-parietal electrode sites (see Figure 9.2a). The interactions between condition and site on frontal and fronto-central electrode rows reflect additional frontal activity which is predominantly present over midline-electrode sites.

For the 1000-1600 ms time window the initial ANOVA revealed a significant main effect of condition [$F(1,13) = 7.4$, $p < 0.05$] along with interactions between condition and hemisphere [$F(1,13) = 39.1$, $p < 0.001$], condition, location and hemisphere [$F(2.2,28.9) = 3.4$, $p < 0.05$], condition, hemisphere and site [$F(1.6,20.3) = 5.7$, $p < 5.7$, $p < 0.05$] and condition, location, hemisphere and site [$F(4.1,53.0) = 2.7$, $p < 0.05$]. The subsidiary analyses revealed significant main effects of condition and significant interactions between condition and hemisphere from frontal to centro-parietal electrode rows, along with significant interactions between condition, hemisphere and site at frontal and centro-parietal electrode rows. The subsidiary analyses confirm that the Low JOL Recall effect in the 1000-1600 ms time window is a positive-going effect with a focus over right-frontal electrode sites (see Figure 9.2c). The significant interaction between condition, hemisphere and site at the frontal electrode row reflects the fact that the effect is largest at inferior electrode sites on the right hemisphere whereas it is largest at superior electrode sites on the left hemisphere. Similarly, the significant interaction between condition, hemisphere and site at the centro-parietal electrode row seem to reflect that the effect is largest at inferior electrode sites on the right hemisphere whereas it is largest at mid electrode sites on the left hemisphere.

9.4.3. High JOL Recall Effects

As for the Low JOL Recall contrast, the initial ANOVA on the 300-500 ms time window revealed no significant main effects or interactions (all *Fs* < 1.2). By contrast, for the 500-800 ms time window the initial ANOVA revealed a significant main effect of condition [$F(1,13) = 16.7$, $p < 0.01$] along with interactions between condition and location [$F(1.7,22.5) = 4.8$, $p < 0.05$], condition and site [$F(1.1,13.8) = 5.7$, $p < 0.05$], condition, location and hemisphere [$F(1.4,18.0) = 7.0$, $p < 0.05$] and condition, location, hemisphere and site [$F(3.9,50.1) = 3.3$, $p < 0.05$]. The subsidiary analyses revealed significant main effects of condition across all five electrode rows and an interaction between condition and site at the frontal electrode row. The subsidiary analyses reflect that the High JOL Recall effects in the 500-800 ms time window is also a relatively widespread positive-going effect. Unlike the

Low JOL Recall effect, this effect was not statistically larger on the left hemisphere at posterior electrode rows. Rather (and contrary to the impression from the scalp map in Figure 9.2b), the initial interactions involving the factor of hemisphere reflect how additional activity at the front of the head is slightly skewed to the right, rather than the left, as is the case at posterior rows.

For the 1000-1600 ms time window the initial ANOVA revealed significant interactions between condition and hemisphere [$F(1,13) = 21.9$, $p < 0.001$] and condition, hemisphere and site [$F(1.3,17.2) = 9.1$, $p < 0.01$] reflecting relative widespread positivity on right hemispheric electrode sites (see Figure 9.2c).

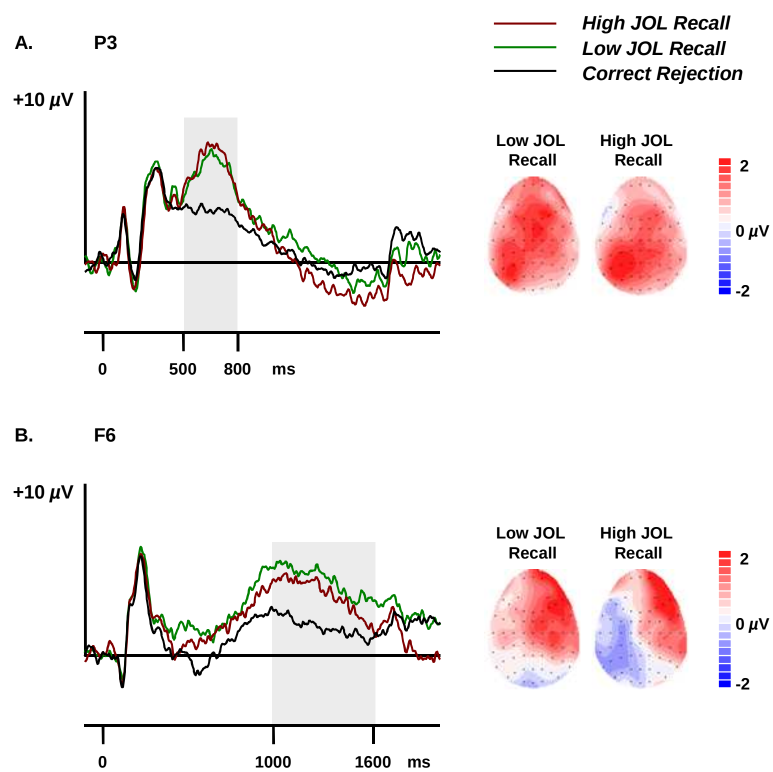

Figure 9.2 Memory retrieval effects at representative electrodes.
Panel A: Retrieval effects at P3 during the 500-800 ms time window. Panel B: Retrieval effects at F6 during the 1000-1600 ms time window. The topographic map illustrates the scalp distributions of the effect (Low JOL Recall minus CR and High JOL Recall minus CR).

Table 9.1 Outcomes of the analyses of the memory retrieval effects.
(F = Frontal; FC = Fronto-Central; C = Central; CP = Centro-Parietal; P = Parietal).

Low JOL Recall/CR

500-800ms	F	FC	C	CP	P
Condition	$F(1,13)=7.8$; $p<0.05$	$F(1,13)=7.1$; $p<0.05$	$F(1,13)=9.0$; $p<0.05$	$F(1,13)=14.6$; $p<0.01$	$F(1,13)=20.3$; $p<0.01$
Condition x Hemisphere					$F(1,13)=4.9$; $p<0.05$
Condition x Site	$F(1.1,14.1)=7.5$; $p<0.05$	$F(1.3,16.5)=4.5$; $p<0.05$			
Condition x Hemisphere x Site					
1000-1600ms	**F**	**FC**	**C**	**CP**	**P**
Condition	$F(1,13)=9.0$; $p<0.05$	$F(1,13)=8.2$; $p<0.05$	$F(1,13)=7.8$; $p<0.05$	$F(1,13)=4.7$; $p<0.05$	
Condition x Hemisphere	$F(1,13)=33.0$; $p<0.001$	$F(1,13)=22.7$; $p<0.001$	$F(1,13)=11.0$; $p<0.01$	$F(1,13)=26.5$; $p<0.001$	
Condition x Site					
Condition x Hemisphere x Site	$F(1.7,22.3)=7.9$; $p<0.01$			$F(1.7,22.4)=5.5$; $p<0.05$	

High JOL Recall/CR

500-800ms	F	FC	C	CP	P
Condition	$F(1,13)=10.5$; $p<0.01$	$F(1,13)=6.7$; $p<0.05$	$F(1,13)=11.1$; $p<0.01$	$F(1,13)=23.0$; $p<0.001$	$F(1,13)=31.7$; $p<0.001$
Condition x Hemisphere					
Condition x Site	$F(1.1,13.9)=7.5$; $p<0.05$				
Condition x Hemisphere x Site					

9.4.4. Comparison of Low and High JOL Recall Effects

The ANOVAs comparing the Low JOL and High JOL Recall effects revealed no significant differences in any of the two latest time windows (all *Fs* < 4.3; the first time window was not included in this analysis because no effects were evident)

9.4.5. Analyses of Scalp Distributions

Scalp distribution analyses were carried out to establish whether the effects in each time window were generated by separable neural systems. Since no statistical differences were evident between low JOL and high JOL recall, analyses were performed on data collapsed across JOL, forming two response categories: Recall and CR (topographic maps are provided in Figure 9.3). The analyses were conducted using ANOVA with factors of time window (Middle versus Late), location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and site (superior, mid, inferior). The early time window was not included in the analyses because no significant effects were present during 300-500 ms post-stimulus.

The ANOVA on the rescaled data revealed a significant interaction between time and location [$F(1.5,19.3) = 5.9$, $p < 0.05$], time and hemisphere [$F(1,13) = 16.3$, $p < 0.01$], time, hemisphere and site [$F(1.3,17.3) = 17.3$, $p < 0.001$] and between time, location, hemisphere and site [$F(5.1,66.4) = 2.4$, $p < 0.05$]. These analyses reflect the fact that the early effect is positive-going with a focus over left posterior electrode sites, whereas the late effect is characterised by positivity over right-frontal electrode sites (along with slight negativity over posterior sites). The analyses of scalp distributions therefore strongly suggest that the effects observed in the 500-800 ms and 1000-1600 ms time windows are produced by different sets of neural generators.

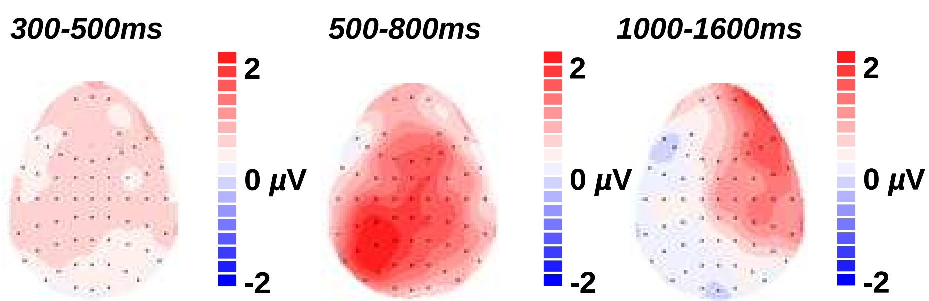

Figure 9.3 Distributions of memory retrieval effects from Experiment 1.
The topographic map illustrates the scalp distributions of the recall effect during three time windows collapsed across level of JOL (Recall minus CR).

9.4.6. Experiment 2

The initial ERP analyses comprised assessments of the test phase ERPs sorted according to the behavioural response categories: Low JOL hits, Medium JOL hits, High JOL hits and CR. Each of the JOL conditions was statistically compared against CR to confirm the presence of potential memory retrieval effects. Following, the JOL conditions were compared against each other. For consistency, the same time windows and ANOVA structure were employed as for Experiment 1. Waveforms for the retrieval effects are shown in Figure 9.4 at electrodes included in the analyses. The outcomes of the subsidiary analyses producing significant results are summarised in Tables 9.2 and 9.3.

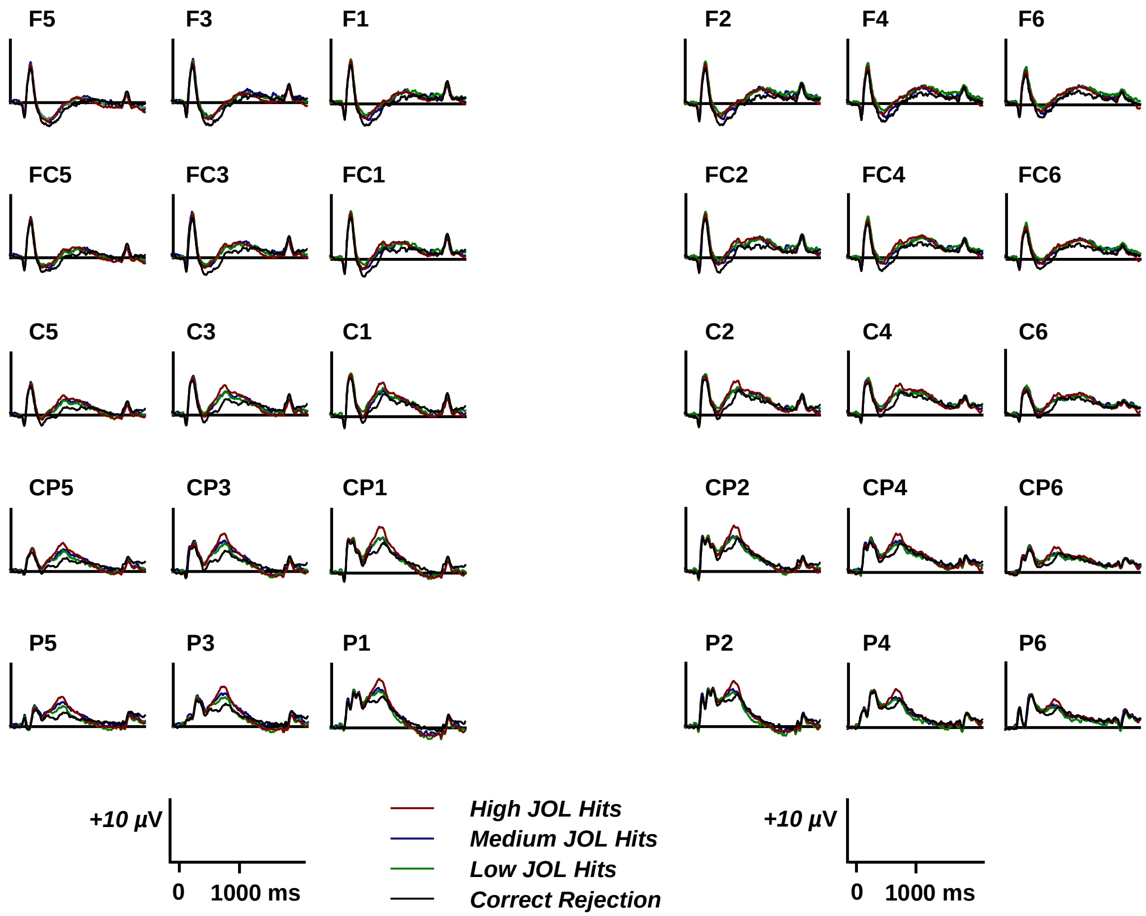

Figure 9.4 Memory retrieval effects.
Grand average ERPs for Correct Rejections (black lines), High JOL Hits (red lines) and Low JOL Hits (green lines).

9.4.7. Low JOL Hits

For the 300-500 ms time window the initial ANOVA revealed a significant main effect of condition [$F(1,20) = 13.3$, $p < 0.01$] along with significant interactions between condition and site [$F(1.1,21.7) = 7.1$, $p < 0.05$] and between condition, location and hemisphere [$F(2.0,40.1) = 3.3$, $p < 0.05$]. The subsidiary analyses revealed significant main effects of condition at all five electrode rows, significant interactions between condition and site at fronto-central to centro-parietal electrode rows and a significant interaction between condition, hemisphere and site at the fronto-central electrode row. The subsidiary analyses confirm that the Low JOL Hit effect in the 300-500 ms time window is a relatively widespread positive-going effect with a focus over frontal recording sites that is slightly skewed to the right on the fronto-central electrode row (see Figure 9.5a).

In the 500-800 ms time window the initial ANOVA revealed a significant main effect of condition [$F(1,20) = 11.5$, $p < 0.01$] along with a significant interaction between condition, location and hemisphere [$F(1.5,30.6) = 4.1$, $p < 0.05$]. The subsidiary analyses revealed significant main effects of condition at all five electrode rows, and significant interactions between condition and hemisphere at centro-parietal and parietal electrode rows. The subsidiary analyses reflect that the Low JOL Hit effect in the 500-800 ms time window is a relatively widespread positive-going effect which is most prominent over the left hemisphere at posterior electrode rows (see Figure 9.5b).

In the 1000-1600 ms time window, the initial ANOVA revealed significant interactions between condition and hemisphere [$F(1,20) = 5.2$, $p < 0.05$], condition, location and site [$F(1.8,36.2) = 6.4$, $p < 0.05$] and between condition, hemisphere and site [$F(1.7,33.5) = 5.3$, $p < 0.05$]. The subsidiary analyses revealed a significant main effect of condition along with a significant interaction between condition and site on the parietal electrode row, as well as significant interactions between condition and hemisphere and between condition, hemisphere and site on frontal and fronto-central electrode rows. The subsidiary analyses reflect the fact that the Low JOL Hit effect in the 1000-1600 ms time window is a positive-going effect with focus over right-frontal electrode sites (see Figure 9.5c). The interaction between condition, hemisphere and site at frontal and fronto-central electrode rows seem to reflect that the effect is largest at superior electrode sites on the left hemisphere but equal across sites on the right hemisphere. The main effects and interactions on the parietal electrode row reflect the presence of a simultaneous negative-going effect.

9.4.8. Medium JOL Hits

In the 300-500 ms time window the initial ANOVA revealed no significant main effects or interactions (all *Fs* < 3.1). By contrast, in the 500-800 ms time window the initial ANOVA revealed a significant main effect of condition [$F(1,20) = 6.0$, $p < 0.05$] reflecting the presence of a widespread positive-going effect with a focus over left-parietal electrode sites (see Figure 9.5b).

In the 1000-1600 ms time window the initial ANOVA revealed significant interactions between condition and hemisphere [$F(1,20) = 7.4$, $p < 0.05$], condition, location and site [$F(2.6,52.4) = 4.1$, $p < 0.05$] and between condition, hemisphere and site [$F(1.7,34.2) = 3.8$, $p < 0.05$]. The subsidiary analyses revealed significant interactions between condition and hemisphere at frontal and fronto-central electrode rows and a significant interaction between condition and site at the parietal electrode row. The subsidiary analyses confirm that the effect is positive-going, with a focus over right-frontal electrode sites (Figure 9.5c). Again, an additional interaction between condition and site on parietal electrode row seem to reflect the presence of a simultaneous negative-going effect.

9.4.9. High JOL Hits

In the 300-500 ms time window the initial ANOVA revealed a significant main effect of condition [$F(1,20) = 7.8$, $p < 0.05$] reflecting the presence of a widespread positive-going effect with a focus over mid-frontal electrode sites (see Figure 9.5a).

In the 500-800 ms time window the initial ANOVA revealed a significant main effect of condition [$F(1,20) = 38.9$, $p < 0.001$] along with interactions between condition and hemisphere [$F(1,20) = 8.3$, $p < 0.01$], condition and site [$F(1.1,21.0) = 7.3$, $p < 0.05$], condition, location and hemisphere [$F(1.7,33.9) = 5.7$, $p = 0.01$], condition, hemisphere and site [$F(1.4,28.2) = 5.3$, $p < 0.05$] and between condition, location, hemisphere and site [$F(3.2,63.7) = 3.1$, $p < 0.05$]. The subsidiary analyses revealed significant main effects of condition across all five electrode rows, significant interactions between condition and hemisphere on centro-parietal and parietal electrode rows, significant interactions between condition and site from fronto-central to parietal electrode rows and significant interactions between condition, hemisphere and site from central to parietal electrode rows. The subsidiary analyses confirm that the presence of a relatively widespread positive-going effect with a clear focus over left-parietal electrode rows (see Figure 9.5b). The interactions between condition and site reflect the fact that the effect is most prominent towards superior electrode sites. Similarly, the interactions between condition, hemisphere and site reflect that the effect is largest at mid electrode site on the left hemisphere and at superior electrode sites on the right hemisphere.

In the 1000-1600 m time window the initial ANOVA revealed significant interactions between condition and hemisphere [$F(1,20) = 8.8$, $p < 0.01$] and between condition, location and site [$F(2.2,44.9) = 5.3$, $p < 0.01$]. The subsidiary analyses revealed significant interactions between condition and hemisphere at frontal, fronto-central, centro-parietal and parietal electrode rows and a significant interaction between condition and site at the parietal electrode row. The subsidiary analyses confirm that the effect is positive-going with a focus over right-frontal electrode sites (see Figure 9.5c). As for the Low JOL Hit and Medium JOL Hit effects, the interactions between condition and site on the parietal electrode row reflect the presence of a simultaneous negative-going effect.

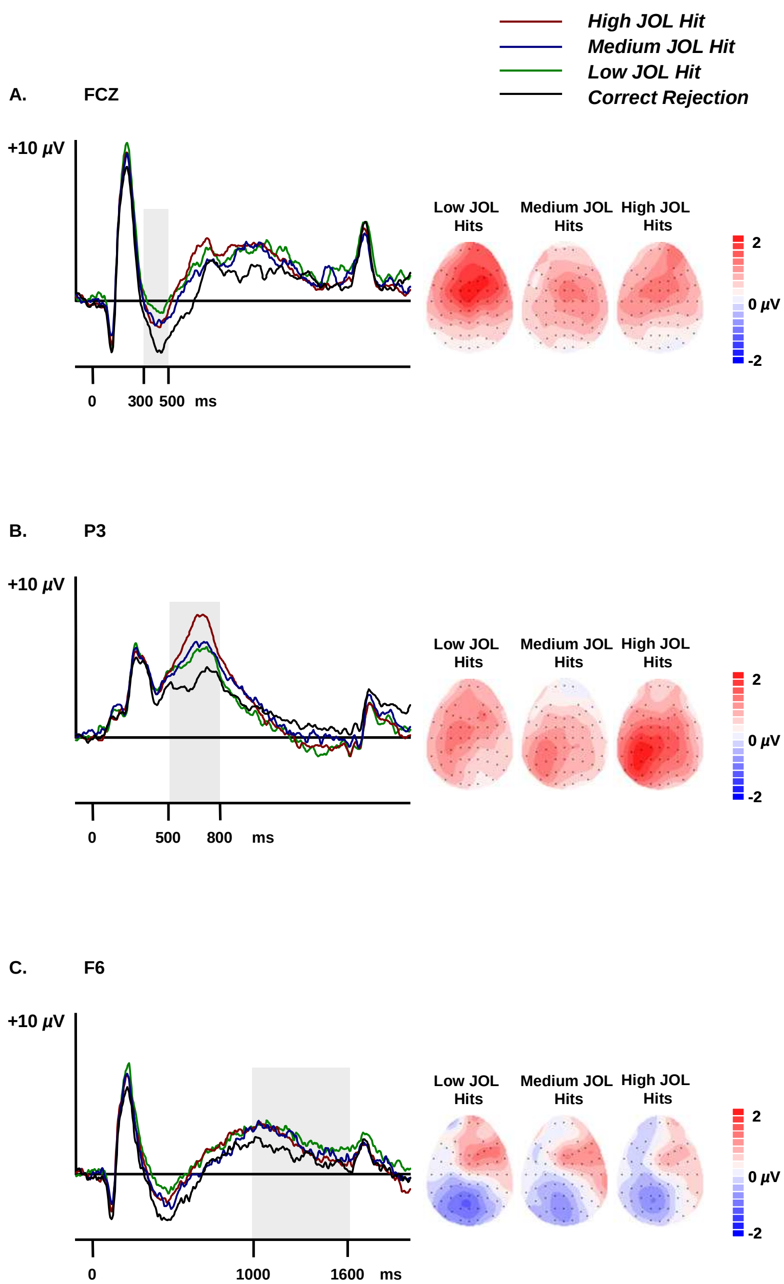

Figure 9.5 Memory retrieval effects at representative electrodes.

Panel A: Retrieval effects at FCZ during the early (300-500 ms) time window. Panel B: Retrieval effects at P3 during the 500-800 ms time window. Panel C: Retrieval effects at F6 during the 1000-1600 ms time window. The topographic map illustrates the scalp distributions of the effect (Low JOL Hits minus CR, Medium JOL Hits minus CR and High JOL Hits minus CR).

Table 9.2 Outcomes of the analyses of the memory retrieval effects.
(F = Frontal; FC = Fronto-Central; C = Central; CP = Centro-Parietal; P = Parietal).

Low JOL Hits/CR

300-500ms	F	FC	C	CP	P
Condition	$F(1,20)=7.6$; $p<0.05$	$F(1,20)=10.5$; $p<0.01$	$F(1,20)=17.0$; $p<0.001$	$F(1,20)=17.5$; $p<0.001$	$F(1,20)=8.9$; $p<0.01$
Condition x Hemisphere					
Condition x Site		$F(1.2,23.5)=4.5$; $p<0.05$	$F(1.2,23.6)=6.7$; $p<0.05$	$F(1.2,23.3)=8.9$; $p<0.01$	
Condition x Hemisphere x Site		$F(1.7,34.7)=4.1$; $p<0.05$			
500-800ms	**F**	**FC**	**C**	**CP**	**P**
Condition	$F(1,20)=7.0$; $p<0.05$	$F(1,20)=8.7$; $p<0.01$	$F(1,20)=12.3$; $p<0.01$	$F(1,20)=10.7$; $p<0.01$	$F(1,20)=6.9$; $p<0.05$
Condition x Hemisphere				$F(1,20)=5.3$; $p<0.05$	$F(1,20)=6.6$; $p<0.05$
Condition x Site					
Condition x Hemisphere x Site					
1000-1600ms	**F**	**FC**	**C**	**CP**	**P**
Condition					$F(1,20)=6.3$; $p<0.05$
Condition x Hemisphere	$F(1,20)=8.1$; $p<0.05$	$F(1,20)=4.3$; $p<0.05$			
Condition x Site					$F(1.1,22.6)=4.2$; $p<0.05$
Condition x Hemisphere x Site	$F(1.6,32.3)=4.6$; $p<0.05$	$F(1.8,41.4)=4.6$; $p<0.05$			

Medium JOL Hits/CR

1000-1600ms	F	FC	C	CP	P
Condition					
Condition x Hemisphere	$F(1,20)=8.8$; $p<0.01$	$F(1,20)=7.4$; $p<0.05$			
Condition x Site					$F(1.2,23.9)=6.5$; $p<0.05$
Condition x Hemisphere x Site					

High JOL Hits/CR

500-800ms	F	FC	C	CP	P
Condition	$F(1,20)=10.0$; $p<0.01$	$F(1,20)=19.2$; $p<0.001$	$F(1,20)=39.5$; $p<0.001$	$F(1,20)=63.8$; $p<0.001$	$F(1,20)=54.6$; $p<0.001$
Condition x Hemisphere				$F(1,20)=17.6$; $p<0.001$	$F(1,20)=20.8$; $p<0.001$
Condition x Site		$F(1.2,23.2)=6.7$; $p<0.05$	$F(1.1,22.0)=8.2$; $p<0.01$	$F(1.1,22.6)=7.4$; $p<0.05$	$F(1.1,22.4)=4.9$; $p<0.05$
Condition x Hemisphere x Site			$F(1.5,29.7)=6.1$; $p<0.05$	$F(1.5,29.4)=9.2$; $p<0.01$	$F(1.5,29.1)=10.4$; $p<0.01$
1000-1600ms	**F**	**FC**	**C**	**CP**	**P**
Condition					
Condition x Hemisphere	$F(1,20)=10.7$; $p<0.01$	$F(1,20)=5.6$; $p<0.05$		$F(1,20)=5.6$; $p<0.05$	$F(1,20)=20.4$; $p<0.001$
Condition x Site					$F(1.1,22.1)=8.2$; $p<0.01$
Condition x Hemisphere x Site					

9.4.10. Comparison of Low and High JOL Hits

For the 300-500 ms and 1000-1600 ms time windows, the initial ANOVAs revealed no significant main effects or interactions (all *Fs* < 3.4). By contrast, for the 500-800 ms time window the ANOVA revealed a significant main effect of condition [$F(1,20) = 6.7$, $p < 0.05$] along with significant interactions between condition and location [$F(1.1,21.9) = 6.2$, $p < 0.05$] and between condition, hemisphere and site [$F(1.2,24.4) = 5.1$, $p < 0.05$]. The subsidiary analyses revealed significant main effects of condition as well as significant interactions between condition, hemisphere and site from central to parietal electrode rows and a significant interaction between condition and site at the centro-parietal electrode row. The subsidiary analyses confirm that ERPs to High JOL Hits are more positive-going relative to ERPs to Low JOL Hits over posterior electrode sites. This effect is equal across sites on the left hemisphere but is largest on superior electrode sites on the right hemisphere.

9.4.11. Comparison of Low and Medium JOL Hits

For the 500-800 ms and 1000-1600 ms time windows the initial ANOVAs revealed no significant main effects or interactions (all *Fs* < 3.1).

9.4.12. Comparison of Medium and High JOL Hits

Similarly, for the 500-800 ms and 1000-1600 ms time windows the initial ANOVAs revealed no significant main effects or interactions (all *Fs* < 4.4).

Table 9.3 Outcomes of the comparisons of memory retrieval effects.
(F = Frontal; FC = Fronto-Central; C = Central; CP = Centro-Parietal; P = Parietal).

Low JOL Hits/High JOL Hits

500-800ms	F	FC	C	CP	P
Condition			$F(1,20)=6.5$; $p<0.05$	$F(1,20)=16.4$; $p<0.01$	$F(1,20)=14.6$; $p<0.05$
Condition x Hemisphere					
Condition x Site				$F(1.3,25.9)=4.0$; $p<0.05$	
Condition x Hemisphere x Site			$F(1.5,29.4)=4.2$; $p<0.05$	$F(1.7,33.0)=5.5$; $p<0.05$	$F(1.4,27.8)=8.6$; $p<0.01$

9.4.13. Analyses of Scalp Distributions

As for Experiment 1, scalp distribution analyses were carried out to establish whether the effects in the three time windows were generated by separable neural systems. Data were collapsed across JOL, forming two response categories: Hits and CR (topographic maps are provided in Figure 9.6). The analyses were conducted using ANOVA with factors of time window (Early versus Middle, Early versus Late, Middle versus Late), location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and site (superior, mid, inferior).

The comparison of the early and middle time windows revealed significant interactions between time and location [$F(1.2,23.8) = 8.0$, $p < 0.01$] and between time and hemisphere [$F(1,20) = 8.3$, $p < 0.01$]. The comparison of the early and late time windows revealed significant interactions between time and hemisphere [$F(1,20) = 10.3$, $p < 0.01$], time and site [$F(1.1,22.4) = 5.9$, $p < 0.05$] and between time, location and site [$F(2.6,52.4) = 3.1$, $p < 0.05$]. The comparison between the middle and late time windows revealed significant interactions between time and location [$F(1.1,22.3) = 4.5$, $p < 0.05$], time and hemisphere [$F(1,20) = 22.3$, $p < 0.001$], time and site [$F(1.2,23.2) = 11.0$, $p < 0.01$], time, location and site [$F(1.8,36.8) = 4.9$, $p < 0.05$] and between time, hemisphere and site [$F(1.2,25.0) = 10.0$, $p < 0.01$]. Altogether these analyses reflect that the three retrieval effect depicted in Figure 9.6 are produced by different sets of neural generators; the early effect is characterised by mid-frontal positivity, the middle effect is characterised by left-parietal positivity, and finally, the late effect is characterised by right-frontal positivity with additional negativity at mid posterior electrode sites.

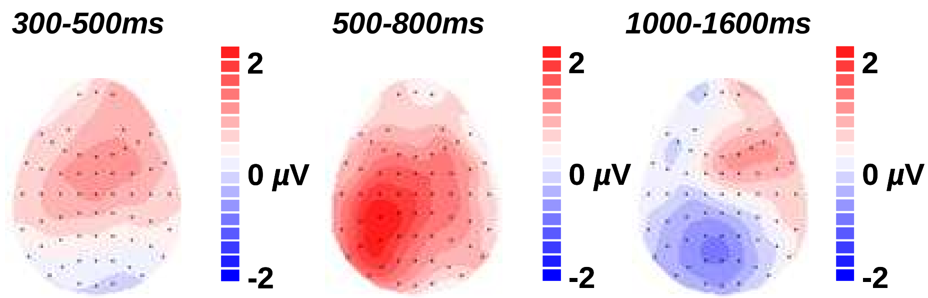

Figure 9.6 Distributions of memory retrieval effects from Experiment 2.
The topographic map illustrates the scalp distributions of the recognition effects during three time windows collapsed across level of JOL (Hits minus CR).

9.5. Discussion

The current experiments investigated the consequences JOL assessments have for the engagement of retrieval processes during memory tests. Measures of familiarity, recollection and post-retrieval monitoring were obtained using ERPs that were acquired time-locked to the onset of cues and lures during cued recall (Experiment 1) and recognition (Experiment 2) memory tasks. Tests of cued recall produced left-parietal (recollection) and right-frontal (post-retrieval monitoring) effects but not a statistically reliable mid-frontal effect (familiarity). Neither of the ERP effects were differentially engaged for items assigned low versus high JOLs at study. By contrast, old/new recognition tests produced three reliable retrieval effects. Moreover, while the mid-frontal and the right-frontal effects were equal across different levels of JOL, the left-parietal effect was clearly modulated by JOL; the higher the JOL the larger the effect. These results are consistent with the assumption that contextual cues, which later support the recovery of episodic memory for the study items, provide a reliable basis for making JOLs. The findings from each of the respective experiments will be discussed in turn below.

9.5.1. Experiment 1

It is slightly surprising that cued recall task used in Experiment 1 did not reveal any evidence of a mid-frontal old/new effect. Notably, however, the sample size was rather small (*N=14*) and the lack of an effect could therefore have been due to low power. Although left-parietal effects have been observed in the absence of mid-frontal effects previously (e.g. Yovel & Paller, 2004), it is difficult to interpret this null result. The presence of frontal activity during the 500-800 ms time window could signify that the mid-frontal effect of familiarity occurred later than expected, however this possibility has not been explored further due to the overlap in time course with the left-parietal effect.

The more important finding from Experiment 1 was that the left-parietal effect was of comparable size for the Low JOL and High JOL Recall conditions. It is slightly problematic that the High JOL Recall effect was not statistically larger over the left hemisphere; however since the effect exhibited similar time course and morphology to the Low JOL Recall effect, it would be difficult to argue against similar functional interpretations. The lack of a modulation of the left-parietal effect is consistent with the foregoing predictions; when participants performed the cued recall task, trials included in the ERPs were a selection of the low and high JOL items that were fully recollected.

Investigations of the 1000-1600 ms time window revealed evidence of a right-frontal old/new effect which was, as the left-parietal effect, equal across conditions. Although the analyses of the High JOL Recall effect indicated the presence of an additional negative-going effect at parietal electrode sites, this effect is likely reflecting the late posterior negative slow wave (see Wolk et al., 2006) and will not be considered further. Visual examinations of the waveforms (see Figures 9.1 and 9.2c) also give the impression that the Low JOL Recall condition produces an effect which is slightly more positive-going relative to High JOL Recall. Whether this difference is real or reflects noise is hard to establish given the power issues mentioned above. What significance such a difference would have if it were real is also hard to conceptualise. The current understanding is that the right-frontal effect reflects some kind of monitoring of the product of (episodic or semantic) memory retrieval; possibly the product of Low JOL Recall is more effortful to monitor, however no further speculations will be brought forward due to the lack of statistical differences across conditions. At their strongest the results from Experiment 1 suggest that retrieval effects are not differentially engaged for items assigned high and low JOLs at study when memory is assessed through cued recall.

9.5.2. Experiment 2

In contrast to Experiment 1, there was clear evidence of mid-frontal effects during the 300-500 ms time window for Experiment 2; both Low JOL Hits and High JOL Hits produced effects believed to signify familiarity based recognition and these were equal in magnitude. Surprisingly, however, the Medium JOL Hits condition did not produce a reliable effect in the early time window. From the waveforms in Figures 9.4 and 9.5a, however, it seems clear that effects are present but seemingly did not reach significance. The most likely explanation to the lack of a reliable mid-frontal effect for Medium JOL Hits is therefore lack of power; consistent with this interpretation, fewer trials were included in the Medium JOL Hits condition (45) compared to Low JOL Hits (53) and High JOL Hits (95). This was because Medium JOL Hits only comprise JOL responses of ‘3’ whereas Low and High JOL Hits comprise ‘1+2’ and ‘4+5’ responses respectively.

The left-parietal effect observed in Experiment 2 was clearly modified by the JOL responses made at study; the higher the JOL rating the larger the effect. Statistically the effect was present for all three conditions, however whereas High JOL Hits were significantly larger than Low JOL Hits, Medium JOL Hits did not differ statistically from either Low JOL or High JOL Hits. Nevertheless, these outcomes suggest that the ERPs to the Medium JOL Hits fit between Low JOL and High JOL Hits and this is also the impression gained from Figures 9.4 and 9.5b. The correlation between JOL and the magnitude of the left-parietal effect, combined with the lack of a modulation of the mid-frontal effect, suggest that only processes consequential to conscious recollection, and not familiarity, provide bases for making JOLs at study – an observation which is consistent with the behavioural findings provided by Daniels et al. (2009). One remaining question concerns the specifics of the processes that later recollection is contingent upon. One possibility, which is also raised by Daniels et al. (2009), is that participants make use of contextual cues at the time of study when they make JOL decisions and that these cues later aid conscious recollection at the time of retrieval. Hence, by this view, the same properties of an item are assessed at study as are re-assessed at test when participants decide whether an item has previously been encountered.

As in Experiment 1, all conditions showed evidence of right-frontal old/new effects (in addition to late posterior negative slow waves; Wolk et al., 2006), which were equal in magnitude. Since modulations of the effects were evident, and no clear hypotheses had been outlined regarding a potential relationship with JOLs, the right-frontal effects were not further discussed in this chapter.

9.6. Summary and Conclusion

The aim of examining the retrieval phase ERPs from Experiments 1 and 2 was to investigate whether JOLs made at study have any consequences for the pattern of retrieval processes engaged during cued recall (Experiment 1) and recognition (Experiment 2). Tests of cued recall produced left-parietal and right-frontal effects that were equal for Low JOL Recall and High JOL Recall, but there was no evidence of mid-frontal effects (possibly due to lack of power). Recognition tests produced mid-frontal, left-parietal and right-frontal effects; however only the left-parietal effect correlated with JOL (higher JOLs were associated with larger effects). These results strongly suggest that only processes leading to later recollection form a reliable basis for making JOLs at study.

Chapter 10.

Judgments of Learning and the ERP Correlates of Memory Retrieval for Pictures

10.1. Introduction

Having established that the neural correlates of JOLs to pictures and words are different, the next step was to further investigate the material specificity of the JOL effects by examining the ERPs during the retrieval phase of Experiment 4. Specifically, the question is: will JOL be reflected in the neural correlate of recollection-based retrieval in the same manner as in Experiment 2?

As highlighted in Chapters 3, the nature of SM effects is profoundly sensitive to numerous aspects of the study episode, such as the choice of encoding task, the intentions to encode and the types of stimulus material, the latter of which is the focus of the present chapter. Unlike SM effects, the literature on memory retrieval effects reports surprising resistance to changes in stimulus materials. For example, the mid-frontal effect, believed by many researchers to constitute an ERP correlate of familiarity[12], has been found for words (Curran, 2000; Nessler et al., 2001), pictures (Curran & Cleary, 2003), faces (Curran & Hancock, 2007) and even

[12] See Chapter 3 for an alternative functional interpretation of the mid-frontal old/new effect.

computer-generated two-dimensional polygons (Curran et al., 2002). Similarly, the left-parietal effect has been identified in studies using words (Donaldson & Rugg, 1998), line drawings (Curran & Cleary, 2003), landscape/object compound stimuli (Tsivilis et al., 2001) and information presented in different modalities (Schloerscheidt & Rugg, 2004). This collection of evidence supports the understanding that the mid-frontal and left-parietal effects are not material-specific but index generic retrieval processes. This understanding has, however, been seriously challenged by a series of recent experiments investigating retrieval of face stimuli (MacKenzie & Donaldson, 2007; 2009; Yick & Wilding, 2008; but also see Yovel & Paller, 2004).

In one experiment by MacKenzie & Donaldson (2009) participants studied faces paired with names and were later presented with each of the studied faces and names (one after another, separately) intermixed with a number of new faces and names. The memory task was first to make old/new judgments to each test item and, following each ‘old’ judgment, to indicate whether the item was remembered or familiar. Remembered names elicited the traditional mid-frontal and left-parietal effects. Remembered faces, in contrast, were associated with an anterior effect that was present during the time window in which a left-parietal effect was expected (500–700 ms post-stimulus presentation).

MacKenzie & Donaldson (2009) did not suggest that the anterior recollection effect was face-specific primarily because they claim a similar effect was apparent in a previous study using picture stimuli (Duarte et al., 2004). Rather, they suggest that there are some properties of the stimuli (in addition to being non-verbal) which results in them being recollected in a different way. One possibility, according to MacKenzie & Donaldson (2009) is that the faces and the pictures are simply more difficult to remember.

Whether the indoor scenes used as stimulus material in the current experiment will elicit the typical left-parietal recollection effect or the anterior effect observed by MacKenzie & Donaldson (2007; 2009) is difficult to anticipate. However, the distribution of the recollection effect is not important per se, as it is the modulation of the ERP index of recollection that is of particular interest here. The results from the retrieval data of Experiment 2 (Chapter 9) strongly suggested that JOLs made for word pairs are based on aspects of the study episode that lead to later recollection[13]. This conclusion was based on the observation that items receiving high JOLs at study elicited left-parietal effects of a greater magnitude compared to items assigned low JOLs. Since no modulation of the mid-frontal effect was evident, it seems that processing leading to later familiarity does not contribute significantly to the JOL decision.

If JOLs for pictures are also based on "recollection-related" processes, the ERP index of recollection should also be modulated in Experiment 4. However, when stimuli are presented in the form of pictures rather than word, different perceptual information is available for processing and it is therefore not guaranteed that participants will base JOLs on the same factors (indeed, the study data from

[13] The test data from Experiment 1 showed equal left-parietal effects for items assigned low and high JOLs at study. Importantly, however, these results were obtained using a cued-recall task rather than recognition, and are therefore not used as a basis for predicting the outcomes of Experiment 4.

Experiment 4 suggest differences in processing at the time of study). Therefore, JOLs for pictures could be reliant on factors that are not predictive of recollection, but rather on familiarity (such as perhaps perceptual fluency) and the possible outcomes therefore include a modulation of the familiarity component or, alternatively, no modulations of retrieval effects at all.

In sum, the main goals of the present experiment are (i) to investigate whether the picture and word block elicit comparable ERP retrieval effects, and most importantly (ii) to examine whether the ERP retrieval effects, if present, are modulated by JOL in the same manner as for Experiment 2 (see Chapter 9). To provide a better controlled comparison across stimulus materials, the test phase data were not only analysed for single item pictures but also from single item words (see Chapter 8).

10.2. Method

The retrieval data sets from Experiment 4 are derived from a subset of participants who contributed to the study phase data sets of the same experiment. Participant details therefore deviate slightly from those reported in Chapters 8 and are outlined below.

Of the 24 participants who contributed to the study phase data of Experiment 4, 21 of these performed sufficiently to contribute to the test phase data. This subset of participants (14 female) had a mean age of 20 (range: 18-27).

The stimulus materials and experimental procedures conform to those outlined in Chapter 4 and is also schematically illustrated in Figure 8.1 in Chapter 8. Grand average ERP waveforms were formed for the following response categories: High JOL Hits (items assigned a high JOL at study and which were recognised as old at test), Low JOL Hits (items assigned a low JOL at study and which were recognised as old at test) and Correct Rejections (CR; correctly identified new items). For the word block the mean numbers of trials were 54, 50 and 70 for High JOL Hit, Low JOL Hit and CR categories respectively. For the picture block the mean numbers of trials were 38, 34 and 57 for High JOL Hit, Low JOL Hit and CR categories respectively.

10.3. Behavioural Results

The behavioural results from the sample of participants contributing to the test phases of Experiment 4 do not differ considerably from the behavioural results of the full sample contributing to the study phases. The behavioural results are for that reason not re-reported in this section, but for completeness, the data are summarised in Appendix E.

10.4. Event-Related Potential Results

The initial ERP analyses comprised assessments of the test phase ERPs sorted according to the behavioural response categories: Low JOL Hit, High JOL Hit and CR. Low JOL Hit and High JOL Hit ERPs were examined with a common baseline of CR. Low JOL Hit and High JOL Hit effects were first characterised and analysed separately and then compared against each other.

The ERP data were analysed for the traditional time windows that have been identified in the literature (Allan et al., 1998; Rugg, 1995; Rugg & Curran, 2007); 300-500 ms (mid-frontal old/new effect), 500-800 ms (left-parietal old/new effect) and 1000-1600 ms (right-frontal old/new effect) post-stimulus. Each contrast was first analysed using ANOVA with factors of category (Low JOL Hit versus CR and High JOL Hit versus CR), location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and electrode site (superior, mid, inferior) followed by five subsidiary analyses on each separate location. Waveforms for the retrieval effects are shown in Figures 10.1 (words) and 10.2 (pictures) at electrodes included in the analyses. The outcomes of the subsidiary analyses producing significant results are summarised in Tables 10.1 and 10.2.

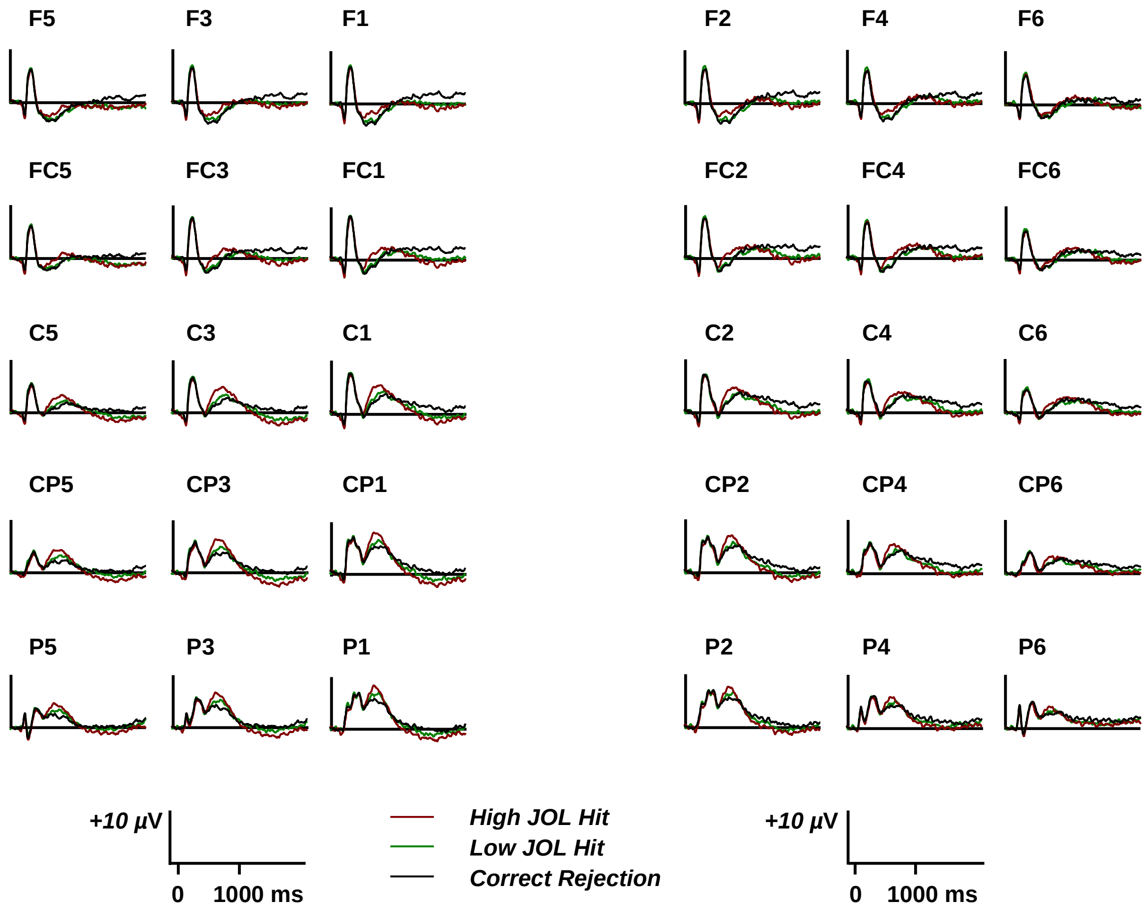

Figure 10.1 Memory retrieval effects for words.
Grand average ERPs for CR (black lines), High JOL Hits (red lines) and Low JOL Hits (green lines).

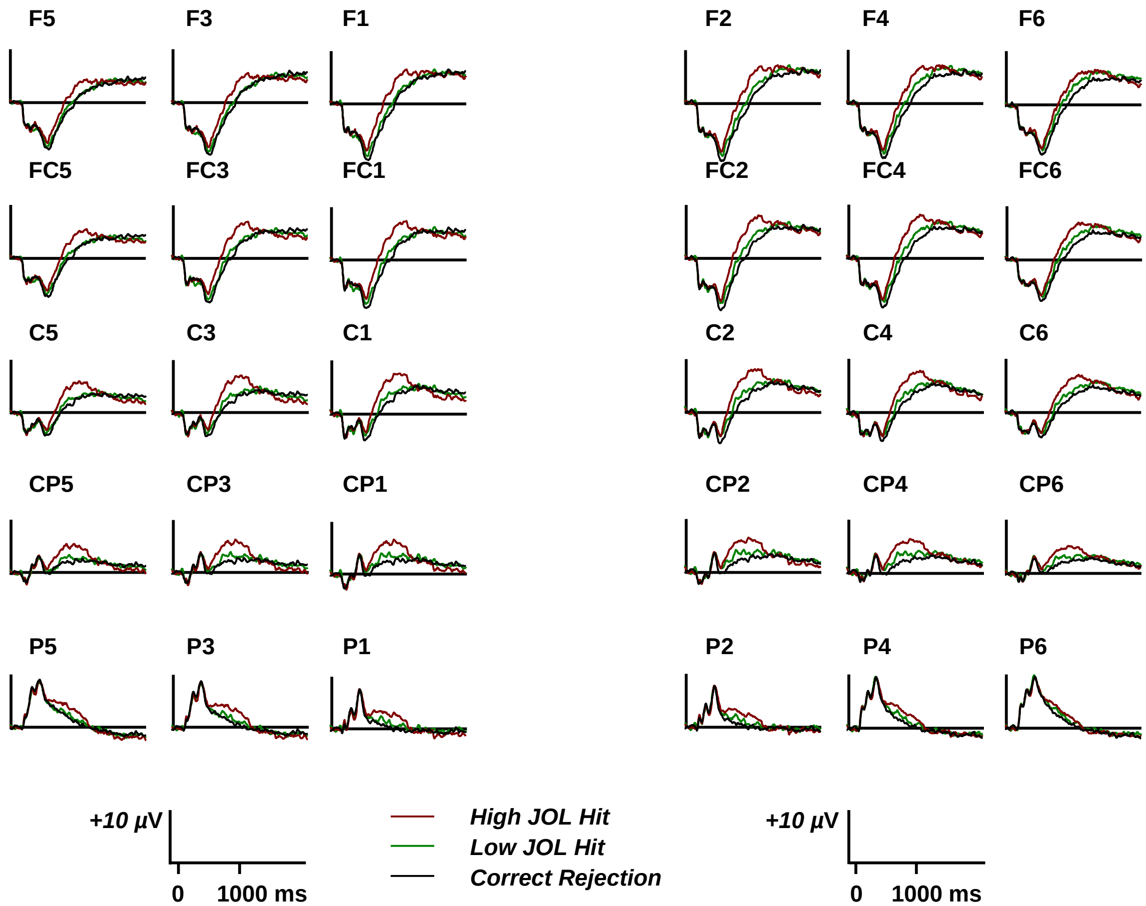

Figure 10.2 Memory retrieval effects for pictures.
Grand average ERPs for Correct Rejections (black lines), High JOL Hits (red lines) and Low JOL Hits (green lines)

10.4.1. Word Block: Low JOL Hit Effects

For both the 300-500 ms and 500-800 ms time windows the initial ANOVAs revealed no significant main effects or interactions (all *Fs* < 2.5). In the 1000-1600 ms time window the initial ANOVA revealed a significant main effect of condition [$F(1,20) = 5.6$, $p < 0.05$] and a significant interaction between condition and site [$F(1.1,21.6) = 5.0$, $p < 0.05$]. The analysis reflects the presence of a widespread negative-going effect which is focussed over midline electrode sites (see Figure 10.3b).

10.4.2. Word Block: High JOL Hit Effects

As for the Low JOL Hit contrast, the initial ANOVA on the 300-500 ms time window revealed no significant main effects or interactions (all *Fs* < 3.5). In the 500-800 ms time window the initial ANOVA revealed only a significant main effect of condition [$F(1,20) = 12.1$, $p < 0.01$] reflecting that the High JOL Hit effect is a widespread positive-going effect that focussed over left-parietal electrode sites (see Figure 10.3a).

In the 1000-1600 ms time window the initial ANOVA revealed a significant main effect of condition [$F(1,20) = 12.0$, $p < 0.01$] and a significant interaction between condition and site [$F(1,20.1) = 7.5$, $p < 0.05$]. As for Low JOL Hits, the analyses reflect the presence of a widespread negative-going effect which is focussed over midline electrode sites (see Figure 10.3b).

10.4.3. Word Block: Comparison of Low and High JOL Hit Effects

In the 1000-1600 ms time window the ANOVA did not reveal any significant main effects or interactions (all Fs < 2.9).

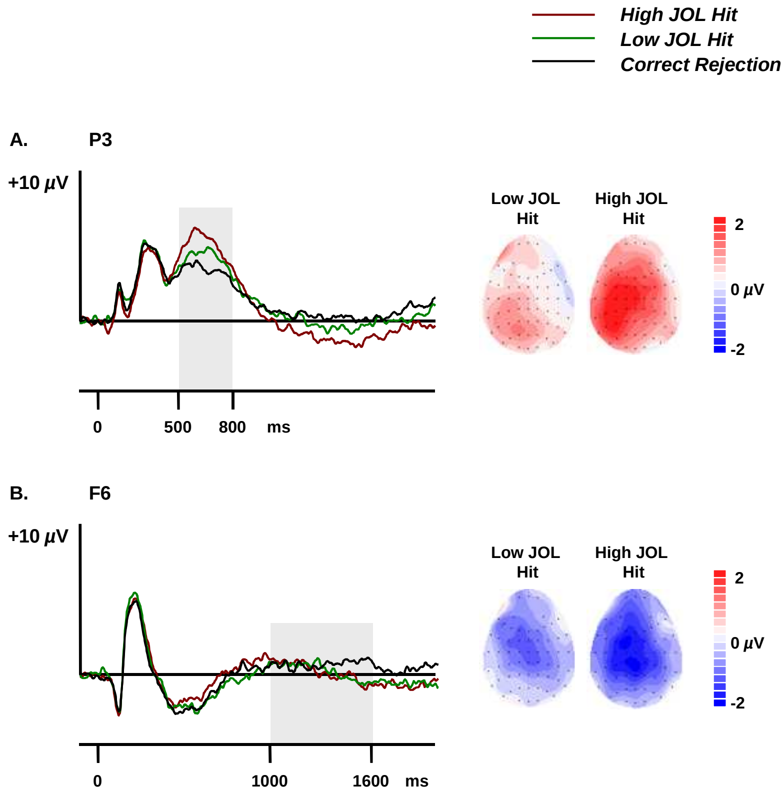

Figure 10.3 Memory retrieval effects at representative electrodes.
Panel A: Retrieval effects at P3 during the 500-800 ms time window. Panel B: Retrieval effects at F6 during the 1000-1600 ms time window. The topographic map illustrates the scalp distributions of the effect (Low JOL Hits minus CR and High JOL Hits minus CR).

10.4.4. Picture Block: Low JOL Hit Effects

For the 300-500 ms time window the initial ANOVAs revealed no significant main effects or interactions (all *Fs* < 2.3). For the 500-800 ms time window the initial ANOVA revealed a significant main effect of condition [$F(1,20) = 6.5$, $p < 0.05$], along with a significant interaction between condition and site [$F(1.2,23.0) = 5.0$, $p < 0.05$]. The analysis reflects widespread positivity with a focus over central electrode sites (see Figure 10.4a).

For the 1000-1600 ms time window the initial ANOVA revealed a significant interaction between condition, location and hemisphere [$F(2.4,48.1) = 3.3$, $p < 0.05$]. The subsidiary analyses revealed significant interactions between condition and hemisphere at frontal and fronto-central electrode rows. The subsidiary analyses confirm the presence of a positive-going effect which is focused over right-frontal electrode sites (see Figure 10.4b).

10.4.5. Picture Block: High JOL Hit Effects

For the 300-500 ms time window the initial ANOVAs revealed no significant main effects or interactions (all *Fs* < 4.2). For the 500-800 ms time window the initial ANOVA revealed a significant main effect of condition [$F(1,20) = 61.2$, $p < 0.001$] along with significant interactions between condition and location [$F(1.4,28.3) = 5.5$, $p < 0.05$] and between condition and site [$F(1.1,21.8) = 24.3$, $p < 0.001$]. The subsidiary analyses revealed significant main effects of condition and significant interactions between condition and site across all five electrode rows. The analyses confirm that effect is characterised by widespread positivity focused over midline fronto-central electrodes (see Figure 10.4a).

For the 1000-1600 ms time window the initial ANOVA revealed a significant interaction between condition and location [$F(1.2,23.7) = 4.1$, $p < 0.05$]. The subsidiary analyses revealed only a significant main effect of condition at the frontal electrode row reflecting the presence of a positive-going effect at frontal electrode sites (see Figure 10.4b).

10.4.6. Picture Block: Comparison of Low and High JOL Hit Effects

In the 500-800 ms time window the initial ANOVA revealed a significant main effect of condition [$F(1,20) = 20.8$, $p < 0.001$], along with significant interactions between condition and site [$F(1.1,22.1) = 10.3$, $p < 0.01$] and condition, location and site [$F(3.4,68.6) = 4.5$, $p < 0.01$]. The subsidiary analyses revealed significant main effects of condition across all five electrode rows along with significant interactions between condition and site from frontal to central electrode rows and significant interactions between condition, hemisphere and site at the parietal electrode row. Overall, the outcomes reflect the fact that the High JOL Hit effect is more positive-going compared to the Low JOL Hit effect; a difference which is widespread but maximal on midline central electrodes (slightly skewed to the right over parietal electrodes).

In the 1000-1600 ms time window the initial ANOVA did not reveal any significant main effect or interactions (all Fs < 2.8).

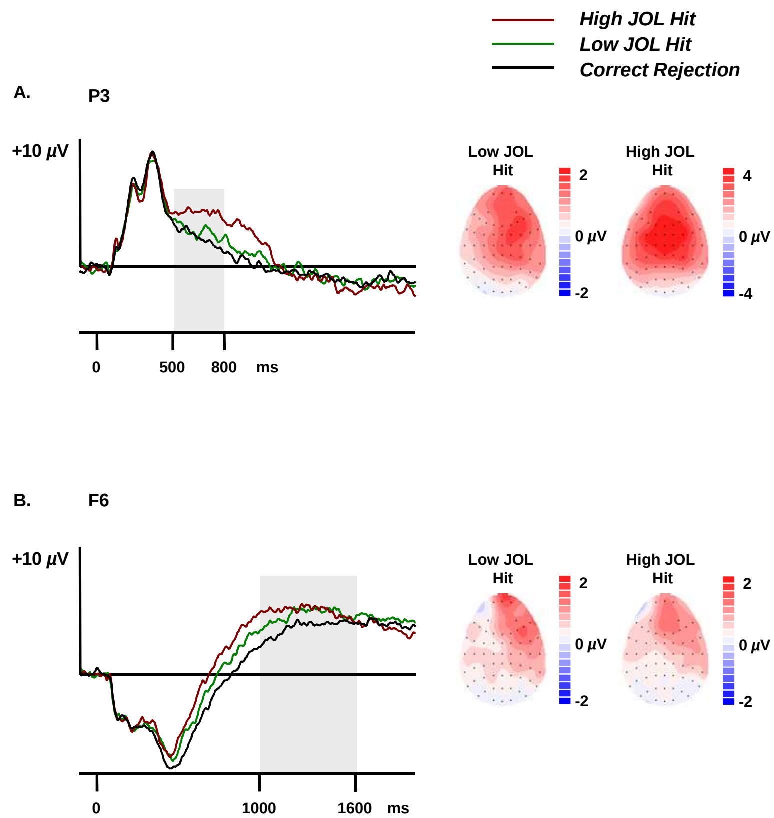

Figure 10.4 Memory retrieval effects at representative electrodes.
Panel A: Retrieval effects at P3 during the 500-800 ms time window. Panel B: Retrieval effects at F6 during the 1000-1600 ms time window. The topographic map illustrates the scalp distributions of the effect (Low JOL Hits minus CR and High JOL Hits minus CR).

Table 10.1 Outcomes of the analyses of the memory retrieval effects.
(F = Frontal; FC = Fronto-Central; C = Central; CP = Centro-Parietal; P = Parietal).

Low JOL Hit/CR

1000-1600ms	F	FC	C	CP	P
Condition					
Condition x Hemisphere	$F(1,20)=5.6$; $p<0.05$	$F(1,20)=5.2$; $p<0.05$			
Condition x Site					
Condition x Hemisphere x Site					

High JOL Hit/CR

500-800ms	F	FC	C	CP	P
Condition	$F(1,20)=35.6$; $p<0.001$	$F(1,20)=44.3$; $p<0.001$	$F(1,20)=59.4$; $p<0.001$	$F(1,20)=59.0$; $p<0.001$	$F(1,20)=29.1$; $p<0.001$
Condition x Hemisphere					
Condition x Site	$F(1.2,23.8)=10.6$; $p<0.01$	$F(1.2,23.3)=21.8$; $p<0.001$	$F(1.2,24.4)=16.0$; $p<0.001$	$F(1.1,22.8)=11.6$; $p<0.01$	$F(1.1,21.6)=10.2$; $p<0.01$
Condition x Hemisphere x Site					
1000-1600ms	**F**	**FC**	**C**	**CP**	**P**
Condition	$F(1,20)=5.4$; $p<0.05$				
Condition x Hemisphere					
Condition x Site					
Condition x Hemisphere x Site					

Table 10.2 Outcomes of the comparison of the memory retrieval effects.
(F = Frontal; FC = Fronto-Central; C = Central; CP = Centro-Parietal; P = Parietal).

High JOL Hit/Low JOL Hit

500-800	F	FC	C	CP	P
Condition	$F(1,20)=11.8$; $p<0.01$	$F(1,20)=16.7$; $p<0.01$	$F(1,20)=19.6$; $p<0.001$	$F(1,20)=18.9$; $p<0.001$	$F(1,20)=11.7$; $p<0.01$
Condition x Hemisphere					
Condition x Site	$F(1.4,27.5)=10.6$; $p<0.01$	$F(1.3,25.5)=13.4$; $p<0.01$	$F(1.3,26.3)=4.8$; $p<0.05$		
Condition x Hemisphere x Site					$F(1.3,26.8)=8.3$; $p<0.01$

10.4.7. Analyses of Scalp Distributions

Scalp distribution analyses were carried out to establish whether the effects in the different time windows were generated by separable neural systems. Data were collapsed across JOL for the picture data, forming two response categories: Hits and CR. For the word data, the analyses were done on the High JOL Hit data since the low JOL Hits did not produce any reliable effect during the 500-800 ms time window. The analyses were conducted using ANOVA with factors of time window (Middle versus Late), location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and site (superior, mid, inferior). 300-500 ms was not included in the analyses since no effects were present during that time window. The analyses were carried out separately for the word and the picture blocks.

For the word block (see Figure 10.5), the ANOVA revealed a significant main effect of condition [$F(1,20) = 5.7$, $p < 0.05$] and significant interactions between time and hemisphere [$F(1,20) = 8.9$, $p < 0.01$], time and site [$F(1.2,22.4) = 32.5$, $p < 0.001$] and between time, hemisphere and site [$F(1.2,24.9) = 7.3$, $p < 0.01$]. The analyses confirm that the two retrieval effects are produced by separate neural generators; the middle effect is characterised by left-parietal positivity and the late effect is characterised by widespread negativity over midline electrode sites.

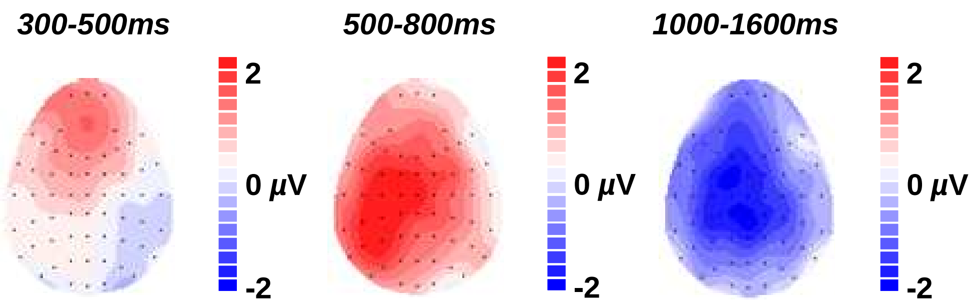

Figure 10.5 Distributions of memory retrieval effects from the word block.
The topographic map illustrates the scalp distributions of the recognition effects for words during three time windows for High JOL Hit effects (High JOL Hits minus CR).

For the picture block (see Figure 10.6), the ANOVA revealed a significant interaction between time and site [$F(1.1,21.9) = 13.2$, $p < 0.01$] and between time, location and site [$F(1.9,38.0) = 3.8$, $p < 0.05$]. The analyses confirm that the middle and the late retrieval effects are produced by at least partially non-overlapping neural generators; the middle effect is characterised by fronto-central positivity focussed over superior electrode sites whereas the late effect is characterised by frontal positivity focussed over inferior electrode sites.

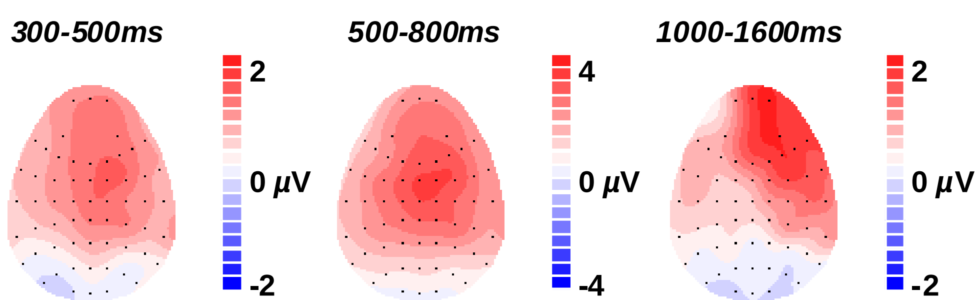

Figure 10.6 Distributions of memory retrieval effects from the picture block.
The topographic map illustrates the scalp distributions of the recognition effects for pictures during three time windows collapsed across level of JOL (Hits minus CR).

10.5. Discussion

The purpose of examining the retrieval phase data of Experiment 4 was again to use established ERP markers of memory retrieval to investigate the kinds of processes that JOLs promote, and (in an extension to the work in Chapter 9) to determine whether these processes differ according to the stimulus materials to which JOLs were made. The study data of Experiment 4 established that the neural correlates of JOLs for pictures differ from the neural correlates of JOLs for words (see Chapter 8); however this difference across stimulus materials need not be present during retrieval. On a superficial level, however, the test data from Experiment 4 has provided comparable findings to that of Experiment 2; the higher the JOL the larger the magnitude of the ERP indices of recollection. Together these results clearly demonstrate that JOL is closely tied to recollection-related processes, whereas the significance of familiarity processes is less certain, since no reliable effects were observed in the traditional 300-500 ms time window for either experiment.

During the later time window of 1000-1600 ms post-stimulus, the word block elicited a negative-going and centrally distributed effect rather than the expected right-frontal positivity. This effect, which was not modulated by JOL, does not resemble the typical distribution of the late posterior negative slow wave (see Wolk et al., 2006) and its functional interpretation is unknown. For pictures, the ERP effect in the late time window was characterised by increased positivity over right-frontal electrode sites. This right-frontal effect was also not modulated by JOL. Both the word and the picture effects will therefore not be further discussed.

10.5.1. Word Block

Surprisingly, there was no statistical evidence of either a mid-frontal familiarity effect or a left-parietal recollection effect for items assigned a low JOL at study. The only identified retrieval effect from the picture block was the left-parietal effect elicited by High JOL Hits. Notably, however, the waveforms shown in Figure 3 suggest that the left-parietal effect was modulated by JOL in the same manner as was demonstrated in Experiment 2.

The absence of reliable retrieval effects in the word block is difficult to interpret, and the safest decision is usually to refrain from drawing firm conclusions from any null result. Certainly, there are a number of possible reasons for the absence of effects in the word block, one of which is lack of power. Assessment of the trial numbers across Experiment 2 and 4 does not, however, suggest any important differences[14]. An alternative possibility is that the use of study word pairs (Experiment 2) as opposed to single item words provides a richer study episode and therefore more contextual information is available for later retrieval. Although participants were not required to report the second word of the word pair at test in Experiment 2, this information was possibly recollected when available. Left-parietal effects have been found to increase with the amount of contextual information that is recovered (Vilberg et al., 2006; Wilding & Rugg, 1996), and for that reason, it is possible that the statistical reliability of the left-parietal effect of Experiment 4 was compromised.

[14] The only noticeable difference is the trial numbers for High JOL Hits (54 in the current experiment and 97 in Experiment 2); however this observation is relatively unimportant given the lack of any effects for Low JOL Hits, which showed comparable trial numbers across experiments.

10.5.2. Picture Block

As for the word block, no early mid-frontal effects were evident in the picture block regardless of JOL made at study. There was, however, statistical support for retrieval effects for both Low JOL and High JOL Hits. These effects did not, however, show left-parietal distribution equivalent to that seen for words. Instead, the effects were widespread with maxima over midline fronto-central electrode sites. The effects seem to resemble previously reported effects for faces judged 'remembered' as opposed to 'familiar' (MacKenzie & Donaldson, 2007; 2009), which provides support for the view that the effects are indeed reflecting recollection-based recognition.

It is unknown why the recollection effect does not exhibit the traditional left-parietal focus, however, MacKenzie & Donaldson (2009) proposed that anterior effects may be consequences of increased performance difficulty and this explanation fits well with the behavioural results of the current experiment. Whereas the hit rate for word stimuli was well above 70%, the hit rate for pictures was slightly below 60%. Whether performance difficulty is the primary cause for the unexpected distribution is merely speculative, however further explorations of the anterior recollection effect will not be provided here as it falls outside the scope of this thesis. The important observations is rather the obvious modulation of the effect; as was the case for Experiment 2, the size of the recollection effect correlated with the JOL rating, showing larger amplitudes for recognition of high relative to low JOL test items. This finding strongly suggests that one important basis for making JOLs for pictures is the contextual information available at study, which also increases the probability of recollection occurring at test.

10.6. Summary and Conclusion

The test data from Experiment 4 showed that recognition of single item words elicited only a left-parietal effect for High JOL Hits during 500-800 ms post-stimulus, whereas recognition of pictures produced reliable effects during the same time window for both Low JOL and High JOL Hits. The effects in this case did not, however, show the typical left-parietal distribution but rather had a focus over midline fronto-central electrode sites. More importantly, the effect was significantly larger for items assigned High JOL as opposed to Low JOL at study, suggesting a clear correlation between JOLs and the size of the anterior effect. No effects were evident during the 300-500 ms time window for either condition in either experiment.

The current findings suggest JOL is predictive of later recollection for both word pairs (as demonstrated in Experiment 2) and pictures, although the respective ERP effects indexing the recollection processes differed in distribution. Experiment 4, therefore adds weight to the hypothesis that contextual information, which later ensures recollection of a study episode, serve as an important basis for making JOLs.

Chapter 11.

General Discussion

The final chapter of this thesis will provide a summary of the findings from Experiments 1-4 and attempt to relate these findings to the existing theoretical frameworks of metamemory. The purpose of the research was to investigate the cognitive and neural basis of Judgments of Learning through the use of Event-Related Potentials; specifically, Experiments 1, 2 and 4 compared the ERP correlates of JOLs and successful memory encoding (Chapters 5, 6 and 8) and also examined whether JOLs were reflected in the neural correlates of memory retrieval (Chapters 9 and 10). Finally, Experiment 3 sought to examine the neural correlates of successful encoding in the absence of JOL requirements to evaluate the contribution of metamemory to actual memory formation. The stimulus materials used across the experiments varied from word associates (Experiments 1, 2 and 3), to single item words (Experiment 4 – word block) and single item pictures (Experiment 4 – picture block), allowing the investigation of potential material specificity of JOL processing. The change from using a cued recall test of memory retrieval (Experiment 1) to using recognition tests (Experiments 2, 3 and 4) similarly allowed the subtleties of the ERP effects recorded at both study and test to be explored further. Altogether, the four experiments have provided rich characterisations of the interaction between memory and metamemory, which has not been reported previously.

11.1. Summary of Results

11.1.1. Behavioural Results

The series of experiments reported in this thesis were specifically designed to investigate the neural correlates of memory and metamemory using ERPs. Not surprisingly therefore, the experiments did not include any experimental manipulations that were designed to produce novel behavioural findings. Instead, existing metamemory manipulations were employed to provide a firm basis for the interpretation of the ERP data. Nonetheless, the behavioural results from the experiments are summarised below in Tables 11.1-11.3. These were provided primarily to confirm that participants' behaviour remained consistent across experiments.

The distribution of JOL responses were clustered towards the middle of the scale, exhibiting the shape of an inverted 'u', as confirmed by quadratic trends in the data. The most important aspect of this finding is that participants are making use of the full scale, and although many ERP trials are lost by the assignment of medium JOL responses (JOL = 3), this means that trials in which participants were presumably guessing where appropriately excluded. This exclusion further ensured that the ERP effects would not be unnecessarily diluted. It is important to note that participants were instructed to make use of the full rating scale during the experiment and this is likely to have influenced the distribution of responses. The reason why the specific instructions were given was primarily to ensure enough trials to form ERPs for each response category. If participants were not encouraged to respond in this way it is possible that the responses would have been more clustered. Clustering would probably have caused problems in terms of trial numbers, but the pattern of responses would likely have been a more accurate reflection of the participants' perceptions.

Similarly, the reaction times for making JOLs also exhibited quadratic trends for all Experiments except the picture block of Experiment 4 (which showed no main effect of JOL). The inverted 'u' shaped reaction time curve is a common finding in the JOL literature (see Son & Metcalfe, 2005) and presumably reflects uncertainty regarding the memorability of the relevant stimuli.

Table 11.1 Summary of trends in behavioural performance at study.

Experiment	Distribution of JOL resp.	RT across JOL
1	*Quadratic trend* ∩	*Linear and quadratic trends* ╲∩
2	*Linear and quadratic trends* ╱∩	*Linear and quadratic trends* ╲∩
4 (words)	*Linear and quadratic trends* ╲∩	*Quadratic trend* ∩
4 (pictures)	*Linear and quadratic trends* ╲∩	*No effect*

Table 11.2 shows the behavioural trends at test, which are also relatively consistent. For all experiments, the probability of correctly recalling (Experiment 1) or recognising (Experiments 2 and 4) items increased with increasing JOLs. This finding is well established in the behavioural JOL literature and discussed in detail in Chapter 1. In contrast to the reaction time measures at study, however, the reaction time at test was negatively correlated with JOL. This finding indicates that the time it takes to uncover memories for items judged unlikely to be remembered is longer compared to items that were judged likely to be remembered.

Table 11.2 Summary of trends in behavioural performance at test.

Experiment	Performance across JOL	RT across JOL
1	*Linear trend* /	*Linear trend* \
2	*Linear and quadratic trends* / ∪	*Linear trend* \
4 (words)	*Linear trend* /	*Linear and quadratic trends* \ ∩
4 (pictures)	*Linear and quadratic trends* / ∪	*Linear trend* \

The overall recognition and false alarm rate are summarised in Table 11.3, along with the Gamma correlation coefficient (G) and d_a, which are both measures of metamemory accuracy. The recognition rates did not differ considerably across experiments, with the exception of Experiment 3 and the picture block of Experiment 4, which have considerably lower recognition rates, presumably reflecting the lack of a specific encoding task and the use of a relatively homogenous picture set respectively.

In the wider literature, immediate JOLs are generally found to be moderately accurate (approximate G of 0.3) and this was also the case for the experiments reported in this thesis. Analyses revealed that the only significant difference in accuracy scores (as measured by both G and d_a) was between the word block with the lowest accuracy score (Experiment 2) and the picture block of Experiment 4[15]. Although this difference is relatively small, it suggests that pictures are more easily assessed than words.

Table 11.3: Summary of memory and metamemory accuracy.
Memory accuracies are displayed as mean percentage and corresponding S.E.

Experiment	Recog. rate	False alarm rate	G	d_a
1	77.0 (3.2)	12.3 (3.6)	0,29	0.40
2	79.1 (1.4)	16.4 (2.2)	0,26	0,37
3	66.1 (2.4)	20.2 (2.0)	N/A	N/A
4 (words)	75.5 (2.0)	15.7 (1.9)	0,36	0,53
4 (pictures)	59.5 (2.5)	15.5 (1.6)	0,38	0,56

[15] One-way ANOVA on G scores across experiments revealed a significant effect of experiment [$F(3,88) = 3.9$, $p < 0.05$]. Post hoc comparisons with Bonferroni corrections revealed that Experiment 2 and the Experiment 4 (pictures) were significantly different ($p < 0.05$). Similarly, the one-way ANOVA on d_a revealed a significant effect of experiment [$F(3,88) = 3.7$, $p < 0.05$]. Post hoc comparisons with bonferroni corrections revealed again that Experiment 2 and Experiment 4 (pictures) were significantly different ($p < 0.05$).

11.1.2. Study ERP Results

ERPs collected during the study phases of the experiments were examined in the following manner: (i) ERPs to items subsequently remembered were contrasted against ERPs to items that were subsequently forgotten thereby revealing the appearance of *SM effects* (Paller et al., 1987) and (ii) ERPs to items rated likely to be remembered (High JOL items) were contrasted against ERPs to items rated unlikely to be remembered (Low JOL items) thereby revealing the appearance of *JOL effects* (not characterised previously). The study phase effects from each experiment are summarised below in Figures 11.1 – 11.3, however before any detailed discussion of the results from the experiments is provided it is necessary to briefly outline some issues related to the statistical analyses and interpretation of the effects.

Some caution is necessary when evaluating the SM and JOL effects because the trials contributing to the two contrasts were the same, simply sorted and averaged according to different criteria, and the behavioural results showed reliable correlations between memory performance and JOLs (although these correlations were weak or moderate at the most). Consequently, activity related to memory processing could contaminate the appearance of JOL effects and vice versa. The overlapping trials are also the reason why the effects were characterised separately, without any attempts at direct statistical comparisons. Higher trial numbers allowed an examination of JOL effects within trials that only included subsequent hits in Experiment 2. The resulting effects were indistinguishable from the original effect and on basis of this observation it was assumed that the original JOL effects are genuine. However, since it was not possible to carry out comparable analyses of SM effects that were not contaminated by JOL it is impossible to establish whether the observed SM effects are accurate representations of the neural activity that predicts future memory.

The SM and JOL effects from the study phases of Experiments 1 and 2 are shown in Figure 11.1. Experiments 1 and 2 employed identical study paradigms but slightly different test paradigms. At study, participants saw a number of paired associates and were asked to make a JOL to each (on a five point scale). At test, participants who took part in Experiment 1 were presented with the upper words of each word pair from the study phase, intermixed with new lure words. The initial task was to make an old/new judgment for each word, indicating whether they remembered encountering the item during the study phase or not. Following each old judgment they were asked to report (by saying out loud) the second word of the pair. Participants who took part in Experiment 2 were only required to make the initial old/new judgment. The trials that formed the SM contrast were therefore sorted based on cued recall performance in Experiment 1 and on old/new recognition performance in Experiment 2. The JOL, since they were made during the study phase, should be unaffected by the change of test instructions (participants were kept unaware of the test format during the study phases). Potential differences in ERP effects between Experiments 1 and 2 were therefore expected to reflect changes in memory rather than metamemory related processing. As Figure 11.1 illustrates, no major differences were observed between the two experiments. Both paradigms elicited positive-going SM effects with posterior foci during a time window of 550-1000 ms post-stimulus. Furthermore, JOL effects with characteristics similar to the SM effects were also obtained in both experiments; however these effects were followed by negative-going effects from 1300-1900 ms post-stimulus. Notably, the late negative-going JOL effects were of different topographical distribution across the two experiments; while the effect from Experiment 1 was left-hemispheric, the effect from Experiment 2 showed a clear mid-posterior focus. The most apparent explanation for this distributional difference is that the JOL rating scale in Experiment 1 was not counterbalanced, whereas it was in Experiment 2 (see Chapter 4).

The primary aim of Experiment 2 was to attempt to manipulate the SM effect in isolation, thereby identifying the contribution of successful memory encoding to the early effect. Experiment 2 failed, however, to generate noteworthy differences. Instead the experiment generated enough trials to allow a parametric investigation of the JOL effect (i.e. the inclusion of Medium JOL trials), the analyses of which strongly suggest that the early JOL effect is clearly modulated by JOL whilst the later effect is not. This difference adds weight to the claim that the early and late JOL effects are reflecting functionally distinct processes.

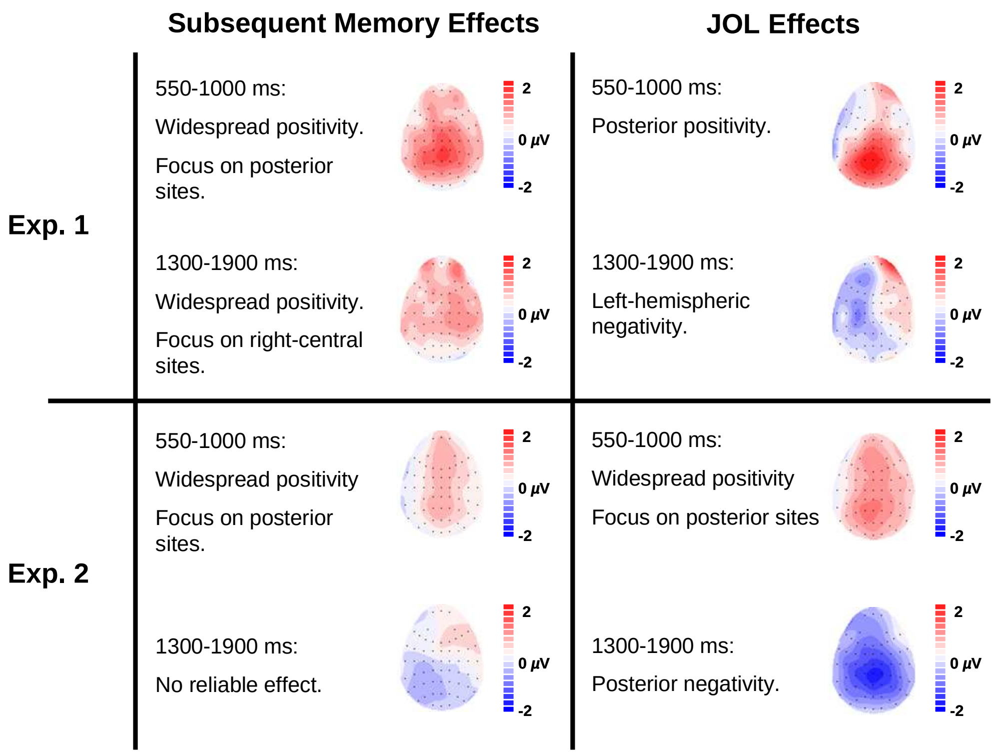

Figure 11.1 SM and JOL effects from Experiments 1 and 2.

Since changing the memory test format did not add to the understanding of the functional interpretation of the early positive effect that was shared between SM and JOL, Experiment 3 used an alternative approach to investigate these effects. By removing the requirements to make JOLs during the study phase it was possible to examine the appearance of SM effects that were presumably uncontaminated by metamemory processing. If the SM effects from Experiment 3 were found to be similar to those of Experiments 1 and 2, this would provide support for the claim that successful memory encoding operations were also contributing heavily to the early effects. If, by contrast, the SM effects turned out to be qualitatively different, this hypothesis would be difficult to defend.

Figure 11.2 shows the SM effect from Experiment 3, in which participants were instructed to press a key to terminate a study trial rather than to make JOLs (followed by a standard old/new recognition test identical to Experiment 2). The effect had a later onset time and was longer-lasting, with a frontal, rather than posterior, focus. These differences in both time course and apparent topographical distribution suggest that the processes that were supporting successful memory encoding in Experiment 3 were dissimilar to those supporting successful encoding in Experiments 1 and 2.

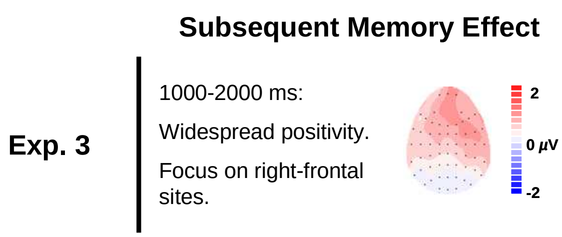

Figure 11.2 SM effect from Experiment 3.

Thus far, Experiments 1 and 2 have suggested the existence of early positive-going effects that are shared between successful memory encoding and JOLs in addition to late negative-going effects that are specific to JOLs. Furthermore, the results from Experiment 3 indicate that the shared ERP deflection could reflect JOL-specific SM effects. Overall, this set of findings corresponds well with the fMRI findings reported by Kao et al. (2005)[16], who found separate brain regions involved in memory and metamemory, but also a third set of regions that were active for both

[16] Strictly speaking, Experiments 1 and 2 did not provide any clear evidence of a memory-specific ERP effect, although the wide distribution of the early effect could hypothetically reflect the existence of two separate peaks, of which the frontal component could represent successful memory encoding and the dominant posterior component could represent JOL related processes. Alternatively, it is possible that memory-specific activity originates from brain regions that do not project activity to the scalp and for that reason is not detectable through the use of EEG.

memory and metamemory. Kao et al. (2005) employed pictures in their investigation of JOLs, which suggests that JOL-specific activity may be present across different kinds of materials. The last experiment in the series reported in this thesis was specifically designed to investigate the material specificity of the JOL effect. To allow direct comparison between encoding and JOLs to single item words and pictures, the experiment consisted of two separate within-participant blocks. The results from both blocks were first analysed using the original 550-1000 ms and 1300-1900 ms time windows (reported in Chapter 8), however visual inspections of the waveforms suggested that, for the word stimuli in particular, these did not appropriately capture the ERP effects. Alternative time windows for the word block was therefore identified and used for re-analysis. Scalp maps depicting the SM and JOL effects for both the word and picture blocks are summarised in Figure 11.3.

The single item word block produced SM effects that had earlier onsets compared to the previous experiments; during 300-800 ms post-stimulus the positive-going effect was widespread, with a focus over posterior electrode sites. Although the time course of this effect is different from the early effects of Experiments 1 and 2, the distribution appears to be similar. During 800-1200 ms post-stimulus, however, the effect exhibited a frontal focus. The JOL effects in the word block were characterised by positivity at prefrontal electrode sites during 300-800 ms and a combination of positivity at prefrontal electrode sites and negativity over posterior electrode sites during 800-1200 ms. Although the negative-going effect at posterior electrode sites might possibly be the same as the late negative effects from Experiments 1 and 2, the prefrontal positivity has not been demonstrated previously.

It is also unclear whether the frontal SM and JOL effects in the late time window are separate effects or originate from the same neural generators. The ERP results from the word block therefore appears to have some similarities to the results from Experiments 1 and 2, however, there are also some clear discrepancies.

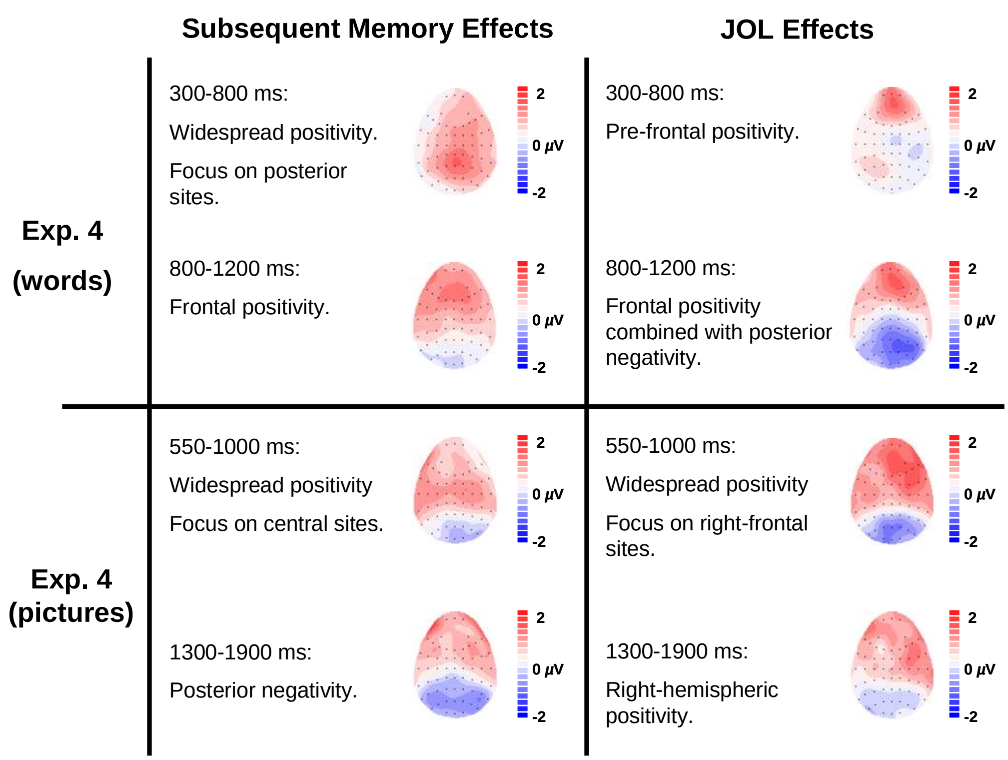

Figure 11.3 SM and JOL effects from Experiment 4.

The SM effects found in the picture block were characterised by widespread positivity, with a focus on central electrode sites during 550-1000 ms post-stimulus. During 1300-1900 ms post-stimulus there was no evidence of a positive effect; however a negative-going effect was present over posterior electrode sites[17]. This late effect from the picture block therefore represents the only negative-going SM

[17] It is unlikely that this effect is related to the late negative-going JOL-specific effects demonstrated previously, given that it is present exclusively in the successful memory encoding contrast.

effect in this series of experiments. The effects found for pictures were relatively small and diffuse, but because it is not feasible to compare SM and JOL effects statistically, it is impossible to establish whether they do in fact reflect the same pattern of neural responses or not. Nonetheless, visual inspection reveals that in both cases, and for both time windows, the effects were characterised by positivity that was most prominent over central and frontal electrode sites.

11.1.3. Test ERP Results

ERPs collected during the test phases of the experiments were sorted based on the following categories: new items correctly identified as new (Correct Rejections; CR), old items correctly identified as old and which received low JOL at study (Experiment 1: Low JOL Recall; Experiments 2 and 4: Low JOL Hits) and items correctly recognised as old and which received a high JOL at study (Experiment 1: High JOL Recall; Experiments 1 and 4: High JOL Hits). ERPs to the correctly identified old items were plotted against the baseline of CRs, revealing the appearances of *memory retrieval effects*. The retrieval effects from each experiment (except Experiment 3) are summarised below in Figures 11.4 and 11.5.

ERP memory retrieval effects have been extensively researched and the effects that have been identified have shown more consistency across experiments as compared to SM effects. For that reason, clear expectations regarding the timing, polarity and distribution of the retrieval effects under investigation were outlined prior to statistical analyses. The time courses used for examining the presence of mid-frontal familiarity effects, left-parietal recollection effects and right frontal post-retrieval monitoring effects were 300-500 ms, 500-800 ms and 1000-1600 ms post-stimulus respectively[18]. As can be seen in Figure 11.4, Experiment 1 did not produce any mid-frontal effects (during 300-500 ms post-stimulus) regardless of the JOL assigned at study. Although some positivity was apparent for Low JOL Recall, this did not reach significance. By contrast, during 500-800 ms and 1000-1600 ms post-stimulus, both Low JOL Recall and High JOL Recall produced left-parietal and right frontal effects of similar magnitudes. For the Low JOL Recall condition in particular, there appeared to be some positivity at frontal electrode sites during the 500-800 ms time window. One possibility is therefore that the familiarity effects were occurring slightly later than the traditional time window and shows some temporal overlap with the later time window, resulting in the effects being masked by the larger left-parietal effect. At the most, however, the results show that the items from Experiment 1 were recognised on the basis of recollection and the strength of recollection was the same for all items, regardless of the JOL assigned at study.

The pattern of engagement of retrieval processes was noticeably different in Experiment 2; both Low JOL Hits and High JOL Hits produced mid-frontal and right-frontal effects of comparable magnitudes. During the later time window, both JOL conditions in Experiment 2 elicited left-parietal effects; however the effect was significantly larger for High JOL Hits compared to Low JOL Hits. These findings are clearly in stark contrast to those of Experiment 1.

[18] Although the timing of the retrieval effects from the picture block of Experiment 4 seemed to deviate slightly from the traditional time course, the use of alternative time windows did not result in important difference in the characterisation of the effects.

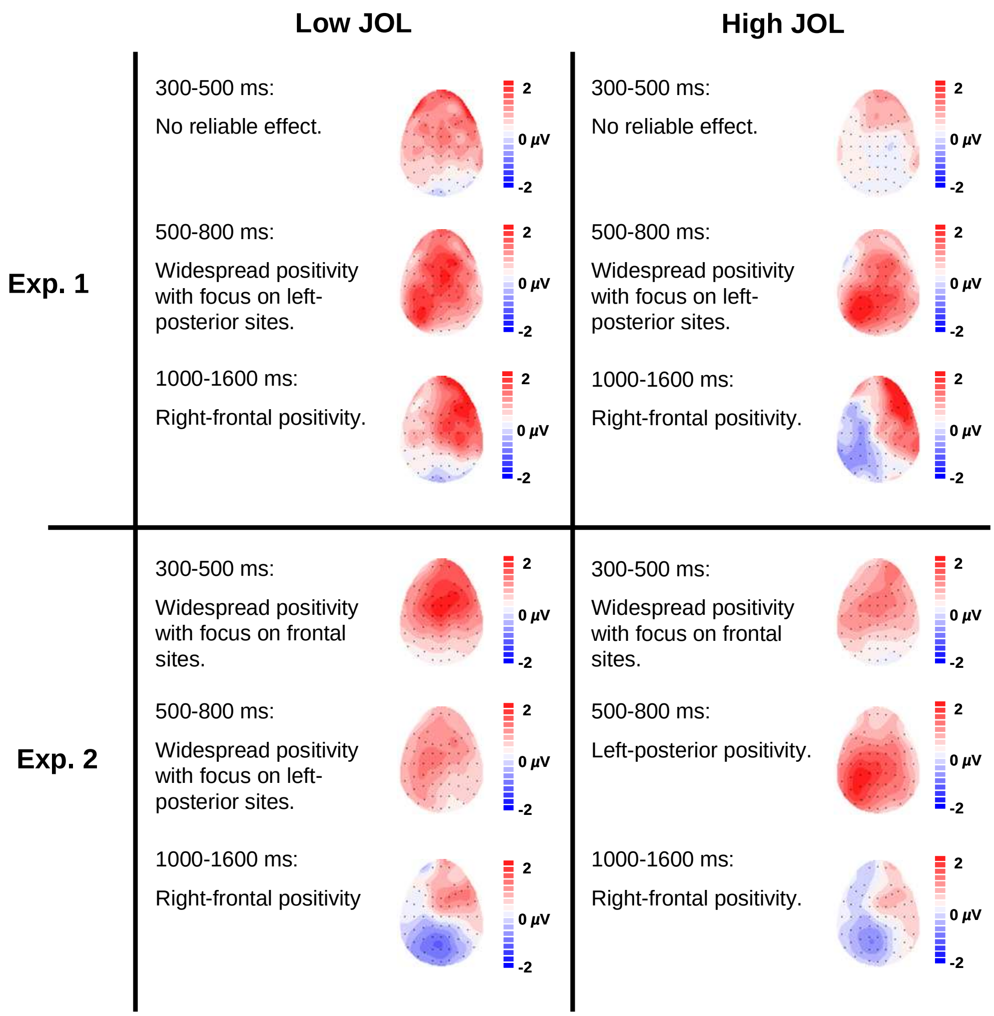

Figure 11.4 Memory retrieval effects from Experiments 1 and 2.

Both Experiments 1 and 2 produced late right-frontal effects that were equal across JOL assigned at study. It is unclear what the right-frontal effect signifies, however the lack of JOL modulation suggest that the process that is supporting this effect is not affected by metamemory processes. Since no clear hypotheses regarding the right-frontal effect were put forward, the effect will not be further discussed.

A summary of the retrieval effects from Experiment 4 are shown in Figure 11.5. The effects elicited by single item words followed the same pattern as the effects from Experiment 2, however all except from the left-parietal effect elicited by High JOL Hits failed to reach significance. There was evidence of statistically robust effects during 1000-1600 ms post-stimulus; however these did not exhibit the right-frontal distribution as expected. Instead, the effects were widespread and negative-going. Importantly, the magnitude of this unknown effect was not modulated by JOL.

There was no statistical evidence of effects in the early time window for pictures, however during the 500-800 ms time window, both Low and High JOL Hits produced relatively large positive-going effects with frontal foci. This effect seemed to correlate with JOL in the same manner as the left-parietal effect from Experiment 2 as the effect was significantly larger for High JOL Hits as opposed to Low JOL Hits. In the latest time window, both Low and High JOL Hits produced equal right-frontal effects.

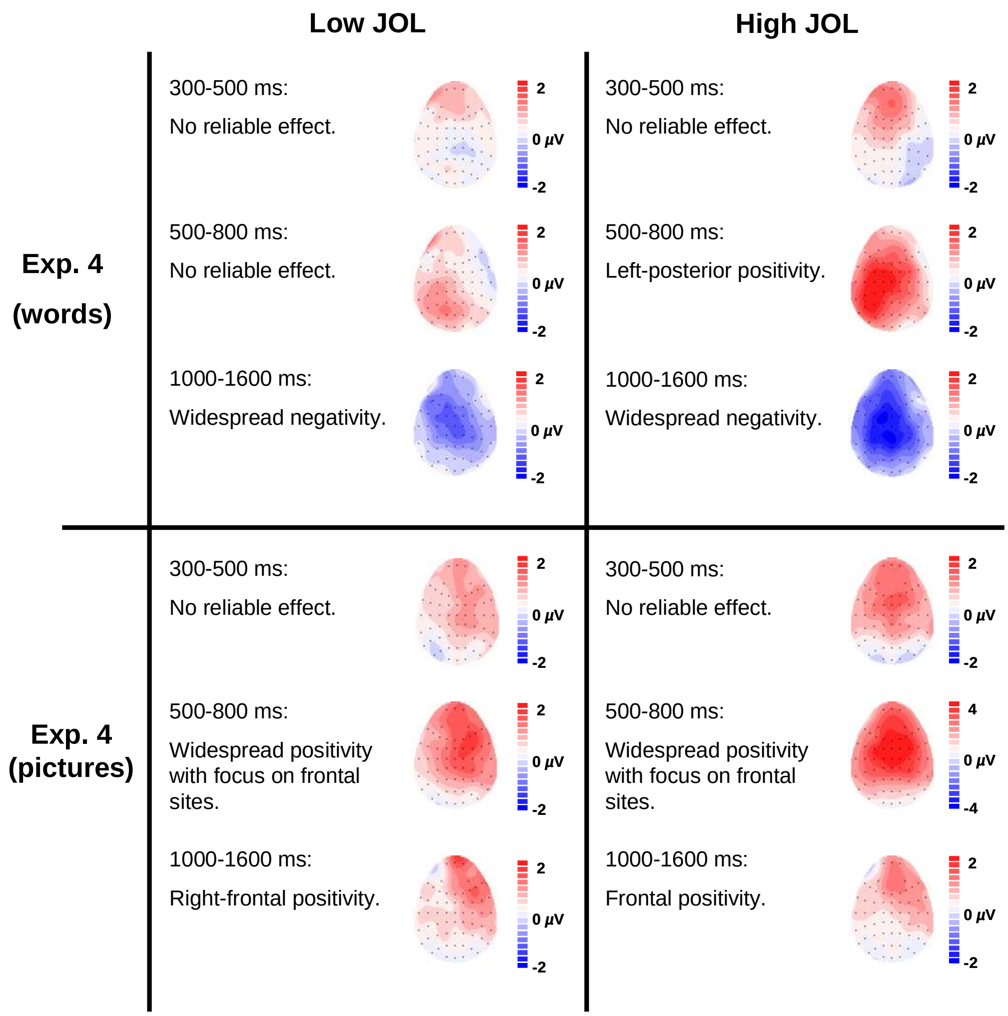

Figure 11.5 Memory retrieval effects from Experiment 4.

11.2. Theoretical Implications

11.2.1. Study ERP Results

The ERP findings from Experiment 1 and 2 have specifically suggested that JOLs are associated with brain activity that is partially overlapping with, but also partially distinct from, those of successful memory encoding. This overlapping ERP deflection in the early time window could be viewed as evidence in favour of a direct/trace access approach to metamemory, however accepting this conclusion is difficult because it implies that the effect in the JOL contrast is in fact exclusively caused by memory-related activity. This interpretation is unlikely because i) the JOL effects are larger in magnitude compared to the SM effect, ii) the effect is still present in the data from Experiment 2 when memory is controlled for and iii) the results from Experiment 3 suggest that the SM effects are sensitive to the removal of the requirement to make a JOL. Thus, rather than reflecting pure memory processing, it is likely that the early posterior effects are in fact reflecting metamemory related activity or, more likely, an interaction between memory and metamemory (i.e. JOL-specific SM effects).

The JOL instructions given to participants taking part in Experiments 1 and 2 represent encoding tasks that encourage participants to act upon the study material. One shortcoming of Experiment 3 was that participants were not given any explicit encoding tasks, and one cannot confidently conclude that the early posterior effects were in fact JOL-related unless additional studies are carried out which employ alternative encoding tasks. The lack of specific encoding instructions in Experiment 3 was presumably also the reason why the memory performance were considerably lower in Experiment 3 compared to Experiments 1 and 2. In sum, although the theory of JOL-specific SM effects can currently be made only tentatively, the findings from Experiments 3 point to the important role played by JOLs in the production of the posterior SM effects seen in Experiments 1 and 2.

Posterior SM effect have previously been tied to rote learning strategies (see Chapter 1), however it is unclear why participants would have relied more on rote learning in Experiments 1 and 2 compared to Experiment 3. An alternative possibility is that the posterior effect reflects encoding driven by distinctiveness detection (Fernandez et al., 1998). This interpretation is however inconsistent with results from a recent experiment investigating the ERP correlates of subjective distinctiveness ratings (Ames, Skavhaug, Ellis and Donaldson, 2009). This experiment was identical to Experiment 2 reported in this thesis, with the only exception that participants made Judgments of Distinctiveness (JODs) instead of JOLs. Surprisingly, although JODs elicited subsequent memory effects that were identical to those of Experiment 2, the ERP correlates of JODs differed markedly from the ERP correlates of JOL. Items receiving high JODs were more positive-going compared to items receiving low JODs and this difference was evident approximately 250 ms post stimulus. The effect was frontally distributed and changed focus from left-frontal electrode sites (250-500 ms) to mid-frontal (550-1000 ms) and finally to right-frontal electrode sites (1300-1900 ms). The discrepancies in ERP results cannot be explained by behavioural differences as behaviour was remarkably consistent across the two experiments. These findings strongly suggest that distinctiveness is not the driving force behind the JOLs or SM effect reported in this thesis.

The JOD Experiment is also interesting with regards to the interpretation of the late negative-going JOL effect. If this effect was in fact related to response preparation, it should also have been present for JODs because the JOD Experiment used a rating scale that was identical to the one used in Experiment 2. Hence, the cognitive processes that are supported by the late negative-going JOL effect do not appear to be required for JODs. One interpretation that possibly fits this description is that the late negativity is reflecting working memory processes. Researchers have established that when working memory load is increased this produces an enhancement of slow-wave activity that seem to resemble the late negative-going JOL effect (Ruchkin, Berndt, Johnson, Ritter, Grafman & Canoune, 1997; Ruchkin, Johnson, Canoune & Ritter, 1990; Ruchkin, Johnson, Grafman, Canoune & Ritter, 1992; Ruchkin, Johnson, Mahaffey & Sutton, 1988). According to the Nelson & Dunlosky's (1991) MDM principle (see Chapter 1), immediate JOLs are based partly on long-term memory (LTM) processes and partly on short-term memory (STM)/working memory processes. Eventual memory performance is reliant exclusively on LTM processes and because participants incorrectly assign significance to the knowledge they currently hold in STM, this adds noise to the JOL outcome. Activity associated with STM will therefore not be apparent in the SM contrasts, but if it is contributing to the JOL, it should be apparent in the JOL contrast. There are several alternative ways of investigating the validity of the MDM interpretation in future studies and the most palpable option is to examine the ERP correlates to delayed JOLs. This is because the MDM principle predicts that STM contamination should be abolished following a delay that is long enough to exceed the duration of information in STM (Nelson and Dunlosky, 1991). Other possibilities include manipulating STM load by, for example, introducing dual task conditions.

The word block of Experiment 4 did not show exactly the same pattern of effects as Experiments 1 and 2. It is important to note, however, that the differences are difficult to assess because the effects from the word block exhibited a time course which did not match the time courses identified in Experiments 1 and 2. It necessarily takes longer to process two words compared to just one, and this could be the reason why the timing of the effects was not identical across the experiments. While the posterior SM effects present in an early time window (300-800 ms) possibly corresponds to the early posterior effects from Experiments 1 and 2, the JOL contrast revealed a prefrontal distribution, meaning that the early effects did not overlap in this case. In a later time window, however, the SM and JOL effects both exhibited frontal foci (notably, the focus appears more prefrontal for the JOL effect and is combined with negativity at posterior electrode sites). Although the findings from the word block are difficult to fully reconcile with the findings from Experiments 1 and 2, they demonstrate that early JOL effects can exist independently; offering yet more evidence to suggest factors other than memory can support JOLs.

The general rationale behind this series of experiments was to identify the basis on which JOLs are made as a first step towards teaching individuals how to better predict and take control over their learning. Arbuckle & Cuddy (1969) speculated that if memory traces are like other types of input signals, then individuals should be able to make accurate decisions simply by reading the strength of the appropriate traces (as per the direct/trace access hypothesis, also see King et al., 1980). It is unclear, however how such “readings” would come about if they come about at all. The present findings do not rule out the possibility of accessing memory traces, but do suggest that individuals are able to place emphasis on factors other than memory, an account which is more consistent with Koriat's (1997) cue-utilization theory of JOL (Koriat, 1997). Cue-utilization theory assumes that JOLs are products of evaluations of available cues, believed by the learner to predict future memory (e.g. experience with material, presentation time etc). One compromising possibility is that JOLs are sometimes based on memory and sometimes on other factors; however memory trace strength is evaluated indirectly, for example, through partial retrieval attempts.

According to the cue-utilization view, availability and use of cues will, naturally, vary across study materials and learning situations, thus from this perspective it is expected that the neural correlates of JOLs will differ between experiments that employ word pairs as opposed to single item words as stimuli. Previous experiments have also demonstrated that SM effects are sensitive to a number of factors related to the learning situation (see Chapter 3), suggesting that both successful memory encoding and metamemory judgments rely on multiple neural systems. That both the SM and JOL effects from the picture block of Experiment 4 show few similarities to the preceding experiments is therefore unsurprising. The effects in this case were relatively diffuse, with poorly defined time courses, providing insufficient evidence to claim that successful memory encoding and JOLs are associated with distinct ERP effects. The most prominent discrepancy between the picture block and the preceding experiments is, nonetheless, the lack of a negative-going JOL-specific effect.

The existence of a late onsetting negative-going JOL-specific effect (Experiment 1, 2 and word block of Experiment 4) suggests that the direct/trace access theories of JOL are insufficient, because it indicates that some processes contributing to metamemory are working independently of memory itself. It is unclear, however, whether these late effects are directly associated with the JOL decision or rather reflect processes that operate following the JOL decision. The latter interpretation is compatible with Nelson & Narens' (1990) framework for cognitive monitoring, which claims that monitoring outcomes can initiate the engagement of (effective or ineffective) control strategies (see Chapter 1). By this account, the reason why the effect is not present for pictures reflects the fact that the particular processes underlying the effect are not appropriate for pictorial stimuli or operate over content that is less available in pictures.

As outlined previously, it is possible that the late negative-going effect is associated with working memory processes. One alternative way of conceptualising the involvement of working memory in JOLs is that participants are manipulating the low JOL items in working memory as an attempt to improve memory for items that are poorly learnt. This theory of the late negative-going effect unites the working memory hypothesis with Nelson and Naren's (1990) framework of metamemory control strategies. Importantly, accepting this view of the JOL-specific effects implies that the late negative-going effect does not provide evidence to suggest that metamemory and memory operate independently. This does not mean, however, that a direct-access theory is necessarily providing the most accurate general explanation of the bases of JOLs. This is because the analyses of JOL effect without memory confounds from Experiment 2 suggest that also the early positive-going effect operate independently of the processes that support actual memory formation (see Chapter 6).

The exact functional interpretations of the JOL-specific effects are impossible to establish based on the experiments reported in this thesis alone. The presence of the effects across three experiments does, however, inspire confidence that the effects genuinely reflect relatively stable set of cognitive operations. Future studies should be particularly concerned with the possibilities of separating the early positive-going effects that are associated with JOLs and successful memory encoding respectively. This is because the observation that JOLs do elicit this effect independently of memory is crucial and merits further exploration. One possibility is that the memory and metamemory sometimes rely on the same neural structures but that they do so separately. Alternatively, successful memory encoding could be an incidental consequence of JOL-related processing. This possibility is supported by the observation that memory performance declines when JOLs are no longer required and that the SM effects changes both in time course and topography (see Chapter 7). That memory is a consequence of JOLs, rather than the other way around, is in complete contrast to the assumptions underlying the direct-access approach.

All four experiments for which study ERP data were examined revealed interesting and novel findings that have highlighted the complexities of metamemory. Future research is nevertheless necessary to reach a coherent understanding of the underlying bases of JOLs. Specifically, the aim should be to relate the current findings to findings from future experiments making use of delayed JOL paradigms. Delayed JOLs, as outlined in Chapter 1, are made after a pre-determined delay usually filled with the presentation of additional study items. The particular interest in delayed JOLs stems from the observations that they are usually considerably more accurate compared to immediate JOLs. The increase in accuracy has, however, not been adequately explained by previous behavioural JOL experiments. Recording ERPs in response to delayed JOLs will potentially reveal important differences in neural and cognitive processes that can enhance the understanding of the crucial timing aspects of metamemory.

Another focus of future research should concern the generality of the JOL effects observed in the current experiments: are these effects specifically associated with memory predictions or do they reflect engagement of generic metamemory processes? This question can be addressed by examining the ERP correlates of alternative monitoring judgments such as Ease of Learning Judgments. Some of the monitoring judgments are not easily compared to JOLs, however, because they require the use of very different paradigms. For example, Feelings of Knowing are recorded at retrieval and require participants' recognition memory to initially fail before memory performance on forced-choice tests can be assessed. Previous behavioural experiments have failed to observe a clear correlation between various monitoring judgments (Leonesio & Nelson, 1990; Souchay et al., 2004), however this does not necessarily imply that no commonalities exist that tie these phenomena together in terms of their metacognitive qualities.

11.2.2. Test ERP Results

The rationale behind the assessments of the test phase ERPs was to examine whether the retrieval of high and low JOL items relied differentially on the retrieval processes that are described in the ERP literature (for reviews see Allan et al., 1998; Friedman & Johnson, 2000; Rugg, 1995; Rugg & Curran, 2007). Specifically, the aim was to investigate whether the neural correlates of familiarity and recollection were modulated by the JOL made at study. The existence of modulations of retrieval processes (or lack thereof) could provide insights into the processes that are engaged at the encoding stage of the experiment.

As summarised in the previous section of this Chapter, only Experiment 2 produced reliable familiarity (mid-frontal) effects. There are two likely explanations to the lack of familiarity effects: i) familiarity is present but the effects are small and failed to reach significance due to lack of power, and ii) familiarity is not operating to a great enough extent to produce reliable ERP effects[19]. The mid-frontal familiarity effects that were recorded in Experiment 2, nonetheless, were equal for items assigned low and high JOLs at study. This observation suggests that familiarity is not modulated by JOL and that encoding processes that result in later familiarity do not contribute substantially to the JOL assignment.

Although Experiment 1 did not reveal any reliable mid-frontal effects, left-parietal effects were evident for both Low JOL Recall and High JOL Recall. Since the

[19] The independence view of the relationship between recollection and familiarity propose that either one of the processes can occur independently of the other (see Jacoby, Toth & Yonelinas, 1993). Although other views exist (see Joordens & Merikle, 1993; Knowlton, 1998), independence is assumed here. A further discussion of the relationship between familiarity and recollection falls beyond the scope of this thesis.

observed effects were of equal magnitude, this could suggest that recollection does not specifically contribute to the JOL assignment. However, given that memory performance was assessed by cued recall it is possible that the trials that were included in the ERPs consisted of a proportion of recognised trials which were accompanied by vivid recollection. Previous research has indeed demonstrated that correct old/new recognition responses can be made in the absence of recollection, but that recollection is necessary for more demanding retrieval, such as cued recall (see Chapter 3).

In Experiment 2, trials were included to form ERPs if they were recognised (regardless of the quality of retrieval). The result was a clear modulation of the left-parietal effect; the higher the JOLs the larger the amplitudes (this trend was also evident in the word block of Experiment 4, although the effects were less statistically robust). It therefore seems possible that participants were relying on factors that are predictive of subsequent recollection when making JOLs at study. One possibility is that participants are assessing the amount of contextual information available at study when assigning their JOL and that contextual information subsequently aids recollection at test, as suggested by Daniels et al. (2009). By contrast, participants might not have conscious access to, and are therefore unable to assess, the factors that predict later familiarity. This does not imply that such processes are never of importance. For example, it is possible that participants would rely more heavily on non-specific aspects of the study episode (i.e. processing fluency, Begg et al., 1989; Koriat, 2000) under dual task conditions or when response time is limited. When all cognitive resources are directed towards the JOL task and the responses are self-paced (as in Experiment 2), however, the outcomes are predictions specifically reflecting the likelihood of future recollection.

The picture block of Experiment 4 was the only experiment not to elicit the traditional left-parietal effect of recollection. Instead there was a presence of a large positive effect exhibiting a frontal focus. This effect was modulated by JOL in the same manner as the left-parietal effects in Experiments 2 and the word block. Although this effect has a frontal distribution, its late time course suggests it is not familiarity related (although this possibility cannot be entirely discounted). Recently, moreover, a series of experiments have demonstrated the existence of a frontal old/new effect found for recognition of faces, and that seems sensitive to the same experimental variables as the traditional left-parietal effect, suggesting that this effect is also an index of recollection (MacKenzie & Donaldson, 2007; 2009; Yick & Wilding, 2008). One interpretation of this frontal effect is that it reflects recollection for non verbal material (rather than faces per se), suggesting that it may be expected for the pictures stimuli used in Experiment 4. If this assumption is correct, then all three experiments for which the retrieval ERPs were investigated have shown that ERP correlates of recollection are modulated by the JOL made at study when memory retrieval is assessed through the use of standard recognition tasks.

11.3. Conclusion

The findings from the series of experiments reported in this thesis have provided novel insights into the underlying basis of Judgments of Learning. These insights were provided by the use of Event-Related Potentials which allowed the examination of the neural responses associated with both the formation of new memories and of the subjective experience of having formed new memories, as well as the processes engaged during retrieval of items assigned low and high JOLs.

The investigation of study phase ERPs led to the understanding that JOLs are supported by processes which partly over lap with, but which are also partly distinct from, memory encoding processes. This finding is inconsistent with direct/trace access theories, but consistent with inferential theories of metamemory such as Koriat’s (1997) cue utilization view. Investigations of memory retrieval ERP effects further suggest that when memory and metamemory processes overlap, this overlap is specifically relevant to memory encoding processes that are consequential to subsequent recollection. These processes possibly reflect the assessment of contextual information, as recently suggested by Daniels et al. (2009). In sum, the ERP results suggest that JOLs reflect genuine metacognitive assessments, which do not reduce to, but interact closely with, memory encoding processes.

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Appendix A

Visual inspection of the waveforms from Experiment 2 led to the observation of early (300-500 ms post stimulus) SM and JOL effects with similar appearances. This effect is characterised by an increase in positivity for Hits relative to Misses (see Figure A.1) and High JOL relative to Low JOL (see Figure A.2) on frontal electrode sites – a pattern which is reversed at posterior electrode sites.

As for the effects reported in Chapter 6, data were first analysed using ANOVA with factors of category (Hits versus Misses, High versus Low JOL), location (frontal, fronto-central, central, centro-parietal, parietal), hemisphere (left, right) and electrode site (superior, mid, inferior) followed by five subsidiary analyses when appropriate. The outcome of these analyses will be reported below.

The initial ANOVA performed on the SM effect revealed significant interactions between condition and hemisphere [$F(1,23) = 4.4$ $p < 0.05$], and between condition, hemisphere and site [$F(1.3,29.8) = 6.9$, $p < 0.01$]. The outcome of these analyses confirms the impression that the SM effect is slightly positive-going at right-frontal electrode sites and negative-going at left-parietal recording sites.

By contrast, the analyses of the JOL effect revealed a single significant interaction between condition and location [$F(1.3,30.6) = 5.2$ $p < 0.05$]. This location interaction reflects that the JOL effect is positive at frontal electrode sites and negative at posterior electrode sites. However, none of the five subsidiary analyses revealed any significant main effects or interactions (all Fs < 2.9); the effect is clearly statistically weak in this case.

It is difficult to comprehend what the functional significance of these small and early SM and JOL effects are, however they appear to reflect processes that vary with successful memory encoding and memorability ratings in the same manner as the positive effects observed between 550-1000 ms. This interpretations is not unreasonable given that SM effects have sometimes been found 200 ms post stimulus presentation (Smith, 1993; Sommer et al., 1995) or even earlier (Otten & Rugg, 2001a). The early effects described in this Appendix are nevertheless not considered critical in the context of this thesis and will therefore not be discussed further.

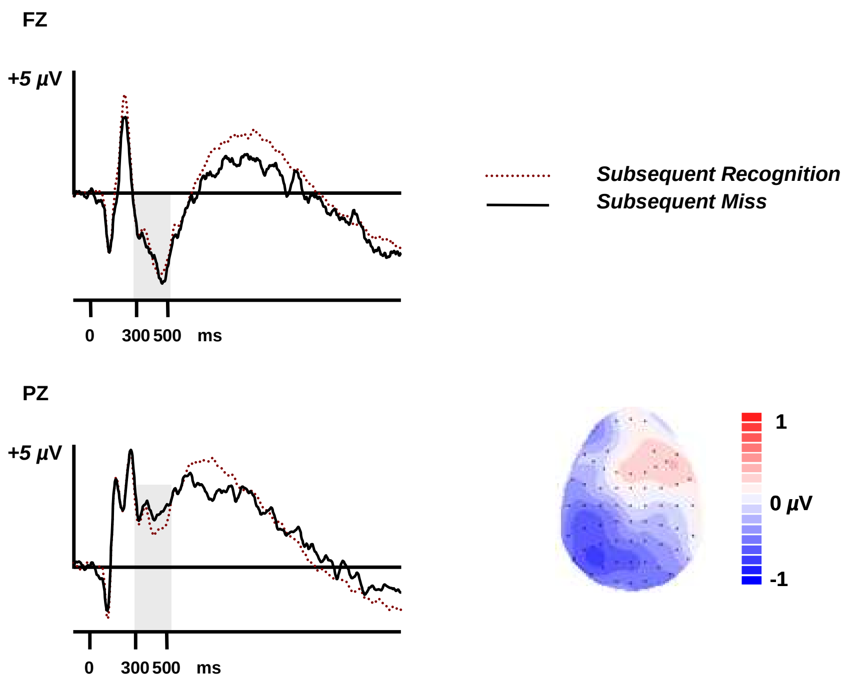

Figure A.1 SM effects during the 300-500 ms time window.
Effects are shown at frontal (FZ; upper waveform) and parietal (PZ; lower waveform) electrodes. Scalp map illustrates the distribution of the effects. The front of the heads is at the top of the maps and the scale bars represent the sizes of the effects in µV.

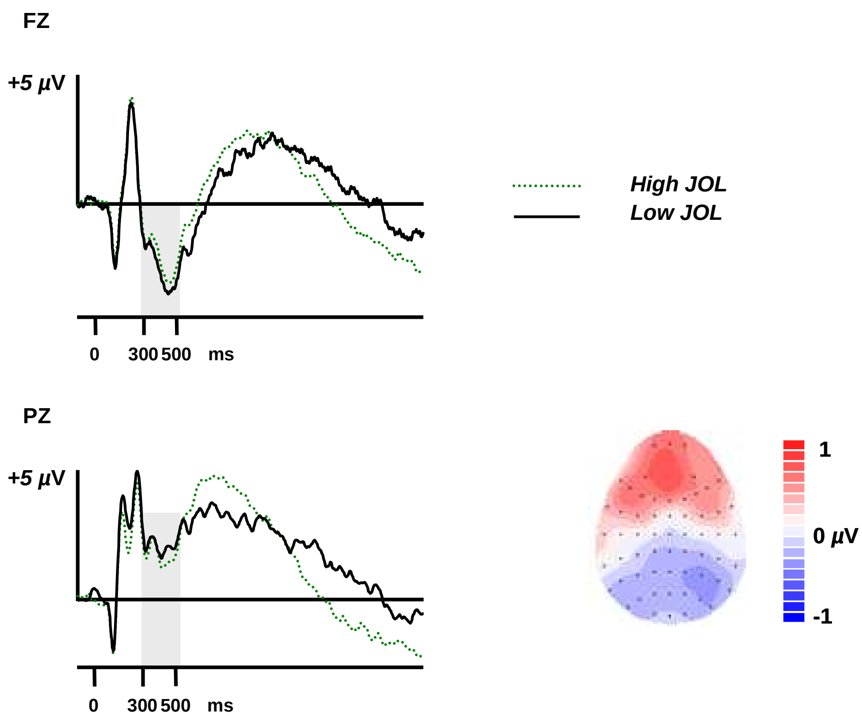

Figure A.2 JOL effects during the 300-500 ms time window.
Effects are shown at frontal (FZ; upper waveform) and parietal (PZ; lower waveform) electrodes. Scalp map illustrates the distribution of the effects. The front of the heads is at the top of the maps and the scale bars represent the sizes of the effects in μV.

Appendix B

The SM and JOL effects from the picture block of Experiment 4 were initially analysed using the original time windows from Experiments 1 and 2. Visual inspections of the waveforms suggested that the effects are better characterised by the use of one single time window. This alternative time window was identified as 600-1500 ms and the outcome of the re-analyses are reported below and in Tables B.1 and B.2.

B.1. ERP results

B.1.1. Picture Block: SM Effects

In the 600-1500 ms time window, the SM effect was maximal at F7[20] [$t(23) = 3.6$, $p < 0.01$] (waveform and scalp distribution are shown in Figure B.1). The outcome of the initial ANOVA was a significant interaction between condition and location [$F(1.5,34.4) = 9.3$, $p < 0.01$]. The subsidiary analyses revealed significant main

[20] F7 is not included in the original analyses. Additional analyses including four, rather than three factors of site (covering electrodes at far inferior sites) were therefore carried out, however the outcome of these analyses did not differ from the original analyses and are for that reason not reported.

effects from frontal to central electrode rows. The analyses seem to reflect a widespread increase in positivity with a focus on frontal electrode sites.

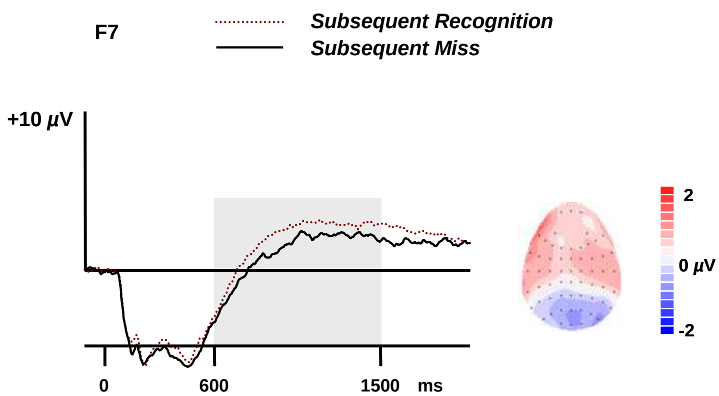

Figure B.1 SM effect at F7.
Zero indicates stimulus onset. The topographic map illustrates the scalp distributions of the JOL effect (subsequent Hits minus subsequent Miss) over the 600-1500 ms time window. The front of the head is at the top of the map and the scale bar represents the size of the effect in µV.

B.1.2. Picture Block: JOL Effects

In the 600 to 1500 ms time window, the JOL effect was maximal at FC4 [$t(23) = 3.1$, $p < 0.01$] (waveform and scalp distribution are shown in Figure B.2). The outcome of the initial ANOVA was significant interactions between condition and location [$F(1.3,30.7) = 8.2$, $p < 0.01$] and between condition, location and hemisphere [$F(1.6,36.0) = 4.7$, $p < 0.05$]. The subsidiary analyses revealed significant main effects of condition from frontal to central electrode rows and a significant interaction between condition and hemisphere at the frontal electrode row. Overall, the analyses reflect increase positivity over right-frontal electrode sites.

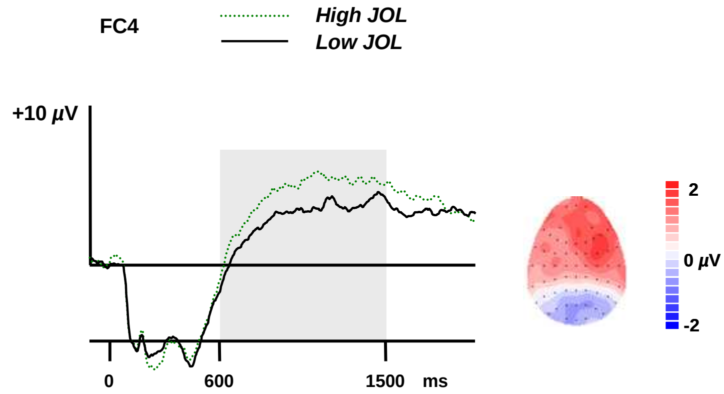

Figure B.2 JOL effect at FC4.
Zero indicates stimulus onset. The topographic map illustrates the scalp distributions of the JOL effect (High JOL minus Low JOL) over the 600-1500 ms time window. The front of the head is at the top of the map and the scale bar represents the size of the effect in μV.

Table B.1 Outcomes of the analysis of the SM effects.
(F = Frontal; FC = Fronto-Central; C = Central; CP = Centro-Parietal; P = Parietal).

Recognition/Miss

600-1500ms	F	FC	C	CP	P
Condition	$F(1,23)=4.6$; $p<0.05$	$F(1,23)=7.0$; $p<0.05$	$F(1,23)=4.7$; $p<0.05$		
Condition x Hemisphere					
Condition x Site					
Condition x Hemisphere x Site					

Table B.2 Outcomes of the analysis of the JOL effects.
(F = Frontal; FC = Fronto-Central; C = Central; CP = Centro-Parietal; P = Parietal).

High JOL/Low JOL

600-1500ms	F	FC	C	CP	P
Condition	$F(1,23)=6.9$; $p<0.05$	$F(1,23)=7.6$; $p<0.05$	$F(1,23)=6.2$; $p<0.05$		
Condition x Hemisphere	$F(1,23)=4.4$; $p<0.05$				
Condition x Site					
Condition x Hemisphere x Site					

Appendix C

In the word block of Experiment 4, the early JOL effect exhibited a prefrontal distribution. Prefrontal electrodes (FP1, FP2, AF3 and AF4) were therefore included in an additional set of analyses. Since these electrodes were not originally included in the analyses conducted on the JOL contrasts in Experiments 1 and 2, additional analyses have been carried out and are reported below.

JOL data from the 550-1000 ms time window were analysed using ANOVA with factors of category (High JOL versus Low JOL), location (fronto-polar, anterior-frontal) and hemisphere (left, right). For experiment 1, the analysis revealed a significant interaction between condition and hemisphere [$F(1,19.0) = 7.5$, $p < 0.05$]. The interaction reflects slight positivity on the left hemisphere with simultaneous negativity on the right hemisphere (see Figure C.1). The interaction does not seem to reflect a positive-going effect as described for the word block of Experiment 4 (Chapter 8).

For Experiment 2 the ANOVA revealed no significant main effect or interactions (all *F*s < 3.9). Based on these analyses it was concluded that the early prefrontal JOL effect observed in the word block of Experiment 4 was not present in preceding Experiments 1 and 2 (see Figure C.1).

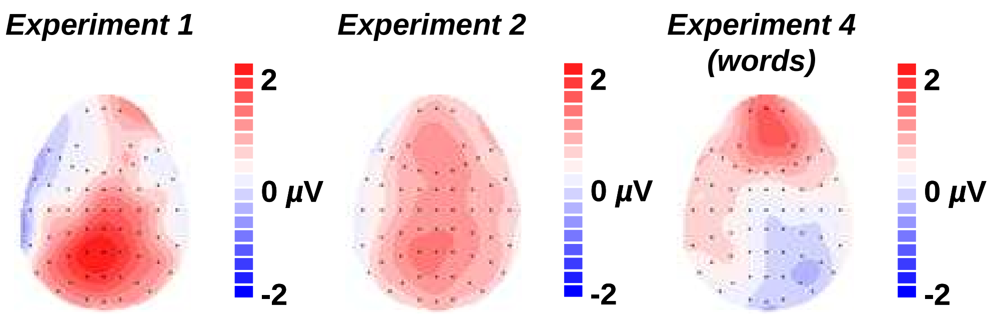

Figure C.1 The early JOL effects from Experiments 1, 2 and 4 (words).

Appendix D

Of the 20 participants who contributed to the study phase data of Experiment 1, 14 of these performed sufficiently to contribute to the test phase data. Similarly, of the 24 participants who contributed to the study phase data of Experiment 2, 21 performed sufficiently to contribute to the test phase data. The behavioural results of these subsets of participants do not deviate significantly from those of the full samples, but are, for completeness, reported below.

D.1. Behavioural Results

D.1.1. Experiment 1: Study

JOL response rates are shown in Figure D.1a, exhibited an inverted ‘u’, with more responses in the middle of the scale. ANOVA revealed a main effect of JOL [$F(4,52) = 6.4$, $p < 0.001$], with an accompanying quadratic trend [$F(1,13) = 18.7$, $p < 0.01$]. The pattern of reaction time (RT) for making JOLs at study also formed the shape of an inverted “U” when plotted against each level of JOL (Figure D.1b). ANOVA revealed a significant main effect of JOL [$F(4,48) = 11.7$, $p < 0.001$], exhibiting linear [$F(1,12) = 13.1$, $p < 0.01$] and quadratic trends [$F(1,12) = 15.9$, $p < 0.01$].

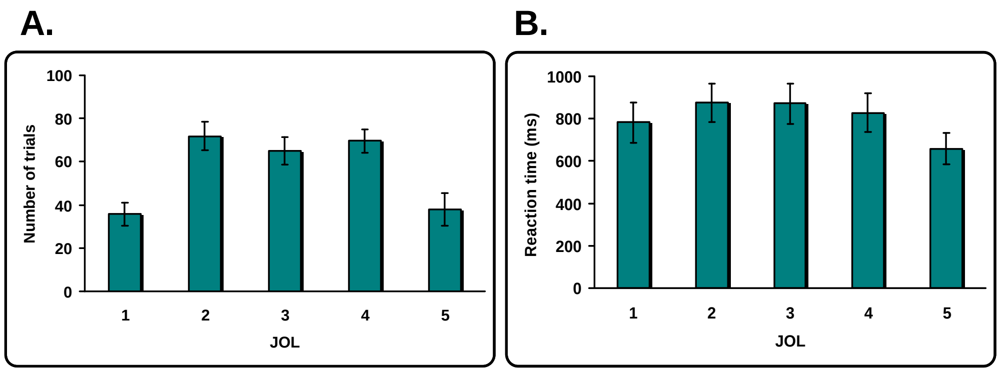

Figure D.1 Behaviour at study.
Mean (and S.E.) number of trials assigned each JOL category at study (A) and reaction times for making each level of JOL at study (B).

D.1.2. Experiment 1: Test

Overall recognition responses are shown in Figure D.2a. Figure D.2b shows the mean recognition accuracy for old items distributed across the levels of JOLs assigned at study. It is evident from the graph that recognition performance improved with increasing JOL, and a repeated measures ANOVA confirmed that the effect of JOL was significant [$F(4,52) = 18.8$, $p < 0.001$], exhibiting a linear [$F(1,13) = 58.0$, $p < 0.001$] trend. The mean G score of 0.30 (SD = 0.17) was significantly above zero [$t(14) = 6.71$, $p < 0.001$]. Mean d_a was 0.42 (SD = 0.28) and was also signficantly above zero [$t(14) = 5.78$, $p < 0.001$]. The reaction times measured at test are shown in Figure D.2c. ANOVA confirmed a main effect of JOL [$F(4,52) = 6.9$, $p < 0.001$], again exhibiting linear [$F(1,13) = 7.7$, $p < 0.05$] and quadratic [$F(1,13) = 6.5$, $p < 0.05$] trends.

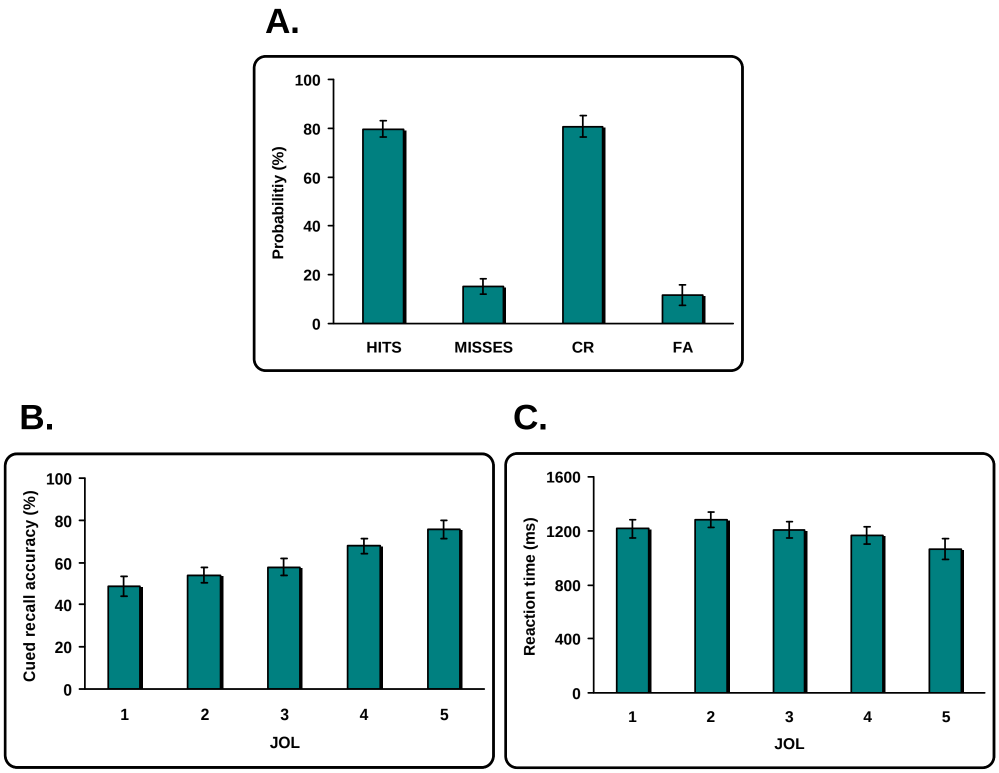

Figure D.2 Behaviour at test.
Mean (and S.E.) recognition responses for each response category at test (A), cued recall performance across JOL at test (B) and reaction time measured at test split according to JOL (C).

D.1.3. Experiment 2: Study

JOL response rates are shown in Figure D.3a. ANOVA revealed a main effect of JOL [$F(4,80) = 14.9$, $p < 0.001$], with accompanying linear [$F(1,20) = 15.4$, $p < 0.01$] and quadratic trends [$F(1,20) = 20.9$, $p < 0.001$]. The reaction times (RT) for making JOLs at study are shown in Figure D.3b. ANOVA revealed a significant main effect of JOL [$F(4,80) = 4.6$, $p < 0.01$], again exhibiting linear [$F(1,20) = 4.6$, $p < 0.05$] and quadratic trends [$F(1,20) = 11.3$, $p < 0.01$].

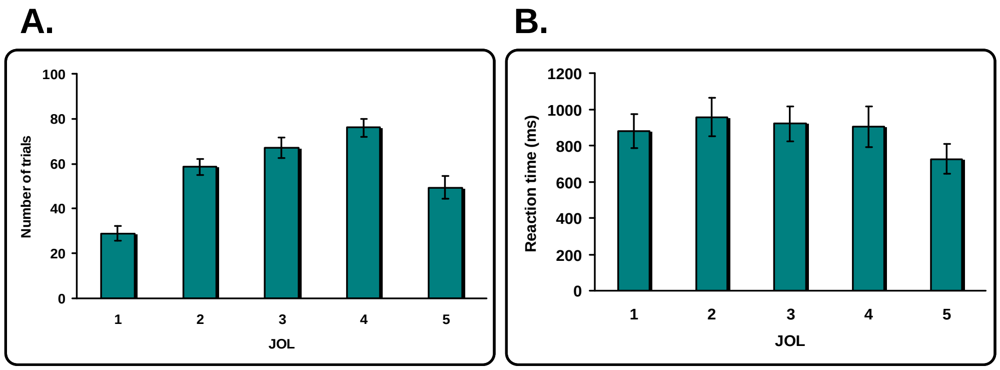

Figure D.3 Behaviour at study.
Mean (and S.E.) number of trials assigned each JOL category at study (A) and reaction times for making each level of JOL at study (B).

D.1.4. Experiment 2: Test

Overall recognition responses are shown in Figure D.4a. Figure D.4b shows the mean recognition accuracy for old items distributed across the levels of JOLs assigned at study. It is evident from the graph that recognition performance improved with increasing JOL, and a repeated measures ANOVA confirmed that the effect of JOL was significant [$F(4,80) = 20.7$, $p < 0.001$], exhibiting linear [$F(1,20) = 40.4$, $p < 0.001$] and quadratic trends [$F(1,20) = 5.6$, $p < 0.05$]. The mean G score of 0.25 (SD = 0.16) was significantly above zero [$t(20) = 7.17$, $p < 0.001$]. Mean d_a was 0.37 (SD = 0.25) and was also significantly above zero [$t(20) = 6.67$, $p < 0.001$]. Reaction times measured at test are shown in Figure D.4c. ANOVA confirmed a main effect of JOL [$F(4,80) = 7.9$, $p < 0.001$], accompanied with a significant linear trend [$F(1,20) = 18.9$, $p < 0.001$].

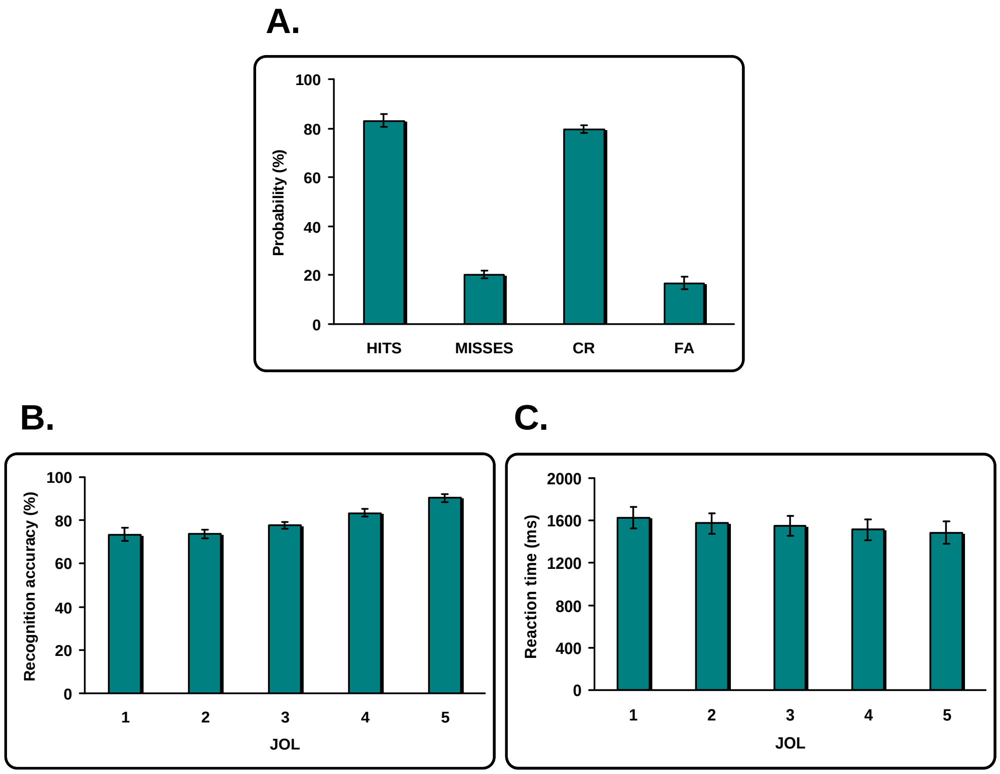

Figure D.4 Behaviour at test.
Mean (and S.E.) recognition responses for each response category at test (A), recognition performance across JOL at test and (B) reaction time measured at test split according to JOL (C).

Appendix E

Of the 24 participants who contributed to the study phase data of Experiment 4, 21 of these performed sufficiently to contribute to the test phase data. The behavioural results of this subset of participants do not deviate significantly from those of the full sample, but are, for completeness, reported below.

E.1. Behavioural Results

E.1.1. Word Block: Study

JOL response rates are shown in Figure E.1a. ANOVA revealed a main effect of JOL [$F(4,76) = 18.2$, $p < 0.001$], with an accompanying quadratic trend [$F(1,19) = 19.5$, $p < 0.001$]. The pattern of reaction time (RT) for making JOLs at study formed the shape of an inverted "U" when plotted against each level of JOL (Figure E.1b). ANOVA revealed a significant main effect of JOL [$F(4,76) = 3.3$, $p < 0.05$], exhibiting a quadratic trend [$F(1,19) = 18.8$, $p < 0.001$].

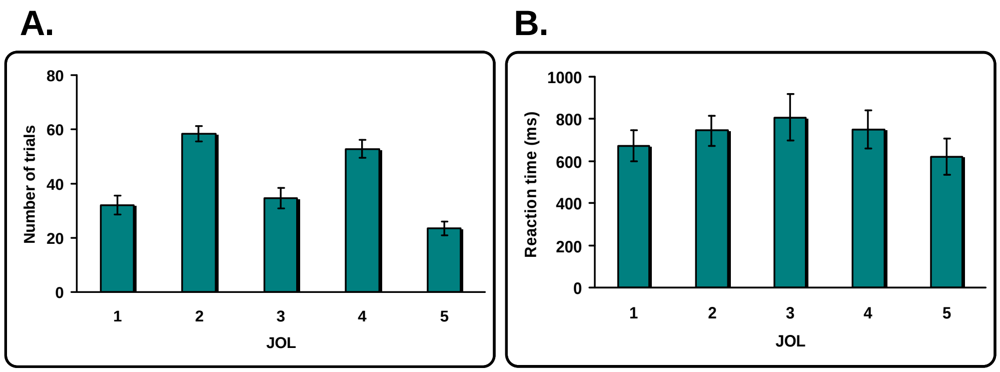

Figure E.1 Behaviour at study.
Mean (and S.E.) number of trials assigned each JOL category at study (A) and reaction times for making each level of JOL at study (B).

E.1.2. Word Block: Test

Overall recognition responses are shown in Figure E.2a and Figure E.2b shows the mean recognition accuracy for old items distributed across the levels of JOLs assigned at study. It is evident from the graph that recognition performance improved with increasing JOL and a repeated measures ANOVA confirmed that the effect of JOL was significant [$F(4,76) = 19.7$, $p < 0.001$], exhibiting a linear [$F(1,19) = 32.7$, $p < 0.001$] trend. The mean G score of 0.36 (SD = 0.13) was significantly above zero [$t(20) = 12.82$, $p < 0.001$]. Mean d_a was 0.53 (SD = 0.23) and was also signficantly above zero [$t(20) = 10.77$, $p < 0.001$]. The reaction times measured at test are shown in Figure E.2c. ANOVA confirmed a main effect of JOL [$F(4,76) = 6.3$, $p < 0.001$], again exhibiting linear [$F(1,19) = 17.8$, $p < 0.001$] and quadratic [$F(1,19) = 4.9$, $p < 0.05$] trends.

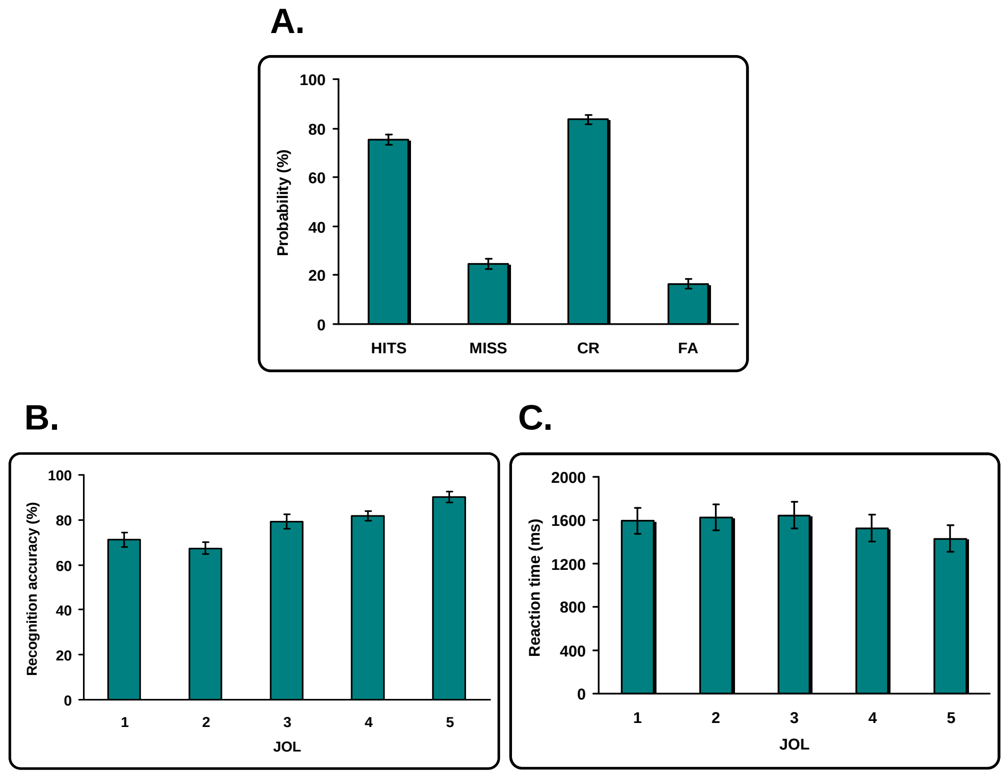

Figure E.2 Behaviour at test.
Mean (and S.E.) recognition responses for each response category at test (A), cued recall performance across JOL at test (B) and reaction time measured at test split according to JOL (C).

E.1.3. Picture Block: Study

JOL response rates are shown in Figure E.3a. ANOVA revealed a main effect of JOL [$F(4,76) = 35.6$, $p < 0.001$], with accompanying linear [$F(1,19) = 24.6$, $p < 0.001$] and quadratic trends [$F(1,19) = 33.6$, $p < 0.001$]. Figure E.3b shows the pattern of reaction time (RT) for making each level of JOL. The ANOVA did not reveal a significant effect of JOL (F=0.1)

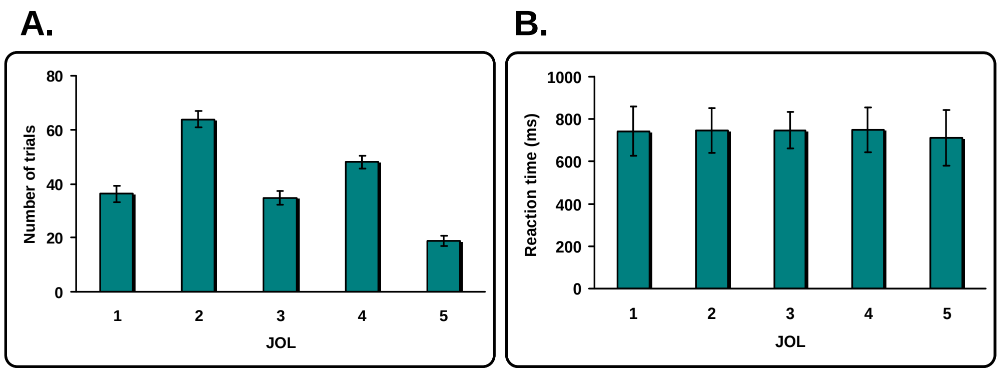

Figure E.3 Behaviour at study.
Mean (and S.E.) number of trials assigned each JOL category at study (A) and reaction times for making each level of JOL at study (B).

E.1.4. Picture Block: Test

Overall recognition responses are shown in Figure E.4a and Figure E.4b shows the mean recognition accuracy for old items distributed across the levels of JOLs assigned at study. It is evident from the graph that recognition performance improved with increasing JOL and a repeated measures ANOVA confirmed that the effect of JOL was significant [$F(4,74) = 23.5$, $p < 0.001$], exhibiting linear [$F(1,19) = 26.5$, $p < 0.001$] and quadratic trends [$F(1,19) = 10.6$, $p < 0.01$]. The mean G score of 0.38 (SD = 0.12) was significantly above zero [$t(20) = 14.05$, $p < 0.001$]. Mean d_a was 0.57 (SD = 0.19) and was also signficantly above zero [$t(20) = 13.57$, $p < 0.001$]. Reaction times measured at test are shown in Figure E.4c. ANOVA confirmed a main effect of JOL [$F(4,76) = 13.5$, $p < 0.001$], accompanied with a linear trend [$F(1,19) = 21.6$, $p < 0.001$].

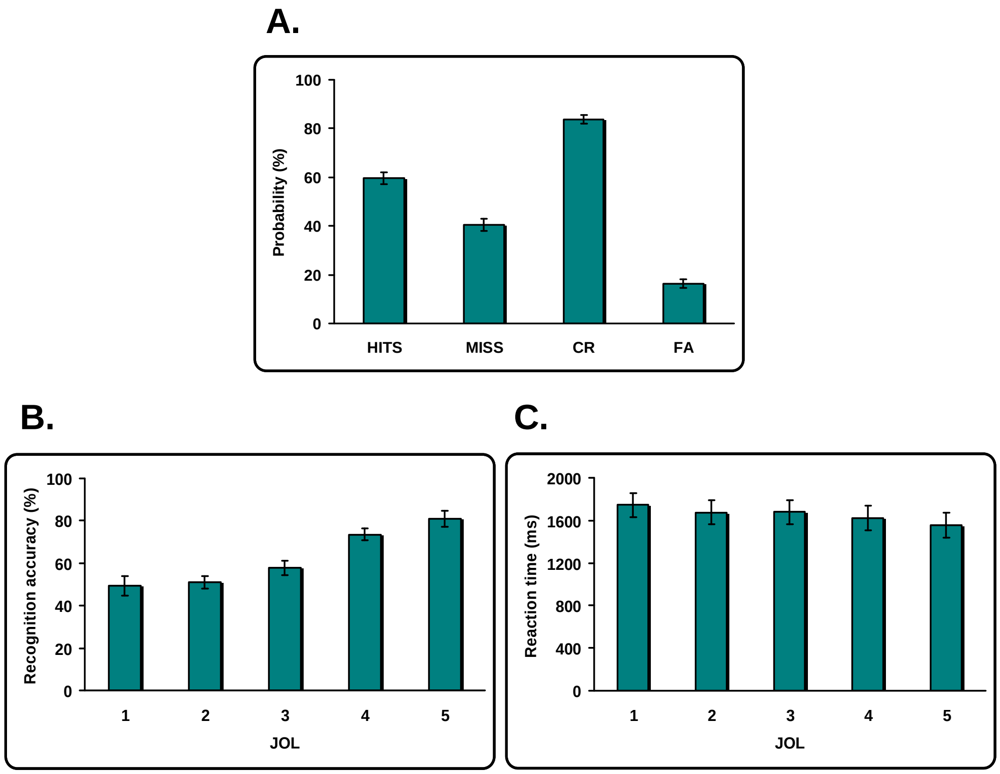

Figure E.4 Behaviour at test.
Mean (and S.E.) recognition responses for each response category at test (A), recognition performance across JOL at test (B) and reaction time measured at test split according to JOL (C).