An Investigation into the Memory Processes that Underlie Judgements of Recency.

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Abstract

Judgements of recency (JORs) are decisions about how long ago a repeated item was initially presented. Event-related potentials (ERPs) were acquired in three experiments, alongside behavioural measures, in order to determine the number and nature of memory processes contributing to JORs. In a series of continuous verbal memory tasks (adapted from Yntema & Trask, 1963), participants were presented with a long list of words and for each item participants were required to make an *old/new* recognition judgement, followed by a numerical JOR. The repetition intervals and JOR response options varied across experiments from between 5 to 35 intervening words. The mid-frontal *old/new* effect and the left parietal *old/new* effect were two ERP modulations which varied in a strength-based manner across time and JOR. These bore resemblances to effects reported in previous studies where they were associated with familiarity and recollection memory processes respectively. Late frontal ERP activity was also identified in the experiments and this is discussed in relation to previous theory. A series of behavioural experiments was employed in addition to the ERP studies, which also involved continuous memory tasks. These studies all had 6 different repetition lags and JOR response options which were between 5 and 30 with increments of 5 (adapted from Hintzman, 2003). This research was conducted in order to address further questions about how recollection and familiarity might support JORs under different circumstances. Additional support for the notion that memory processes underpin JORs in a strength-based manner was identified in this behavioural series. The findings in this thesis therefore suggest that JORs are based in part on an assessment of memory strength, and that two memory processes are likely to support memory for recency under some circumstances.

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CHAPTER 1: MEMORY FOR RECENCY

Introduction

Time perception, including the ability to make judgements about the age of retrieved memories, is hugely important for survival even in the modern world of clocks, calendars and diaries. Being able to recall how long ago one injected oneself with insulin, or how long ago you tested your smoke detector, are examples of memory time judgements which need to be reasonably accurate for well-being. How precise is one likely to be in making these judgements? Furthermore, how is it that the human brain comes to make these judgements of time in the first place? The topic of time and memory, and more specifically, judgements of recency (JOR), is the area of research with which this thesis is concerned. For the purposes of this research, judgements about how long ago a repeated event or item was initially encountered are referred to as judgements of *recency*.

Memory for time includes both memory for recency, as described above, and memory for duration. It is memory for recency that this thesis is concerned with, which is distinguished conceptually from memory for duration (Block & Zakay, 2001), although exactly how these two areas of research relate to one another functionally is still to be determined. Duration judgements differ from recency judgments in that the former can be both retrospective (e.g. how long did that last?) *and* prospective (e.g. how long do you think this will last?), whereas recency memory is by nature entirely retrospective (how long ago did that occur?). One cannot make a recency judgement about the future, but one can make a duration judgment about the future, albeit sometimes based on retrospective experience (e.g. I think this movie is likely to last two hours).

Perhaps a sensible starting point when considering memory for recency is to view the ways in which judgments about when events occurred differ from other kinds of judgments about episodic memory details. Tulving's widely cited characterisation of episodic memory (e.g. Tulving, 1983) is that it involves the recovery of 'what, when and where' information about an event. What is absent from this characterisation is any indication about how the bases for making recency memory judgments ('when' judgments) differ from those supporting 'what' and 'where' judgments. Clearly however, there is a fundamental difference between the sources of information that might be employed to make what, when, and where judgments. The difference stems from the fact that the strengths of memories diminish with time, and this feature provides a source of information that is relevant to 'when' judgments in a way that is less relevant for 'where' and 'what' judgments. In the latter two cases, a weak memory will simply reduce the likelihood of making an accurate memory judgment about, for example, the place an event occurred, or who did what. For 'when' judgments however, the 'strength' of a memory can in principle be a guide, in so far as memory strength can be employed as diagnostic for how recently an event occurred: strong memories are likely to signal that an event occurred more recently than are weak memories (Hinrichs, 1970).

The focus in this thesis is on questions about how the strengths of memories (and what kinds of 'strengths') might support judgments about when events occurred. This line of argument is developed by considering how two processes that support long-term memory judgments (recollection and familiarity) can support judgments about when events occurred, with the particular emphasis being on the question of whether either or both of these processes contribute to accurate recency judgments when memory 'strength' is, by virtue of experiment designs, the principal source of information that is available to people. In the following sections, broad conceptual considerations about memory for recency are described. Much of the current chapter will be based on work by Friedman (1993), who in a detailed and comprehensive review characterised the kinds of information that could support recency memory. Furthermore in this chapter, considerations about memory strength as a basis for recency judgments will be linked to the processes of recollection and familiarity. A review of the evidence that supports the distinction between recollection and familiarity is provided. This is necessary, because there remains controversy about the separation between these processes, as well as how these processes might be instantiated neurally.

The second chapter also includes the justification for employing event-related potentials (ERPs) as indices of memory processes. Critically, Chapter 2 provides the argument that the strength of familiarity *and* recollection may support 'when' judgments, and that an assessment of this account can be obtained through an analysis of how neural activity varies in tasks where people make JORs.

Memory for Recency

Several theories that offer to explain memory for recency have been proposed. These include: Time Tagging Theory, Strength theory, Perturbation Theory, Associative Chaining Theory and the Scale Invariant Memory, Perception and Learning Model. Each of these is outlined below in rough chronological order. After this historical review, work by Friedman (1993) will be discussed, which is considered most relevant to the current work, and which provides a strong theoretical basis upon which judgements about time can be made. This work is then used as a framework for the discussion of much relevant empirical research, and has informed and supported the research carried out in this thesis.

The name 'time tag' refers to hypothetical information about time that is bound to a memory trace at the time of encoding (Friedman, 1990). Time tags were considered to be part of a memory organization system that was not exclusive for coding temporal information (Yntema & Trask, 1963). For example, Yntema and Trask (1963) noted that memories might be associated with a number of *tags* that provide categorical information, linguistic information, temporal information and so on. Hasher and Zacks (1979) also advocated a theory of memory consistent with the notion of time tags, claiming that information about time is automatically bound into a memory trace through a temporal coding system.

There is much evidence that opposes time tag models, for example in one early study of memory for recency, JORs were compared for abstract and concrete words in a continuous recognition paradigm (Yntema & Trask, 1963). The researchers were interested in whether time tags were used to determine the age of an item in memory. Yntema and Trask (1963) showed that people were more variable when making JORs for abstract than concrete words, which doesn't fit with a time tag theory, since there is no logical reason for concrete items to be associated with a more recent time tag during encoding. Time tag models are also challenged by the findings of Wagenaar

(1986) who, in a diary study, found that date of encoding information is of little benefit when attempting to recall an episode.

Finally, more recent findings show that when comparing the relative recency of two items in memory, participants stop searching memory for temporal information when they recover time associated with the most recent item (e.g. Muter, 1979). This reaction time data (RT) is inconsistent with the notion that each event is associated with its own separate time tag, because this cannot explain why accessing one tag might allow you to make a relative order judgement (since both tags would surely have to be accessed by the participant). Thus, time tag theories cannot account for many recency memory research findings (in addition see Friedman, 2001). A more promising line of thought is a strength theory of recency.

Strength-based accounts of memory for recency are an alternative to time-tagging theories. An early strength-based account of JORs was put forward by Hinrichs (1970) who provided evidence in support of the idea that the estimation of memory age is based on the amount of memory-related activity produced when a trace is reactivated. This strength level is postulated to decline with increasing memory age. Thus an estimate of the age of a memory could be based on the level of strength gauged at retrieval. Memory strength is assumed to decline with increasing age through interference of other more recently encountered items and through less efficient trace activation (Hinrichs, 1970).

Hinrichs also noted that a decision process would be required before attributing an item with a JOR, where a criterion would be set about what level of strength corresponds to each degree of time (1970). Setting the strength criteria could be based on: (i) comparison with other items in time; (ii) comparison with strength at encoding; or (iii) comparison to a fixed and pre-determined global strength. Therefore, to determine the recency of a memory one would require some means of assessing strength levels, along with a decision process based upon criteria for attributing strength to a point in time (Hinrichs, 1970). Strength theory was not widely advocated at this time and was thought by some to be a poor account of recency memory. Hintzman and Block (1971) for example, had shown that items presented near the beginning of a list are better discriminated than items at the end of a list. This would be unexpected according to a strength theory of recency, since more recently experienced items would be expected to have greater memory strength (Hintzman, 2000). However data such as this can be accounted for by strength theory – since items at the beginning of a list may be rehearsed more than items at the end of a list, making them even stronger in memory than the most recently encountered items. The possibility that memory strength may provide a basis for recency judgements is a key concept that is returned to throughout this thesis.

In the late seventies, researchers began developing ideas about how memory for serial order is established. An account of recency was put forward by Lee and Estes in 1981. In their model, the temporal properties of an item (A) are encoded at the time of presentation. As more items are experienced (B, C), the temporal properties of the item (A) are updated through a process of reactivation. According to this notion, to retrieve the temporal properties of an item, one would need to move through a list of items backwards in time according to order of presentation. The relations between the items in the list serve as temporal context, and rehearsal of the order needs to occur in order to preserve the temporal context in memory (Lee & Estes, 1981). During rehearsal, some re-activations may cause items to be placed out of order mistakenly ('perturbed'), having a knock-on effect for the order of related items.

Friedman (1993) noted that there is much support for perturbation models of memory for time, for example, the fact that memory for recency is often associated with temporal landmarks, such as the beginning of a list. It also accounts for scale effects - accuracy on a fine time scale, but less accuracy on a wider time scale (e.g. Friedman & Wilkins, 1985). However, it is unlikely that perturbation theory accurately describes the mechanics of recency memory under all situations. Perturbation theory is likely to be applicable for short sequences of items for example, and not when there is a long list of items in which there are few temporal landmarks (e.g. Hintzman, 2001). In several circumstances there would be limited scope for item order rehearsal (Friedman, 1993). In very long lists, many of the items are likely to be forgotten and therefore cannot provide information about the recency of other items from the list – yet under these circumstances, people are still able to make recency judgements (e.g. Hintzman, 2003). Thus perturbation theory is promising but is unlikely to provide a complete account of memory for recency.

Associative chaining models emerged in the late 1980s, and these models are similar to the perturbation theory of memory for recency, in that they were formed to describe temporal memory for fairly short sequences of items. Lewandowsky and Murdock (1989) developed a model linked to the Theory of Distributed Associative Memory (TODAM), a single process view of recognition memory. Murdock (1982) proposed that items in memory are seen as lists of random features, and presentation of a test cue results in a comparison process with information stored in memory. Mismatches result in *new* judgements (i.e. a judgement that the item has been presented for the first time in the list), whereas a particular degree of matching of test item and stored information in the long-term memory store will result in *old* judgments (i.e. a judgement that the item is a repetition in the list).

In the Lewandowsky and Murdock (1989) model, memory for temporal order is stored in the associations between pairs of items in a sequence. These may be associations between single items such as words, or between groups of items on a larger scale (chunks). For example, if there are three items in a list (A, B, C), one must store the association between the first two (A, B) and the second two (B, C) items on the list to enable one to retain order information (Lewandowsky & Murdock, 1989). In practical terms, this might mean that we would date an event only by associating it with other events.

The main problem with the associative chaining model is that it does not make clear the scale at which temporal associations are stored, and that (as is also the case for perturbation theory) the theory does not allow for the fact that episodic memory usually gives rise to limited rehearsal (Friedman, 1993). If temporal memory is mediated by associative chaining, it is unclear how this could work over very long lists of items, or over long time scales. A more recent account of recency memory has since been put forward that views this class of memory as being based on chronological order of occurrence, rather than on the associations between events, and this is described below.

Brown, Neath and Chater (2007) have proposed a Scale Invariant Memory and Perceptual Learning (SIMPLE) model that envisions memory as being organised in a form directly reflecting the organization of actual time. More recently presented items are represented by more easily accessible memory traces than are less recently presented items, explained by SIMPLE through the notion that memories are chronologically organised. Traces for items presented far back in the past are viewed as occupying a congested part of memory, and are thus more confusable and less easily accessed than recently encountered items (Brown & Chater, 2001). Brown et al. (2007) suggest that ease in accessing a memory trace will be dictated by this temporal expanse, and that this will be proportional to the number of items sharing the same region of psychological space. The SIMPLE model is scale invariant, in that it applies equally over different time-scales across prospective and retrospective memories, and this element of the theory is supported by the finding that forgetting curves have the same shape over a range of different time-scales (Maylor, Chater & Brown 2001).

Brown and Chater (2001) suggest that since more recently experienced items or events may be recovered more easily than less recently occurring items (due to forgetting over time), memory must be temporally organised. Furthermore, Brown and Chater (2001) cite evidence in support of their model that the temporal position of some items in a list can be confused with that of other items – and that this is more likely to happen when those items occur closely together in actual time (Healy, 1974). Other support for a SIMPLE model of memory is data showing that the need for information about an event declines with an increase in the amount of time since the event occurred – in line with memory accessibility (Anderson, 1998). Additionally, Brown and Chater (2001) suggest that evolutionary foraging behaviour was the likely precursor to memory developing in this way – in that to save energy an animal must know both how long it will take to travel a certain distance for food. The authors of the model perceive temporal landmarks in memory (such as the start or end of a list) to be reminiscent of spatial cues in foraging behaviour (2001).

Though SIMPLE theory can account for some serial order phenomena (e.g. long term recency effects: Bjork & Whitten, 1974; Talmi & Goshen-Gottstein, 2006), the model fails to account for one of the principal findings in serial order experiments (Friedman, 2001), known as the primacy effect (Murdock, 1962), where items at the beginning of a list are remembered well, relative to mid-list items. According to the SIMPLE account this should not be the case, since items at the start of a list are chronologically further back in time than mid-list items, and must be more confusable. In addition, this theory fails to account for scale effects (Friedman, 2001).

Though this theory has much relevance for an account of serial ordering performance and was developed based on empirical evidence from serial ordering tasks (Chater & Brown, 2008), a SIMPLE view of memory is less able to account for data obtained in long continuous *recency* tasks that are free of contextual landmarks (such as the beginning and end of a list). These are the kinds of tasks that are employed in this thesis. The important distinction here is between judgements of recency and judgements of serial order (Hintzman, 2003), where primacy and recency effects may only in the latter case reflect associations with these contextual landmarks (at least to an extent). Thus, despite the fact a SIMPLE view of memory has been put forward as an account of memory for recency, it is not relevant for the tasks presented within this thesis, nor is it able to fully explain tasks of serial ordering.

In this historical review of theories relevant to memory for recency, each can account for some empirical data (perhaps with the exception of time tagging theories), but not all. Friedman (1993) categorised these theories into location, relative and distance accounts of memory for recency and as will be illustrated later in this chapter, the theories may not need to compete as different accounts of recency. It will be argued that different forms of recency information may be available under different circumstances. Before moving onto Friedman's framework of memory for time however, a potentially important theory of time perception shall be described.

Wearden's Model of Time Perception

In addition to the above theories and viewpoints about memory for time, there is another interesting branch of theory that is related, which concerns perceptions of time duration. Evidence suggests that people often have only a loose sense of time perception, for example when asked to judge the amount of time that has elapsed (i.e. to assess duration), adults tend to make underestimations (Block & Zakay, 1997). Older adults make greater verbal estimates of duration regardless of the time period presented (Block, Zakay, & Hancock, 1998), and young children show greater variability in their time duration judgements than adults, as well as overestimating time periods that have passed (Block, Zakay, & Hancock, 1999). An influential view of time perception is that of Wearden (2003) who has argued in support of a Scalar Expectancy (or Timing) Theory (SET), which provides a description of internal timing mechanisms.

Wearden (2001) described how one might come to make a judgement about the duration of a time interval by using an internal clock that may store the length of time between stimulus presentation and stimulus repetition, which is measured via 'ticks'. It is proposed that the presentation of a stimulus switches a connection between a pace-maker and an accumulator into 'on' mode, which is switched 'off' again at stimulus repetition. The switch is thought as of being variable in the time it takes to initiate, thereby causing inconsistency in duration judgements, which Wearden refers to as 'scalar variance'. This internal clock is one part of the SET model initially developed by Gibbon, Church and Meck (1984), and according to the model accumulated temporal information can be transferred into short- or long-term memory. Decision processes are also incorporated in the model, which are necessary for the stored information to be employed for time judgments. Evidence for the presence of an accumulator has been obtained in animal studies, where pace-makers are employed to produce a certain number of 'ticks' per second and this can guide behaviours that are rewarded only after a certain number of clicks have been encountered (for a review, see Lejeune & Wearden, 2006).

However, while this view of time perception is intriguing, there are difficulties reconciling it with work that seeks to find an understanding of temporal representations in memory. For example, Hoerl and McCormack (2001) have stated that despite the well explicated representations in Wearden's theory, such timers may not be able to provide an animal with enough information to distinguish between events happening at different times (and/or placing episodic events in temporal order), in particular when such disparate events may correspond to the same representations or internal state or clock (Hoerl & McCormack, 2001). In addition, it is not straightforward to envision how one or even a few clocks might accurately represent the passage of time between multiple similar memory episodes in a way that would permit accurate time judgments when several competing episodes intervene between presentation and re-presentation.

It may be that subjective time in memory may be linked to actual passage of time, amongst other factors (Lam & Buehler, 2009). Despite this, JORs are quite different from time as measured by clocks (Gebauer, Broemer, Haddock & von Hecker, 2008; Ross & Wilson, 2002), and thus it is likely that they are based on something other than an internal mirror of actual time passage. Furthermore, in a criticism related to that made by Hoerl and McCormack (2001), while Wearden's model appears to propose logical mechanisms that can represent some aspects of internal time perception, the fact that the model relates to conceptual *representations* of processes at a holistic level rather than to hypothesise about *how* these processes could cognitively or physiologically function, means that it is not easy to investigate, and may require greater refinement (a problem recognised by Wearden himself, 2001). As Staddon noted, no such physiological evidence of an internal clock or pacemaker has yet been found in the 20 years since SET theory was formally described (2005). Wearden's work looks promising, however it requires more development and is of less significance to the current research than more empirically grounded theory such as the work of Friedman (1993) and Hintzman (2001; 2003; 2004).

In summary, a roughly chronological summary of existing models of memory for time highlights that each has various advantages and disadvantages. What follows is a description of a framework of memory for recency by Friedman (1993) which incorporates as well as integrates many of the positive aspects of the above models.

Understanding Memory for Recency: Friedman's Framework

Friedman (1993) has suggested that a person could make use of three types of information when making recency memory judgements. *Relative* information involves making judgements about where (in time) an event fits in to a series of events. The associations between items are thus assumed to provide a form of recency information. For example, a person might determine that their neuroscience meeting took place in June by relating it to a cognitive meeting which took place in May, and to an interview they had in July. Hence, the use of relative information would be useful when one wishes to make chronological re-ordering judgements.

Location information is a second form of information which is likely to be available to people when making judgements about recency in memory (Friedman, 1993). Location-based information is said to be intrinsic and fixed within the memory for the study episode (Friedman, 1993). To date an item's initial occurrence, one must assess the trace for this contextual information, or reconstruct it (Curran & Friedman, 2003). For example, a person might judge that their holiday in Greece occurred eight years ago, because they remember that the Sept 11th terrorist attacks happened while they were there. Knowledge about time systems can be used to interpret the context of an event, in order to date the event.

Distance information is the third form of information which could be utilised when making recency judgements (Friedman, 1993). Distance-based information is assumed to change between the time of encoding and retrieval (Friedman, 1993). Memory strength could be classified as distance information. For example, if vividness was the basis for a person's memory strength, then a highly vivid memory for a birthday party might be the basis for judging that the birthday occurred very recently. That is, assessing levels of strength decay between encoding and retrieval is the basis of this form of distance information. Chronological organization of memory and contextual overlap between encoding and retrieval (see Figure 1 below) are theories which also fall under the bracket of distance information according to the Friedman (1993) model, and these will be discussed further on pages 36-38.

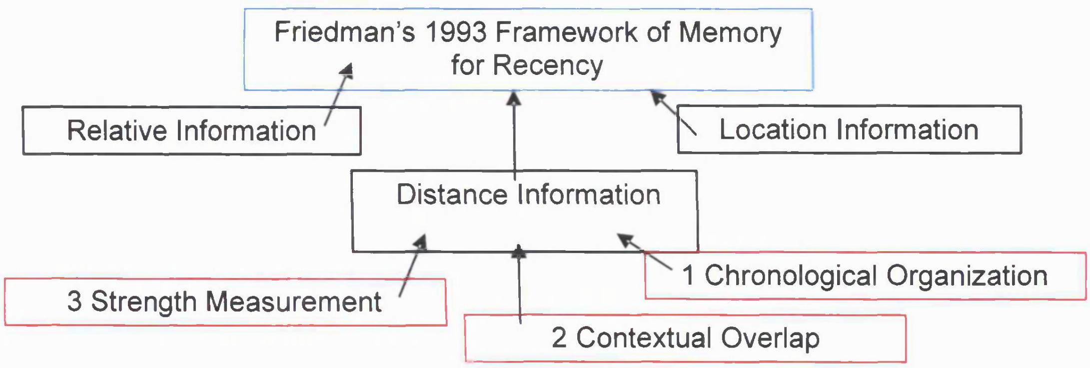

Figure 1. Interpretation of Friedman's (1993) framework of memory for recency. In the black boxes are three potential forms of information that one might use in order to make a recency memory judgement. It was proposed that three types of theory fall under the bracket of distance, and these are indicated in the red boxes.

Friedman's (1993) distinctions between the three classes of information described above (black boxes in Figure 1) are a way of thinking about memory for recency that is fruitful for research, because there is evidence to suggest that these types of information are discrete and that they form the basis for temporal memory judgements in different ways and under different circumstances – as will be demonstrated in the following sections (for an in-depth review, see Friedman 1993; 2001).

Relative, distance, and location are the three types of information that may contribute to judgements of memory for recency (Friedman, 1993), and it is distance information which is of most relevance to the current work. Distance information is of interest, because it is the least researched of the three types, but key evidence suggests that it may be very important under certain circumstances (e.g. Curran & Friedman 2003; 2004; Hintzman 2003). Therefore, particular attention will be paid to research and theory that pertains to distance information, and its key role in informing memory for time and recency judgements. The different possible types of distance information will be discussed in detail later in this Chapter (p36).

What follows is a review of theory and research that is divided into three sections, which focus on the main types of recency information outlined by Friedman (1993). The discussion will describe work that may indicate how and when these forms of information might be used in recency memory judgements. It is distance information which is of most relevance to the work in this thesis, and this kind of information is described last. After these sections, the discussion will then focus on familiarity and recollection memory processes, how these may vary in a strength-based manner, and thus how they might be considered to be a form of distance information.

Studies of Relative Information

This is the information type to which Friedman (1993; 2001; 2004) has given arguably the least weight in his framework, although it is the information type which has been explored the most. Sometimes it is necessary to re-organise events chronologically, and to re-order a series of items, one must make use of relative information - thus Associative Chaining theory and Perturbation theory could be categorised as falling under the bracket of relative information in Friedman's (1993) framework. An example of a typical task which gives rise to reliance on relative information is presenting participants with a list of items at study, and then during test, presenting participants with a list of studied items and asking them to re-order the items according to order of original presentation (e.g. Naveh-Benjamin, 1990). Another example would be to present participants with a list of items at study, then to re-present two items at test and ask participants to select the most recent item. Tasks which are likely to require participants to make use of relative information for temporal judgements, involve comparisons between 2 or more items along a time-line of some form (e.g. Tzeng & Cotton, 1980).

There is evidence that relative time of occurrence is a distinct class of information that is available when one aims to make a judgement of recency. In an important study relating to relative information, Tzeng and Cotton (1980) tested the ability of participants to determine the relative recency of words which were either semantically unrelated (e.g. dog – jug) or related (dog – cat). Participants were more successful in picking the most recent of the two items when the test words were semantically related, and this is thought to be because one word in the pair will more easily remind the participant about the recency of the other related word from the pair (see also Hintzman, Summers & Block, 1975; Nairne & Neumann, 1993; Winograd & Soloway, 1985). Friedman (1993) suggested that this is best explained if one believes that relative information, rather than distance or location information, is the basis for these recency judgements. Consider a list of 5 items: Dog, Jug, Map, Cat and Pit. If 'cat' and 'dog' were presented in a pair and the participant asked to judge the relative recency, participants would be expected to be more accurate in *this* pairing than if 'dog' was paired with 'jug'. Relative theories can explain this finding since activation of the word 'cat' may reactivate knowledge about the position of the word 'dog'. Since 'dog' and 'jug' are not categorically related, there would be no reason for relative order information to be generated for this pairing. A distance or location information theory cannot account for these findings.

The finding that temporal order is judged more accurately if the stimuli are related is consistent over relatively short time periods, but Friedman (2007) has shown that the semantic relation between items over very long periods of time may not influence relative ordering. Participants in Friedman's study were presented with a list of movies put into pairs. If the participant had previously seen both movies in the pair, they were to make a temporal order judgement. The movie pairs were either semantically related (since they contained the same person in the lead roles), or they were semantically unrelated (they had different people in the lead roles). When making judgements of temporal order for movies approximately 5 years old or more, the effect of semantic relation did not influence ordering. This was also the case in a second study of announcements across a three week interval (Friedman, 2007). It is therefore possible that relative order information is lost with increasing time.

Skowronski, Walker and Betz (2003) also conducted a study to investigate recency memory in a way that relative information was likely to be relied upon. They asked participants to log one event per day over a period of 9 weeks. One week after the end of the diary section of the experiment, participants took part in a computer recency test. Two selected events from the diary (based on the same theme) were presented on screen and the participants were asked to give a relative order judgement (Skowronski et al., 2003). The key finding was that semantically related events were not more accurately dated over a long time scale, consistent with Friedman (2007). Perhaps contextual or strength-based information are the types of information used in temporal judgements on larger time scales, however the finding that semantic relation influences recency memory performance over the short term suggests that this is a source of information distinct from the other two categories defined by Friedman (1993).

Naveh-Benjamin (1990) conducted a series of relative ordering experiments in which participants were always presented with a series of 20 words. After the study period, participants were asked to re-order the stimuli according to the study presentation sequence. Ordering performance was better for groups who were expecting to complete a re-ordering task in advance of the test, in comparison to participants who were not expecting to re-order the stimuli (1990). It was also found that when attention was less available for the encoding of order, re-ordering performance was reduced at test. Finally, when participants were told how to improve encoding of the order of the stimuli, performance was enhanced (Naveh-Benjamin, 1990). This research suggests that relative information for temporal order is not automatically encoded. However, this was a complex task where all 20 items were expected to be re-ordered. It might be the case that when re-ordering tasks are less complex, automatically encoded recency information may be recruited by participants.

In a task where participants were asked to re-order a list of just 7 items in the original order of presentation, participants were also more accurate when the temporal re-organization task was anticipated (Van Asselen, Van der Lubbe & Postma, 2006).

This task is likely to make use of relative information, since recency information must be compared for each item to complete this task. Participants had been presented with lists of items where they were told to focus on either the spatial locations or on the temporal order. On some spatial trials, participants were unexpectedly asked for order information. A correct expectation led to a reduced error rate, thus it is likely that some information about temporal order is not automatically encoded in memory (consistent with the findings of Naveh-Benjamin, 1990). Furthermore, spatial judgements were found to have no primacy or recency effects as a function of temporal order – a finding that suggests spatial and temporal short –term memory are distinct source memory types (Van Asselen et al., 2006). These findings conflict with the notions of Hasher and Zacks (1979) outlined on p10, and present a strong challenge to time tag theories of memory for recency.

There is some evidence that use of relative information might be dependent on the integrity of the frontal lobes. In a neuropsychological study, three groups of patients with amnesia were compared with healthy controls on a relative ordering memory task. The patient groups consisted of frontal lobe lesion patients, Korsakoff patients and a mix of non-Korsakoff related amnesic patients. Patients with frontal lesions were impaired on a word sequencing activity, where re-ordering of words according to order of presentation was required, despite the finding that their recognition memory performance did not differ from that of normal controls (Shimamura, Janowsky, & Squire, 1990). The same group of patients also performed more poorly than the other groups in their ability to accurately order news events chronologically. The findings suggest that the integrity of the frontal lobes is necessary for performance on tasks that require re-ordering abilities (Shimamura et al., 1990), but not in tasks that require only recognition memory. This of course also suggests that recency memory and recognition memory do not rely on entirely the same processes. This point will be returned to in later sections (see in particular, p46).

In another neuropsychological study, frontal lobe patients and healthy controls were asked to reconstruct the temporal sequence after studying a list of words (Mangels, 1997). In one condition the participants knew they would be tested for temporal order and in another condition they were unaware of the task that would follow. Patients with damage to the dorsal lateral pre-frontal cortex (DLPFC) did not benefit from prior knowledge about the temporal task, whereas healthy controls did suggesting that they made use of strategies which would aid their ability to reorder the stimuli (Mangels, 1997). Patients with frontal lobe deficits did not differ in terms of their temporal ordering performance under incidental conditions, in comparison with the normal controls (Mangels, 1997). This suggests that the frontal lobes do not have a selective role for dealing with temporal information. Instead, this finding lends support to the view that the frontal lobes are necessary for implementing strategies which support general source memory processing (i.e. the mechanisms underpinning memory for the context in which an item was first presented).

Early imaging research utilising functional magnetic resonance imaging (fMRI) in the investigation of memory for recency also showed that the frontal lobes are implicated in these memory processes (Eyler-Zorrilla, Aguirre, Zarahn, Cannon & D'Esposito, 1996). After studying a long list of words, participants were asked to make judgements of recency (choose the most recent item from a pair) or to make a judgment about oddity (choose the odd one out), in alternating blocks. Recency judgements were associated with activation of the dorsolateral prefrontal cortex bilaterally, while oddity judgments were not (Eyler-Zorilla et al., 1996). This research provides further evidence that the frontal lobes are implicated in tasks where relative time judgements are made.

The notion that the frontal lobes support recency memory non-selectively is reinforced by fMRI evidence that the right DLPFC activity is reflective of a generic strategic ordering process (Rajah & McIntosh, 2006). Normal participants were scanned during a reverse alphabetizing task (said to be related to strategic ordering) and during separate old/new recognition memory and recency memory tasks. In the recognition task participants were asked to pick the *old* (repeated) item from a pair. In the recency task two words from the study list were presented and the most recent was to be judged. The greatest activation in the DLPFC was associated with strategic ordering in the alphabetizing task and activity in this area was more active during the recency than the recognition task (Rajah & McIntosh, 2006).

This finding supports the notion that a sub-region of the frontal lobes is not a critical recency area, but is implicated in recency memory in an executive-based manner – that is, the area is likely to be associated with executive functioning. Executive functioning in memory is likely to involve a strategic or planned control of memory, and not automatic internal responses (Burgess, 1998). Tests of executive functions generally require working memory, inhibition and/or cognitive flexibility (Oosterman et al., 2008). Thus, where most need for strategic control of memory is required (as in the reverse alphabetising task), then the greatest activation in the DLPFC is observed.

In summary, the studies detailed above have implicated the frontal lobes in recency memory judgements, using tasks where relative information is likely to have been employed. Many other relative information studies have also provided evidence to support the idea that the frontal lobes perform an executive role in memory for time of this form (Butters, Kaszniak, Glisky, Eslinger & Schacter, 1994; Dobbins, Rice, Wagner & Schacter, 2003; Dumas & Hartman, 2003; Kessels, Hobbel & Postma, 2007; Konishi et al., 2002; McAndrews & Milner, 1991; Schmitter-Edgecombe & Simpson, 2001; Yasuno et al., 1999).

Summary of Relative Information

Numerous studies in which memory for recency has been investigated have employed tasks in which participants are likely to make use of information about relative times of occurrence. In order to perform successfully in these tasks, participants had to be able to judge the relative recency of each item in a sequence. From this brief review of studies in which it is likely that relative information is utilised, it is clear that some progress has been made into understanding memory for recency.

Behavioural studies have led to findings showing that relative information is likely to be a distinct form of memory information that participants use in their recency judgements, and that this is likely to be more available for items or events which have occurred recently (Tzeng & Cotton, 1980), as compared to those occurring in the more distant past (Friedman, 2007). From the results of behavioural studies it is clear that relative information is not automatically encoded for short complex tasks (e.g. Naveh-Benjamin, 1990), though whether this is true for events and items over much longer periods of time is yet to be understood.

Neuropsychological and imaging studies have shown that the frontal lobes are implicated in memory for recency and that recognition memory does not rely on the frontal lobes in entirely the same way (Shimamura et al., 1990). Furthermore, neuropsychological and imaging evidence has shown that the frontal lobes are implicated in recency judgements in an executive manner – presumably in organising data and implementing strategies (Mangels, 1997; Rajah & Mackintosh, 2006).

In this section some important evidence has been reviewed that suggests relative information is utilised for recency judgements in memory under some circumstances. The frontal lobes have been implicated in tasks where participants are required to make use of relative information for recency judgements. What now follows is a review of studies where participants are likely to make use of what Friedman referred to as location information (1993).

Location Studies

Friedman (1996; 2001) focused largely on the contributions of location information and distance information (see following section) to memory for recency. Tasks where location information is likely to be utilised for recency judgements typically involve studying separate lists of items. Participants are then presented with words from the different lists and are asked to make a JOR for each. List 1 vs. List 2 judgements are likely to provide clear location information since items within the list may act as temporal landmarks – whereby participants form an association between the list (location) and the item (Friedman, 2001).

The existence of scale effects is said to be the most convincing evidence suggesting that location information can be utilised when making judgements about recency (Friedman, 2001). Scale effects are demonstrated where one is able to make a fairly accurate recency judgement on a fine timescale, but to be less accurate on a wider timescale (Friedman, 2001). For example, in reminiscing, a person might be accurate in judging that they dropped a birthday cake at lunchtime (fine scale - within a day), while being inaccurate in judging that the birthday cake was dropped two years ago, when it was actually dropped three years ago (wide scale - within years).

One early study in which a scale effect was observed was conducted by Hintzman, Block and Summers (1973). Participants were presented with four separate study lists of words. After all study phases, the participants were asked to indicate, for each test word, which study list it had come from and where in that study list (list position) the item had been presented. Participants were often incorrect when judging which study list the item belonged to (wide scale), despite being correct about the item's list position (fine scale) (Hintzman et al., 1973). Distance information is presumably not the basis for these effects, because it is likely that big differences in strength (across lists) should be easier to distinguish than small, positional strength differences. Relative order information is also unlikely to be responsible, because it should be easier to assess an item in relation to a big temporal landmark (such as list 1, list 2, etc) than to compare relative information within a list of very many items. Location information can account for this finding, however, because it is likely that information about a fine time-scale would be stored as part of the episode context. These findings therefore support strongly the position that location information is a discrete form of information that can support recency judgments.

Chalmers (2005) conducted a study where participants were likely to rely on location information for their temporal source judgements. Participants studied two lists of novel faces, and half of the faces were repeated three times within each list (frequency manipulation). At test, half of the participants were asked to make a recency judgement for each presented face, while the remainder of the participants were asked to make a frequency judgement. Only frequency level influenced judgements about frequency, whereas an item's frequency *and* actual recency influenced recency judgements, with faces which were presented three times in list 2 attracting the greatest level of accurate responses (Chalmers, 2005). Since frequency judgements were more accurate than recency judgments, it was suggested that the capacity to make these judgements is likely to be dependent on different memory processes (Chalmers, 2005).

These data extend those of Hintzman (2001) who found that, although they are related, participants do not confuse recency and frequency of presentation very often, therefore these types of judgements cannot be based on entirely the same memory processes. Participants have been found to be quite poor in judging the recency of faces in comparison to previous research of a similar nature with pictures (Huppert & Piercy, 1978). Chalmers (2005) suggested that this might have been due to a decreased ability to form associations between each face and its associated context (location information), suggesting that decreasing the availability of location information leads to less accurate recency judgements.

The frontal lobes have been implicated in recency memory in tasks where location is likely to be utilised. Shimamura, Jernigan and Squire have shown that patients suffering from Korsakoff's Syndrome (KS) typically have damage to the frontal lobes (1988). These patients also have damage to the midline diencephalon nuclei, which project to the DLPFC (Langlais, 1995). Korsakoff patients have been reported as exhibiting temporal memory deficits, amongst their other cognitive deficits, such as spatial memory (Postma et al., 2006). In one study, for example, a group of Korsakoff patients were presented with two lists containing twelve words. At test they were required to determine which of two previously studied words (one from each list) was presented the most recently. Korsakoff patients had impaired recency memory in comparison with control participants who had damage restricted to the medial temporal lobe (MTL) (Downes, Mayes, MacDonald, & Hunkin, 2002).

The task reported by Downes et al (2002) was one that is likely to tap recency memory capacities in a location-based manner, since the task involves two well defined separate lists and clear temporal landmarks. This research supports earlier findings with Korsakoff patients, which implemented a time interval of over more than an hour between lists (Kopelman, Stanhope, & Kingsley, 1997). Researchers have postulated that the impairments exhibited by these patients may stem from higher order executive difficulties (Brokate et al., 2003). It is possible that the frontal lobes are contributing to the impairments demonstrated by the KS patients, although the diffuse damage associated with this condition encourages some caution. If this account is correct, however, then the findings are further evidence that the frontal lobes play a role in memory for recency that is not specific for this form of memory, since damage to these regions also impairs spatial memory in KS patients.

A separate study using a similar form of task (list 1/list 2 discrimination) found that, when using face stimuli, there was only a marginal differentiation between patients with damage to the frontal lobes and patients with damage to the posterior cortex in regard to performance on a recency task (Daum & Mayes, 2000). Frontal patients were also impaired in their spatial memory abilities and in tasks measuring executive function (relative to controls). This study provides further evidence to suggest that recency memory is not a selective impairment associated with frontal lesions. It is likely that frontal patients are exhibiting difficulties related to executive functioning such as planning or other forms of organisation (Daum & Mayes, 2000).

Fradera and Ward (2006) conducted a study with older and younger adults. They aimed to assess whether increasing the availability of location information for an event increases the accuracy with which participants can date those events. In this study, a young adult group (mean age 20 years) had not been alive at the time of the actual newsworthy events, unlike the older group of adults (mean age 74 years). Participants were provided with a booklet of events. The task required them to date each event from a multiple choice (9 year intervals across choices), and to answer two multiple choice questions to demonstrate their contextual knowledge of the event (Fradera & Ward, 2006).

Fradera and Ward (2006) showed that the level of contextual knowledge of an event for young adults was related to the accuracy of dating the event. This was not found to be the case for the older group of participants. Though the older group was able to provide a greater volume of contextual information for the events (as shown by their level of accuracy in answering questions about the events), this group was poorer at dating when the event had occurred. This experiment provides some support for the idea that older adults have poorer recency memory abilities (Fradera & Ward, 2006) and suggests that they do not make use of the location information available to them to the same extent as younger participants in tasks of very long-term memory (over 30 years). It may be that this is caused by deterioration of the frontal lobes with increasing age (Moscovitch & Winocur, 1995), leading to a decline in the ability to use location information – a reconstructive process likely to demand many organizational aspects of memory relating to executive functioning.

Summary of Location Information

Fewer studies investigating memory for recency have employed tasks in which participants are likely to make use of location information, in comparison with relative information. In order to perform successfully in these tasks, participants are likely to find associated contextual cues in the memory trace which might indicate when the test item or event was originally presented. Behavioural studies have shown that location information is likely to be a form of information available to participants when carrying out recency judgements (e.g. Chalmers, 2005; Hintzman et al., 1973). Interestingly, a recent study has revealed that greater accuracy in recency judgments may be achieved by increasing availability of contextual information (Chalmers, 2005), which supports the idea that location information is being relied on in this task (rather than relative or distance information). Furthermore, there is good evidence which suggests that scale effects exist, whereby participants may be more accurate at recency memory judgements on a fine time scale than on a grosser scale (Hintzman et al., 1973). This is likely to arise from a reliance on location information where contextual information for the episode is strong, thereby allowing for high accuracy within a narrow timescale. Behavioural research has also shown that recency judgements are not based on entirely the same form of information or memory processes as judgements of frequency (Chalmers, 2005; Hintzman, 2001).

In addition, the findings reported above suggest that the frontal areas of the brain contribute in some way to memory for recency judgements in tasks where location information is likely to be employed (e.g. Daum & Mayes, 2000). It is probable that recency memory relies upon the frontal lobes in an executive manner, in the same way as was argued in the relative information section. Findings from numerous other neuropsychological and imaging studies support this claim (e.g. Simons, Gilbert, Owen, Fletcher & Burgess, 2005; Trott, Friedman, Ritter, Fabiani, & Snodgrass, 1999).

Evidence in support of the notion that Friedman's (1993) relative and location forms of recency information are distinct, and that they are likely to be utilised when making JORs, has now been reviewed. The primary empirical focus in this thesis is on the third potential form of recency information, which is called distance information. A review of studies relating to this category of information follows.

Distance Studies

Friedman (1993) described distance theories as being a partial account of memory for time (as is the case for relative and location information), however he acknowledged the key influence that distance based information can have on temporal judgements. Friedman (2001) argued that scale effects and primacy effects (where memory accuracy is high for items at the start of a list) are unlikely to be explained by use of distance information, thereby indicating that recency memory judgments must be supported under some circumstances, by other kinds of information. However, it is still likely that distance information is important for many recency memory judgements, and in some situations may be the principal kind of information relied upon for these types of temporal memory decisions.

Friedman (1993) noted that perhaps the appropriate experiments to show the usefulness of distance information have not yet been conducted. Tasks which presumably measure primarily the use of distance information must involve studying a list of items which is relatively free of location markers (such as the beginning of a list, for example). Presentation of a very long list, with no clear divisions, is likely to mean that participants will have to rely on distance information when asked about the recency of an item (or event) from that list. A long list will also be likely to exclude the possibility that participants can make JORs based on relative information – since it would be unfeasible to compare the recency of an item to every other item in the list. If they were to compare items, it would have to be a specifically selected few items which are likely to be helpful for the JOR, and distance information would therefore be likely to be the basis of such a selection.

Friedman (1993) outlined that there are three types of information falling under the bracket of distance in his framework. These are strength-based measurements, contextual overlap of information, and chronological organisation information. Common to all three categories is that they involve the use of information in memory that is said to change between the time of encoding and retrieval (Figure 1, p21). Firstly, Friedman (1993) suggested memories that are chronologically organised in order of occurrence, as in a SIMPLE account (Brown, Neath & Chater, 2007), could be viewed as belonging to a distance category of recency information (Figure 1: Subcomponent 1). If memory was found to be chronologically organised, it could be used as a distance-based form of information in that changes in memory (that is, the encoding of new memories) occur between encoding and retrieval, and could be used to make judgements about recency. If a memory is processed fluently, for example, it could be judged as being more recent, because relative fluency might be inferred as a proxy for recency. According to Brown and Chater (2001), changes in fluency occur because more recent items occupy a less congested part of psychological space.

As was outlined on p16, theories that depend on memory being organised in terms of actual order of occurrence in real time still have to account for some simple memory phenomena (e.g. primacy effects: Friedman, 2001). In addition, these theories cannot account for other relevant phenomena, such as there being little evidence that one event primes another in terms of temporal information, unless memory context is a cause for a relation between two events (e.g. both events took place in my seminar – so I know they both occurred in July: Wagenaar, 1986). Also, Friedman and Huttenlocker (1997) have shown that items presented within the same week were not more likely to be judged as next to one another in time than were items presented in different weeks, a finding that is difficult to explain in terms of a chronological account of memory.

Friedman (1993) also identified the contextual overlap between a retrieval cue and a memory trace as being another potential form of distance information (Figure 1: Subcomponent 2). For example: if a person were to judge how long ago they had last attended a lecture, they might think of it as having occurred more recently if they were in another lecture at the time of judgement, compared to being in the supermarket at the time of judgement. One line of evidence in support of this theory is that when emotional state is consistent at the time of encoding and at the time of retrieval, the event in question will appear to have occurred more recently than when no correspondence in mood exists (e.g. Gebauer et al., 2008). It is likely that contextual overlap does have some real basis, although detailed theoretical delineation and experimental testing of these ideas is lacking and therefore shall not be considered here.

Finally, and most crucially for the current work, as has been mentioned earlier (p37), another important type of distance information involves the outcome of a strength assessment of the memory trace (Figure 1: Subcomponent 3). The experiments described in this thesis were designed with the aim of exploring how memory strength could be used as a form of distance information when judging recency, in particular relating to the concepts of *familiarity and recollection.* This will be done in order to extend what is known about this very interesting and well described, but little studied area of memory for time. What follows is a review of relevant studies where a *strength account* of distance information has been implied, and from this point onwards this is the *only* subcomponent of distance information that is considered in this thesis.

Behavioural studies involving children have shown that distance information is likely to be available and used earlier than either relative or location forms of recency information in memory. Friedman and Kemp (1998) have suggested that the ability to re-order events along a timeline is something which does not change with age, since they are of the view that order information is automatically encoded (for an alternate view, see Naveh-Benjamin, 1990). Experiencing an event is said to cause the retrieval of a previous event, establishing an order pattern automatically. In young children however, these orderings are of limited use since they have little knowledge of time cycles and so cannot link events to locations in time (Friedman & Kemp, 1998).

Recently published literature suggests that this is indeed the case - young children are able to do simple re-ordering tasks, but that they fail to make use of the temporal information to answer further questions (McCormack & Hoerl, 2007). For example, four year old children were shown *Doll A* going into a house to brush his hair, and then *Doll A* putting the brush into *Cupboard A*. This was followed by a viewing of *Doll B* going into the same house, doing his hair and putting the same brush into *Cupboard B* this time. The children could correctly state which doll had brushed their hair first, but could not use that information to correctly state where the hairbrush was now located (McCormack & Hoerl, 2007).

Friedman and Kemp (1998) have reasoned that the ability to make use of location information in temporal judgements is likely to develop with age more than reliance on other types of recency information, because children learn more about time patterns with increasing age. In a recent investigation into the ability of children to implement reconstructive memory processing, which would be required in order to make use of location information, Friedman and Lyon found that only children aged around 6yrs and over have this capacity (2005). In their study, groups of children between the ages of 5 and 13 years were compared on their ability to construct and make use of contextual information relevant for temporal dating accuracy. Participants were involved in two salient events, close in time to Halloween. Approximately 3 months later, the children were asked questions about the events, the associated environmental contexts, and about the date of the events. Although the four year olds could recall some context from the events, only by around 6 years of age and onwards could the children recall sufficient information for temporal reconstruction. Good knowledge about time patterns, such as seasons and calendar information, was found in the age groups above 8 years (Friedman & Lyon, 2005). Despite this, the amount of contextual information available to participants did not relate to the accuracy of their temporal judgements (in terms of clock time, month or season) at any age (Friedman & Lyon, 2005). This suggests that children do not make use of location-based information for dating events over a long time period, despite increasing capacity to do so with age, in contrast with young adults (Fradera & Ward, 2006).

Friedman and Kemp (1998) have also shown that children are able to, and do, make use of distance information, in order to make partially accurate judgements about the time of salient events on a wide time scale of up to five months. Young children just under 5 years of age were asked to arrange events along a timeline. The six events, including Valentine's Day and Hanukkah for example, were presented in a random order. Recency judgements increased in subjective distance as did actual distance in time for events up to 5 months in the past (Friedman and Kemp, 1998). This supports the notion that distance information is a valid category as described in Friedman's 1993 paper, in addition to location and relative information. It is likely that, in children at least, distance information is less useful for more remote temporal memory judgements. This is because (as has been demonstrated by Altom and Weil, 1977) recency judgements of children begin to flatten out, rather than increasing with increasing distance in the same manner as actual events. This could mean that distance information is less useful with judgements which need to be made over a very long period of time.

The finding that children's recency judgements begin to flatten out after a period of time is a pattern which is similar to the availability of distance information in adults. After the American festival Thanksgiving, Friedman and deWinstanley (1998) asked adults to rate their memories for the event at regular weekly or bi-weekly intervals over the proceeding 25 weeks. The memories of the adults for the event became less clear over time, but this decline mainly occurred over the first twelve weeks (flattening out thereafter). This finding gives some support for the notion that people are aware of differences in memory strength over time (see also Thompson, 1982) and therefore memory strength differences are potentially useful for recency memory.

Few adult studies of distance information have been carried out, where researchers have tried to limit the possible use of other types of information in recency judgements. Kemp and Burt (1998) asked participants to rate the level of vividness they experienced for newsworthy events, along with asking them to date the event and to rate their level of contextual knowledge of the event (signifying the level of distance information available for each event). Participants were also asked to squeeze a dynamometer, with the pressure of squeeze signifying the recency of the event. Knowledge and vividness ratings were highly linked to the level of squeezing on the dynamometer, suggesting that this measure was used by participants to indicate the strength of their memories. There was a reasonable relationship between squeezing and actual date of the event, though context ratings were much more highly associated (Kemp & Burt, 1998). This study suggests that strength of memories could be relied on at least to some extent in order to make recency judgements.

In a series of experiments, Muter (1979) compared response latencies for recency memory judgements. Participants were presented with a study list of four or ten words. After the presentation of the list, participants were asked to pick the most recently presented word from a pair. Pairs were made up of randomly chosen words from the study list. Muter (1979) found that the most recently presented probe's position affected response latency, unlike the position of the earlier probe. Reaction time (RT) increased as the position of the most recent word increased (i.e. occurred later in the list). This suggests that when the most recent item's recency has been decided, no further search for information about time is carried out. Hacker (1980) extended these findings to show that this is the case even for items which are incorrectly judged as being the most recent item.

A strength account of these findings is likely to be the most appropriate, rather than location or relative order information. According to this account, items occurring earlier in the study list are likely to have decayed to a greater extent than more recent items (Hinrichs, 1970). When items are presented for the recency task described above, it is likely that participants make the judgement on the basis of memory strength. The more recently an item occurred, the stronger the memory. The stronger the memory, the faster the response. RTs are dependant on the position of the most recent item in the list, even when participants are incorrect about the most recent item (as in the case of Hacker, 1980). In this instance, they are incorrect about the recency because the strength of the less recent item is greater, but the RTs are still determined by this stronger item. These important findings provide additional evidence to suggest that distance information is likely to be relied upon for judgements of recency, and thus is a distinct form of mnemonic information in addition to the location and relative categories outlined by Friedman (1993).

In another study where participants were likely to use strength information for recency judgements, it was found that the more semantic (or contextual) information participants reported having for an event, the more recent the date attributed to that event (Brown, Rips & Shevell, 1985). Participants were given a long list of news events, which were matched for age and genre within pairs. In one experiment, the task required one group to rate their knowledge for the events, followed by a judgment about the date on which they believed the event had taken place. A second group conducted the tasks in the opposite order. The participants who rated recency before context judged the events as occurring less recently than the other group. The researchers suggested that this finding was due to the availability of prior contextual information, which made memories for the events more accessible, and thereby more likely to attract shorter recency judgements (Brown et al., 1985).

To ensure that participants were not attempting to keep their judgements consistent due to researcher desirability, another experiment was conducted (Brown et al., 1985). One group of participants was asked to report all information that they could retrieve for each event in the list. A second group was asked only to provide a recency judgement for each event. Here the level of contextual (or semantic) information available to participants was more highly associated with the subjective date than the actual date (Brown et al., 1985). This research indicates that contextual or semantic information is used by participants, perhaps in a strength-based manner (in that high levels of recovered information leads to high memory strength), for making their recency judgements.

Of particular relevance to the research and key themes of this thesis are a series of studies conducted by Hintzman (2003; 2004; 2005) using a variant of a task employed initially by Yntema and Trask (1963). As described on page 10, Yntema and Trask's focus at the time was on 'time tagging' accounts of memory, according to which time judgments are made via recourse to some form of unique temporal tag that is attached to an event. For the purposes of the current research however, this work is important because of the experimental paradigm that was employed. Long lists of items, where there are few if any temporal landmarks, were employed, so distance information is the most likely kind to be used when making recency judgements, as noted already. The link between performance on this kind of task and considerations relevant to distance information as a basis for time judgments was developed by Hinrichs (1970; also see page 11 above), who provided evidence in support of the idea that the estimation of memory age is based on the amount of memory-related activity produced when a trace is reactivated.

In important work Hintzman (2003; 2004; 2005) conducted a series of studies using a variant of the task employed by Yntema and Trask (1963). Across experiments, words were repeated after various lags (ranging from 5-60 intervening items). Participants were required to make *old/new* recognition judgements in response to each word presented in the list. For items judged to be *old* (i.e. those recognised as being repeated in the experiment by participants), numerical JORs were also required. These experiments were devised to be devoid of any location-based information (temporal landmarks), that is – any contextual information which could serve to date the memory. Using this type of experiment, Hintzman found that manipulations which can reasonably be assumed to alter the 'strength' of a memory trace (e.g. concreteness, frequency, etc) had an effect on the JOR. The 'strength' here was inferred from findings on recognition memory tasks: for example, old/new discrimination is superior for low than for high frequency words.

In each of Hintzman's experiments, the subjective recency of an item was shorter as a function of increasing strength. For example, an item repeated after 20 intervening items might be given a JOR of 15 if pictorial, or a JOR of 25 if presented in word form. The explanation offered by Hintzman is that this pattern came about because pictures elicit stronger memories than do words (Nelson, Reed & Walling, 1976). The same argument was applied to explain the fact that, in these continuous tasks, the mean JOR for concrete words is shorter than that for abstract words, and shorter for low than for high frequency words.

Hintzman (2005) also claimed that JORs are not based on entirely the same processes as those used for making *old/new* recognition memory judgements, since repetition lag affects recognition memory judgements to a lesser degree than JORs. Furthermore, recognition confidence does not follow the same pattern as JORs for the same reason (Hintzman, 2005). On the basis of these findings, Hintzman has suggested that a unitary strength account of JORs is insufficient. As a result, Hintzman (2005) suggested that there is a second factor – *factor T*- that supports JORs This 'factor *T*' was not defined, but Hintzman argued that is probably a distance-based form of information. Location-based processes were ruled out on the basis of the argument that the task structure minimises the availability of location-based information.

It is also unlikely that relative information is being utilised in the continuous recency tasks described above. If participants were relying on relative information, it would be expected that JORs would be more closely linked to time than to the number of intervening items (since recency would need to be compared with other items in the list backwards in time). Hintzman (2004) explored this issue by implementing a continuous recognition task like that described above, and varying the interval between trials, which was either 500ms or 2500ms (blocked fast vs. slow trials within the list). Mean JOR was longer in slow than fast blocks and this was more strongly linked to time than number of intervening items (Hintzman, 2004). Therefore relative information is unlikely to be utilised by participants in a continuous recency task.

Feelings of familiarity are considered by some researchers to be a distinct memory process that is graded in nature (Wixted & Stretch, 2004; Yonelinas, 1994). Familiarity could be one memory process that underlies recency judgements, because of this strength-based property. Indirect evidence supporting the possibility that a strength assessment of familiarity could act as distance information comes from fMRI research by Brozinsky, Yonelinas, Kroll & Ranganath (2005). They presented words to participants which repeated after varying lags. *Old/new* judgments were required. The imaging data showed that the left anterior parahippocampal gyrus reliably increased activity levels during trials for *old* items at longer lags (16 and 32 intervening items) when compared with items repeated at lags of shorter duration (2 and 8 intervening items). This region has been linked selectively with familiarity, rather than with recollection (e.g. Aggleton and Shaw, 1996; Aggleton & Brown, 1999; Montaldi, Spencer, Roberts & Mayes, 2006; Yonelinas et al., 1998 - though see Squire et al., 2007; Yonelinas et al., 2005). Since there is evidence that familiarity varies in a strength-based manner, it could be used as a form of distance information.

More recent fMRI research of these effects provided further evidence that this activity is graded in line with increasing numbers of repetitions (Johnson, Muftuler & Rugg, 2008), this time in right lateral hippocampus regions as well as in the region of the left parahippocampus identified by Brozinsky et al. (2005). This suppression effect may be used as an index of familiarity levels (Xiang & Brown, 1998) and therefore could potentially be used to make strength-based recency judgements.

Yassa & Stark (2008) conducted a novel and interesting experiment of repetition effects that is relevant for this thesis. In a continuous recognition task, participants were presented with novel pictures between 1-4 times, and with reference pictures once, about which pre-experimental familiarity levels would be high (e.g. Mona Lisa). These researchers demonstrated that activity in the parahippocampus was graded in line with increasing repetitions of novel items, and that activity differed according to whether a stimuli was a reference picture or a novel one (Yassa & Stark, 2008). Within the left perirhinal cortex, activity was graded according to number of repetitions, but activity here did not distinguish between reference and novel stimuli (Yassa & Stark, 2008). Thus, this evidence can be used to support the notion that the both the parahippocampus and perirhinal cortex reflect recency information, but that additionally, the former brain structure also reflects long term familiarity. Both regions are candidates for providing Friedman's (1993) distance information, since activity decreased with repetition in the parahippocampus and increased in the perirhinal cortex as the interval between first and second item presentations increased (Yassa & Stark, 2008).

Summary of Distance Information

Few studies have been conducted which restrict the use of location and relative information in recency judgements. At present, our understanding of distance information - and how participants may use this for JORs - has largely stemmed from behavioural studies, which have shown that subjective reports of memory strength can be associated with actual dates (Kemp & Burt, 1998), and have shown that recovery of greater levels of semantic or contextual information for an event will lead to that event being judged as having occurred more recently, as compared to recovery of lower levels of that information (Brown et al., 1985).

In addition to earlier findings from recency tasks which emphasised the use of location information, other studies have shown that recognition judgements and JORs are based on different memory processes, at least to some extent (Hintzman, 2005). Behavioural research has also provided evidence to indicate that strength manipulations can have an effect on JORs; as an item's memory strength increases, the more recent the JOR for that item (Hintzman, 2003). Imaging research has also produced data which indicated that familiarity could be one potential basis for distance information (e.g. Brozinzky et al., 2005). This literature review of distance information has revealed that behavioural research has and can continue to provide a wealth of information about judgements of recency. Furthermore, it is clear that imaging data can also increase understanding of memory for recency and how these forms of temporal judgements are considered and made. These pathways of research into distance information should be encouraged to expand in future to bring our level of knowledge in line with that for relative and location information forms.

As was described earlier in this Chapter, the main focus in this section has been on strength assessment of recency memory – rather than relating to contextual overlap or chronological organization theories, that also fall under the bracket of distance information. The research in this thesis is based on strength theories of recency, because this well described theory has received little empirical investigation despite the fact there is evidence to suggest that it may be important under certain circumstances (e.g. Curran & Friedman 2003; 2004; Friedman & Kemp, 1998; Hintzman 2003).

How do these findings relevant to distance information sit with the earlier sections, in which there was good evidence for the use of multiple kinds of information when recency judgments were required? One inference is that different forms of information may be available in combination or at different times to support recency judgments. The failure to address explicitly this possibility is one criticism of Friedman's work, but this element has been incorporated in a recent extension of that account. What follows is a review of a recent model that extends the work of Friedman (1993; 2001), providing information about how and when the different types of recency information may be utilised.

Developing Friedman's Account: Janssen (2006)

One shortcoming of the framework put forward by Friedman is that it fails to explicitly address the possibility that different forms of information, which could provide clues to recency, may be available all at once or at different times depending on the circumstances. Janssen et al. (2006) recently presented a model relevant to this topic based largely on the work of Friedman (1993), which is consistent with the possibility outlined above, suggesting that people are likely to use multiple forms of temporal information. This model, the proponents claim, covers both the potential availability of different forms of temporal information, and the circumstances under which these might be used. Episodic details such as who was present, where the event took place and so on, are referred to as primary temporal information in the model. Landmarks and event 'context' are referred to as secondary clues to the time or date of a memory (Janssen et al., 2006). There is a focus on distance and location information in the model and it is suggested that when primary and/or secondary indications about date are available, one is likely to make recency judgements based on location information. Where these clues are unavailable, one is more likely to make use of distance information where possible (Janssen et al., 2006). Additionally, in this model it is outlined that one is more likely to use distance information for remote events, and to rely on location information for relatively more recent events.

Janssen et al. (2006) suggested that distance-based memory judgements give rise to less accurate recency memory judgments than do location-based recency memory judgements. Furthermore, on the basis of studies exploring long-term memory, these researchers suggested that people are likely to use a combination of different types of temporal information on occasions, in order to aid them in their recency memory judgments (Janssen et al., 2006). Perhaps the availability of, and differential reliance on, these three information types is why not all data (e.g. scale effects) fit any one theory of memory for recency described earlier.

This model is still under development (Janssen et al., 2006) and current problems with the model include the assumption that distance information is only available for remote memories, which cannot be the case based on the results of Hintzman (2003). This is because participants can still make JORs where location information is likely to be unavailable due to a lack of contextual landmarks in continuous memory tasks that require JORs for items still in short-term memory (Hintzman, 2003). In contrast with the views of Janssen et al. (2006), Brown and Chater (2001) have made the opposite claim, suggesting that location information would be more useful than distance information for dating events that originally occurred in the more remote past. Since only distance information is likely to be available over the short-term, with little contextual information to reconstruct about these events, location information is likely to be utilised for events that occurred in the distant past (Arbuthnott & Brown, 2009; Brown & Chater, 2001). Altom and Weil's (1977) research also suggests that distance information is less likely to be useful for more remote memories, since recency judgements flatten out in these instances.

Janssen et al's (2006) theory of memory for time is important for the context of this thesis despite the aforementioned theoretical difficulties, because it suggests that different kinds of temporal information (first categorised in Friedman's 1993 framework) may be available under different circumstances. Though Friedman has argued in the past for and against the use of the three main information types (1993, 2001), it is feasible that all three are used at different times – potentially in combination – in order to carry out recency judgements. This possibility is appealing for several reasons. For example: in a list1/list2 experiment, Huppert and Piercy (1978) showed that frequency and recency are confused in some amnesic populations, unlike in healthy controls. The Janssen et al. (2006) view of temporal memory could provide a neat explanation of this data, in that the amnesic population are entirely reliant on distance information, whereas controls use both distance and location information to perform more accurately on this task. The notion that relative, location and distance information form three distinct ways of forming recency judgements may also underlie feelings of time discrepancies in memory. For example, one might reflect that being at school feels like yesterday and that it's hard to believe how much time has passed (using location information, where you can reconstruct a vivid image of being in school), but on other occasions you might feel that school happened very long ago indeed (using relative information, you have thought of many events that occurred between now and then).

The key point is that all three types of information are likely to be used for making recency judgements under different circumstances. Indeed, one may use more than one form of information, depending on the type of memory judgment that is required of them (e.g. when there is need to be highly accurate). If one form of information is unavailable for whatever reason (e.g. brain damage, lack of contextual landmarks), then another category from Friedman's framework might be relied upon more heavily for that particular judgment. In a task where frequency and recency are being manipulated, for example (e.g. Huppert & Piercy, 1978), distance information is useless for dating and so location information will be relied upon if available to the participant.

Focus of the Current Research

It is clear that there are three categories of information that can support recency judgments. As the literature review on pages 36-50 shows, research which investigates the potential use of distance information is relatively sparse, in comparison to other kinds of recency information. In addition, the principal focus in previous research has been on the concept of memory strength, but with little attention paid to what kinds of strength might support JORs. The focus in this thesis is on the question of what kinds of strengths might support JORs, and the starting point is the possibility that two processes – recollection and familiarity – may contribute to JORs in a strength-based manner.

How might these processes contribute to JORs? Familiarity is considered to be a graded strength signal: old (previously studied) items are assumed to have greater strength than new items on recognition memory tasks. Familiarity could therefore support JORs, whereby the greater the level of familiarity experienced for an event, the shorter the associated JOR. Conversely, if an event elicits little familiarity then one would be likely to judge that this occurred in the distant past. Familiarity is widely considered to be a graded memory process (Yonelinas, 2002), and therefore could be expected to support JORs in this way. Since an assessment of the strength of familiarity is considered as potentially underpinning memory for recency, this falls under the bracket of distance information according to the categories proposed by Friedman (1993).

Recollection may also play a key role in underpinning recency judgements in a similar way. Recollection is recovery of qualitative information about a prior event (Yonelinas, 2002). Consider Hintzman's 2005 experiment as an example, where items are repeated after lags of 5-30 intervening items. Although it may appear unlikely that participants had much contextual information to reconstruct about these rather meaningless events, it is possible that recollection was helpful to some degree. Participants may base their JORs upon the quantitative amount that they were able to recover about the study episode. For example, if presented with the word 'Nectar' for a second time, a participant may recall that during study they had imagined a bumble bee (contextual retrieval of imagery). On the second presentation of 'Evade', however, they may be unable to recover any contextual information about the study episode. If the volume of recollected information is employed as a basis for JORs, then for 'Nectar', the lag judgement would be shorter than the judgment for 'Evade' on the grounds that 'Evade' must have been presented a long time ago (since they could not recover a similar amount of contextual information). These ideas are perhaps comparable to what Yonelinas and Jacoby (1996) termed 'noncriterial recollection'.

If this line of thought about JORs is correct, it would suggest that there are at least two separate memory processes which could support memory for recency in a distance-based manner in a continuous recency task – one being strength of the familiarity signal, another being the volume of contextual recovery of information, or the strength of recollection (Figure 2, p56). It could be the case that only one of these memory processes underpins JORs, or it may be the case that participants perform an assessment of the strength *of both* recollection and familiarity in order to make recency judgements. The experiments reported in this thesis were conducted in order to examine whether these two possible sources of distance information, strength of *familiarity and recollection,* do underlie JORs in this manner. In this way a strength assessment of familiarity and/or recollection would fall under the bracket of providing distance information in terms of the strength measurement (see Figure 2 below). It is not accepted universally, however, that recollection and familiarity do constitute distinct memory processes, hence in the following section the justification for assuming this separation is provided.

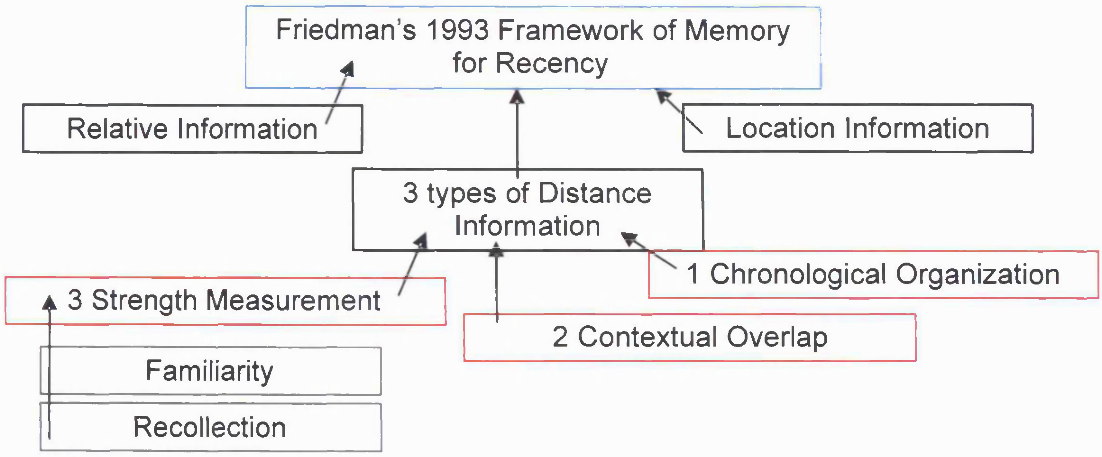

Figure 2. Returning to the interpretation of Friedman's (1993) framework, recollection and familiarity (grey boxes) may be two forms of memory which are graded and can be used as a form of distance information when making recency judgements.

What follows is a further description of the two memory processes of familiarity and recollection, along with a review of research relating to these concepts. Persuasive evidence suggests that familiarity and recollection are distinct recognition memory processes, but there is as yet no consensus on this matter.

Familiarity and Recollection

Identifying that something has previously been encountered constitutes recognition memory (Mandler, 1980). There are principally two classes of theory concerning the composition of recognition memory. According to *dual-process* accounts, recognition memory is based on two processes, recollection and familiarity (Yonelinas, 2002). One definition of recollection is that it is a threshold process involving retrieval of an event which includes remembering associated contextual information. Familiarity is a basis for recognition memory judgments that does not involve recalling associated context, and it is considered to be a strength-based signal that can give rise to a feeling that an event has been experienced previously (Kelley & Jacoby, 2000).

Single process theories of recognition memory, by contrast, advocate the idea that recognition memory relies on only one memory process. There has been much debate concerning these theories (e.g. Ratcliff, van Zandt, & McKoon, 1995; Squire et al., 2007), however dual process models of recognition memory (Jacoby & Dallas, 1981; Yonelinas, 2002) have gained increasing support over the past few years. This growing evidence for dual memory processes stems mainly from brain imaging studies (Woodruff, Hayama & Rugg, 2006), behavioural studies (e.g. Gardiner, 1988; Jacoby, 1991) and through data from neuropsychological cases (e.g. Aggleton et al., 2005; Yonelinas et al., 2002) (for a review, see Yonelinas, 2002). A brief summary of single process theories of recognition memory follows first.

Single Process Models of Recognition Memory

Raaijmakers and Shriffin (1981) devised the Search of Association Model (SAM), which postulates that recognition memory depends upon a single process of familiarity. The SAM model of recognition memory proposes that items requiring recognition judgements are assessed against all information held in long-term memory in a parallel manner. When a cue fits a particular context in memory, a particular level of familiarity signal is elicited. This familiarity level will be assessed against a pre-determined criterion and if the level is above this set criterion, then a judgement of recognition is likely to be given (Gillund and Shriffin, 1984).

Theory of Distributed Associative Memory (TODAM) is a single process view of recognition memory which has similarities to the SAM framework. Murdock (1982) proposed that items in memory are seen as lists of random features. Presentation of a test cue results in a comparison process with information stored in memory. Mismatches result in '*new*' judgements, whereas a particular degree of matching of test item and stored information in long-term memory will result in '*old*' judgments.

The overall principle behind single process theories of recognition memory is that there is one continuous memory signal (which can be described as familiarity) and that *old* items will elicit a greater signal than *new* items. Ratcliff et al. (1995) propose that single process models of recognition memory can account for outcomes derived from the manipulation of study time, word frequency and context during encoding. However, dual process theories of recognition memory have dominated the field of recognition memory for more than thirty years (Higham & Vokey, 2004). The evidence in support of dual process accounts of recognition memory follows.

Dual Process Theory

As previously mentioned, the two memory processes of familiarity and recollection are highly important concepts for this thesis. If recollection and familiarity are separate memory processes, then there should be some manipulations which influence recollection and not familiarity. There should also be evidence for this to occur in the opposite direction, with familiarity alone being influenced by some manipulations (Yonelinas, 2002). Evidence which suggests that this is the case comes from behavioural studies showing that dividing attention constrains recollection more than it does familiarity (Anderson et al., 1998; Craik, Govoni, Naveh-Benjamin & Anderson, 1996). This finding has been more recently supported using ERPs (Curran, 2004) and in studies of aging populations (Castel & Craik, 2003).

Conversely, criterion setting has been demonstrated as having a larger influence on familiarity than on recollection. Changes in response criterion required to accept an item as being *old* has been shown to have very little effect on recollection (e.g. Postma, 1999). Processing fluency manipulations have also been found to have a greater effect over familiarity in comparison with recollection. Priming leads to an increase in the level of familiarity, but does not influence recognition responses based on recollection (Jacoby & Whitehouse, 1989). These dissociations suggest that recollection and familiarity are processes which are functionally separable, at least during retrieval.

There is also evidence that recollection and familiarity have different neural substrates (Ranganath, Johnson & D'Esposito, 2003; Yonelinas, Hopfinger, Buonocore, Kroll & Baynes, 2001; Yonelinas et al., 2005). Recollection is said by some to be largely dependent on the integrity of the hippocampus, whereas there is animal and clinical evidence to suggest that familiarity processes are supported by the parahippocampal gyrus (for a review see: Brown & Aggleton, 2001). The nature of recollection and familiarity signals, and whether they are dual processes or single processes contributing to memory judgments, remains a matter of ongoing debate in psychological studies, in patient studies, as well as in animal studies (for reviews and alternative perspectives, see Squire et al., 2007; Yonelinas, 2002). This brief summary is extended in the section below, where findings relevant to the recollection /familiarity split are considered in the context of three lines of research in which these processes have been investigated: these comprise research using the process-dissociation procedure, receiver operating characteristics, and the remember/know procedure.

Process Dissociation Procedure

The process dissociation procedure was developed in order to assess the relative contributions of familiarity and recollection in recognition memory tasks (Jacoby, 1991). The applications of this procedure are based on the premise that recollection and familiarity are independent processes (Jacoby & Kelley, 1992).

In a typical process dissociation paradigm, words from different categories (e.g. male voice/female voice presentation) are studied in two distinct lists. At test a mixture of *new* and studied words (from both categories) are presented visually. Participants are asked to make *old* responses only for items presented in one of the two categories (e.g. female voice only) and these are known as *targets*. The words previously presented from the other category are *non-targets*, and participants must respond '*new*' to both non-targets and *new* items in the test. In this example, if participants incorrectly judge male voice items from the first list to be *old*, this will be down to familiarity, since conscious recollection would have allowed for retrieval of source context and would have led to source accuracy. Participants are then asked to perform a second test phase where instructed to classify all studied words as *old* (inclusion condition).

Equations have been devised to estimate the separate contributions of familiarity and recollection. R+F - RF = Inclusion indicates the probability of correctly classifying an item as being *old* during the inclusion condition. F - RF = Exclusion estimates the probability of incorrectly classifying a non-target item as being *old* in the exclusion condition. R = Inclusion – Exclusion, is the equation which estimates correctly classifying a target item as *old* based on recollection. To estimate the contribution of familiarity to successful *old* responses in the exclusion condition the equation F = Exclusion/(1-R) is used (Jacoby, 1991).

This task has been used extensively since its development over 20 years ago, showing the different properties of recollection and familiarity processes. For example, Jacoby, Woloshyn and Kelley (1989) found that recollection is more heavily influenced than familiarity by divided attention. In another experiment employing this procedure, aging was shown to have a greater effect on recollection than familiarity (Jennings & Jacoby, 1993). More recently, implementation of the process dissociation procedure has shown that familiarity undergoes a faster rate of deterioration than recollection (Yonelinas & Levy, 2002).

In addition to the process dissociation procedure, two widely employed and tested measures of the contribution of recollection and familiarity processes to recognition memory have been devised. These are the remember-know procedure and receiver operating characteristics (ROCs). Use of these measures has given rise to evidence in support of dual process theory of recognition memory in different ways as described below.

Remember-Know Procedure

The R/K procedure involves studying subjective states of recognition based on responses given by participants. They are asked to provide a description of their basis for *old* judgements, indicating whether they remember (R) or know (K) that the item/items has/have been previously encountered (Gardiner & Richardson-Klavehn, 2000; Tulving, 1985). Remember responses are made when one recognises a previous episode based on retrieval of some associated memory context. Know responses are given when recognition is based on awareness that an episode has previously been encountered only. From a dual-process perspective, Remember responses are assumed to be associated with recollection memory processes. Know responses are assumed to be associated with familiarity processes (Gardiner & Richardson-Klavehn, 2000).

Many variables influence these categories of response differently. Use of non-words (in comparison to words) leads to an increase in Know rather than Remember responses (Gardiner & Java, 1990), and dividing attention has been shown to decrease Remember responses more dramatically than Know responses (Yonelinas, 2001). Items which differ in size at encoding relative to test increase Know responses, but decrease Remember responses (Yonelinas & Jacoby, 1995). Pharmacological studies have shown that some drugs can reduce Remember responses but not Know responses using this procedure (e.g. Curran, Gardiner, Java & Allen, 1993). Remember responses have been found to increase by deep encoding tasks (as compared to shallow encoding), whereas Know responses were greatly decreased (Rajaram, 1993), which contrasts with the work of Gardiner (1988) who found deep processing increased Remember responses without affecting Know response levels.

These studies suggest that two recognition memory processes are operating in this task since some manipulations can influence one more than the other, or can influence them in different ways. Though the remember/know procedure was associated with the assumption that recollection and familiarity are mutually exclusive (Gardiner & Parkin, 1990), it has now been illustrated that they are likely to be independent memory processes (Yonelinas & Jacoby, 1995).

ERP studies of recognition memory have shown that Remember and Know responses differ to some extent in the patterns of brain activity they elicit (e.g. Smith, 1993). Research has shown that brain activity associated with Remember responses come much later in the recording epoch than activity linked to Know responses (Duzel, Yonelinas, Mangun, Heinze & Tulving, 1997; Rugg, Schloerscheidt, & Mark, 1998) and is also qualitatively different This fits with the notion that information associated with recollection memory processes is available after a faster paced familiarity process. Taken together, the findings described above are evidence to suggest that there are two memory processes which provide the basis for recognition memory judgements, and thus support dual process theory.

Despite broad agreement that the R/K procedure is a valid technique for measuring the extent of recollection and familiarity experienced under different circumstances, there is evidence to suggest that the introspective paradigm is not always a useful tool for distinguishing clearly between these types of memory. For example, Wais, Mickes and Wixted (2008) asked participants to study a series of words in various colours. At test, words were represented among new lures in black and participants were asked to make an *old/new* judgement, followed by a remember/know judgement and a source judgement. When participants made source colour judgements, either before or after an *old/new* recognition judgement, they had above chance accuracy with both R and K responses (Wais et al., 2008). This does not fit with the idea that familiarity does not support contextual retrieval, unless one accepts the view that familiarity sustains within-item contextual associations (Jaeger, Mecklinger & Kipp, 2006; Mayes, Montaldi & Migo, 2007).

Further evidence which is not in line with dual process accounts of R/K comes from research in which participants were asked to make speeded recognition decisions. Lengthening the response deadline led to an increase in levels of R *and* K judgements for *old* items and during a short response deadline very few K responses were made. This does not fit with the idea that K responses reflect the quick and automatic nature of familiarity (Gardiner, Ramponi & Richardson-Klavehn, 1999). Therefore, either the R/K procedure does not measure familiarity, or dual process theory, in the form described within this thesis, is not supported by these findings. A third possibility also exists, however – that the reason for the Gardiner et al. (1999) findings is that people only make familiarity judgements *after* they have attempted to recollect. This is one way of accommodating these findings within a dual-process framework.

Receiver Operating Characteristics

ROCs are correctly identified *old* items (hits) plotted as a function of *new* items accepted as being *old* (false alarms) at different criterion points. In memory experiments, recognition judgements are often followed by confidence judgments, which are assumed to reflect different criteria. Thus, for each recognition judgment made, participants will be asked to rate their confidence in the judgement on a point scale (usually ranging from something like: *sure old* to *sure new*). In this way, hit rates can be plotted in terms of confidence across levels of false alarms. ROCs are cumulative probability functions that can be plotted from confidence ratings where the left most point shows the most confident hits versus the most confident false alarms, the second point is a mixture of the most and the second most confident ratings and so on.

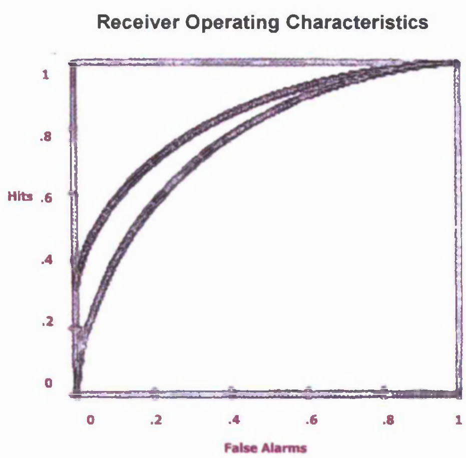

Figure 3. Two types of ROC curves (for original, see Yonelinas, 2001). According to single process accounts, the upper curve represents higher memory strength than the lower, because more test items were given a high confidence rating here (leading to an asymmetrical curve). Dual process theorists instead suggest that the asymmetry is caused by a greater contribution of recollection (the greater the asymmetry, the greater the contribution of recollection).

The most common ROC shape observed in recognition memory tasks is the upper of the two plots in Figure 3. This shape is not predicted by single-process accounts of recognition memory in which the variance of the *old* and *new* item strength distributions is equivalent. According to this model, ROC curves should be symmetrical (as illustrated by the lower of the two ROC plots in Figure 3).

Single process advocates have explained asymmetrical ROCs by suggesting that the reason ROC curves are often skewed is because study of items leads to greater variance in *old* item strength than *new* item strength (Heathcote, Raymond & Dunn, 2006; Wixted, 2007). Dual-process advocates explain the asymmetrical ROCs by proposing that, in addition to an equal variance familiarity strength distribution, a threshold-like recollection process supports high-confidence recognition memory judgments for *old* (but not for *new*) items, and the influence of this process is to push the left-most points of the ROC up, thereby making it asymmetric.

While the debate over the interpretation of ROCs and their utility for discriminating between different models is ongoing, there are data points that are very hard to account for other than by a dual-process account. These include the findings that patients with damage restricted to the hippocampus show relatively symmetrical ROC functions, and that the shapes of these functions don't change when manipulations that improve overall accuracy are employed (e.g. Aggleton et al., 2005; Yonelinas, Kroll, Dobbins, Lazzara & Knight, 1998).

Summary

In this section a review of dual process theory of recognition memory has been presented, along with some important evidence either in support of or against this theory. The distinction between recollection and familiarity is of particular importance for this thesis, since these may be two processes that can support judgments of recency. While findings using the three main approaches described above can be criticised in isolation, the fact that, in all three cases, the data can be readily accommodated in a dual-process framework, means that in combination they present a compelling case for the validity of the recollection/familiarity split. In addition, a further source of evidence for this distinction has come from event-related potential (ERP) studies of memory retrieval, and these studies are the focus of the next section, as ERP indices of recollection and familiarity are used in this thesis to assess how these processes might support judgments of recency

CHAPTER 2: EVENT-RELATED POTENTIALS AND MEMORY

Memory for Recency and the Usefulness of ERPs

The literature review in Chapter 1 of this thesis demonstrated that memory strength manipulations influence JORs in a number of behavioural studies (e.g. Hintzman 2003; 2004). It is possible that strength of familiarity and also strength of recollection are two bases for distance information. Since there is persuasive evidence that event-related potentials index recollection and familiarity (p71-85), and that ERPs can also reflect processes that are assumed to reflect control operations in memory (p85-91), investigation of how known ERP effects behave in recency tasks may contribute to an understanding of the processes that support memory for recency.

How they can do this is elaborated later in this chapter (p97), but what follows first is a description of ERPs, an outline of how ERPs can be employed in studies of memory processing, the limitations of recording ERPs, and finally a review of the literature regarding three ERP *old/new* effects (explained on p71) which can be measured with the aim of understanding memory for recency.

Event-Related Potentials

Electrical brain activity can be recorded and measured non-invasively using ERPs as a marker of cognitive processes. Since the 1930s, brain activity in the form of the electro-encephalogram (EEG) has been measured in an attempt to understand more about cognition (Kutas & Dale, 1997). ERPs are useful in the study of memory for a number of reasons. The first reason for this is that ERPs have high temporal resolution, allowing cognitive processes to be studied in real-time. ERPs also enable the researcher to detect activity in the brain in the absence of behavioural responses, allowing one to detect covert processing (e.g. Paller & Kutas, 1992). Another reason ERPs are useful to aid investigation into cognitive processes is that, by looking at scalp topographies, one can determine when brain activity is reflective of qualitatively different neural and hence cognitive processes (Rugg & Coles, 1995).

When a stimulus is presented to a participant, an electrical response can be recorded which is known as an evoked potential. Different recording epochs can be defined in relation to the stimulus. These time-locked voltage changes are known as event-related potentials. The series of peaks and troughs in a voltage waveform are known as ERP components. In keeping with EEG, these time-locked electrical fields will only be recorded if the population of neurons is large enough to be detected, and if the neurons are firing in a synchronous manner. To attain an ERP, the difference in voltage between two electrode sites must be measured and recorded (Rugg & Coles, 1995).

Different experimental conditions can give rise to both qualitative and quantitative differences in electrical brain activity. A qualitative change in response to a functional manipulation will result in variation in the ERP distribution of activity across the scalp for the different conditions, potentially coupled with differences in signal latency and peak amplitude. When there are quantitative changes in brain activity across two or more experimental conditions, the ERP scalp topographies will be equivalent and only the signal latency and magnitude might differ (Donaldson, Allan & Wilding, 2002). Qualitative changes are indicative of the engagement of different cognitive processes. Quantitative differences in response to some experimental manipulation are suggestive of only a difference in the extent to which the same cognitive processes are engaged.

Properties of Event-Related Potentials

There are some limitations in recording neuronal activity using the ERP method. It is certain that there is much activity in the brain which is never picked up by scalp-based electrodes (Vaughan & Arezzo, 1988). Active neurons firing asynchronously will be missed, since these will not be sufficient to generate electrical fields that can be recorded at a distance. There are brain structures which are organised in such a way that the neurons contained within them will never fire synchronously. The largest proportion of activity recorded using ERPs is generated by pyramidal cells located in the neocortex (Donaldson et al., 2002). Approximately 70% of the neocortex is made of these pyramidal cells.

Another limitation which needs to be considered in making use of ERP data to investigate brain activity is that ERPs recorded around the surface of the scalp do not have very high spatial resolution. This means that one cannot conclusively determine the neural source of electrical activity detected (Donaldson et al., 2002). Since numerous sources could give rise to the same distribution of activity across the scalp, it is impossible to be certain about exactly which neural generators are giving rise to the pattern of electrical activity (Binnie et al., 1996).

These properties of ERPs mean that one must be cautious in interpretation of data collected, since much activity in the brain cannot be indexed using this technique. When looking for divergences between the ERPs elicited in two conditions in an experiment, for example, one may reasonably conclude there are different cognitive processes involved when finding non-overlapping ERP activity, however in finding an absence of divergences one cannot conclude with confidence that there is no variation present. It may be the case that the differential activity is such that it is undetectable using this methodology because the level of activity is not sufficient to propagate to the scalp, or because of the structure of local cellular configurations (Rugg & Coles, 1995). Despite these limitations, however, the fact that elements of the electrical record map closely onto cognitive operations makes ERPs a valuable complement to behavioural measures in experiments designed to isolate and characterise the properties and contributions of distinct information processing stages. That is how ERPs are used primarily in this thesis, and how they do so is expanded upon below.

ERP Old/new Effects

Three ERP effects have been identified as being associated with familiarity, recollection and executive/control processing. Therefore, investigating how these ERP effects behave in recency tasks may contribute to an understanding of the processes that support memory for recency. What follows is a review of the literature in respect of these three ERP *old/new* effects, that is – the difference in ERP waveforms according to whether an item is correctly identified as being *new* or is correctly identified as being *old*.

Left Parietal Old/new Effect

The left parietal *old/new* effect is a modulation that has been investigated for over twenty-five years (Sanquist, Rohrbaugh, Syndulko & Lindsley, 1980). This ERP effect comprises a greater positivity evoked by correctly identified *old* items (hits) compared to correctly classified *new* items (correct rejections), with greater positivity over the left than the right hemisphere (Rugg et al., 1996). The left parietal *old/new* effect is typically observed at a latency of between 450-500ms post stimulus, with a typical duration of approximately 400-500ms (Rugg, Cox, Doyle & Wells, 1995). This ERP *old/new* effect is not evoked by *old* words incorrectly identified as *new* (misses) or by those items incorrectly identified as *old* (false alarms) and can therefore be regarded as an index of successful memory retrieval (Wilding, Doyle & Rugg, 1995).

Early support for the notion that the parietal *old/new* effect is an index of processes tied to recollection comes from the work of Smith (1993) where participants completed a modified recognition memory task. They studied a list of words and at test were presented with a mixture of *old* and *new* items requiring recognition memory judgments. *Old* judgements were to be followed by a subjective report about whether they remembered, or simply knew, that the item had been present in the study list. The activity associated with correct *old* and *new* judgements differed from around 350ms post stimulus at anterior sites, and from around 450ms post stimulus at posterior sites. Between 550ms and 700ms at posterior sites, items given a remember response were more positive-going than those given a know response. If remember responses are based on recollection, then this data suggests that this ERP effect indexes recollection.

Wilding et al. (1995) provided evidence in two experiments supporting the idea that the left parietal effect is reflective of memory judgements based on recollection rather than familiarity in a task which did not rely on subjective assessments of recollection. Mixtures of auditorially and visually presented words were studied by participants. At test, they were required to indicate whether words were *old* or *new*, and if *old* were then asked to judge in which modality the word had initially been presented to them (test words were presented visually in one experiment and auditorially in the other).

Correctly identified *old* items associated with correct source (auditory/visual) judgements elicited more positive-going activity at left parietal sites in a 500-900ms time-window, in comparison with correct rejections. This left parietal *old/new* effect was reduced for *old* items attracting incorrect modality judgements when test words were visual, and was present over a limited latency span when test words were auditorially presented (Wilding et al., 1995). Since there were no increases in effect magnitude when words were presented at test and study in the same modality, a priming account of the effect was rejected based on the notion that fluency of processing would be increased under these circumstances (Wilding et al., 1995). Since familiarity is not thought to support contextual retrieval, the attenuation of this ERP effect for items attracting incorrect modality judgements also does not support a familiarity account of this effect.

Further evidence that the left parietal *old/new* effect is reflective of recollection comes from a study by Duarte, Ranganath, Winward, Hayward and Knight (2004). Here, ERP recording was conducted during both encoding and retrieval. Participants were presented with words during encoding, to which they were cued to respond with either living/non-living judgements or ease of manipulation judgements. At test subjects were then asked to make *old/new* decisions, followed by a 'remember' or 'know' judgement to items they believed to be *old* (Duarte et al., 2004).

Memory judgements to items made on the basis of familiarity (as indexed by Know judgments) had a different spatial topography and time-course during encoding compared with those based on recollection processes (as indexed by Remember judgments) (Duarte et al., 2004). In addition, during retrieval the left parietal *old/new* effect was only observed in response to items that were recollected rather than in response to items judged to be familiar. It is likely that if recollection and familiarity are supported by distinct neural mechanisms then there should be an observable difference in the patterns of brain activity recorded during both encoding and retrieval (Duarte et al., 2004). Therefore these findings support the recollection based account of the left parietal *old/new* effect and also suggest that recollection and familiarity have different neural bases during encoding and subsequent retrieval.

Some of the strongest support for the notion that the left parietal effect indexes recollection comes from an experiment conduced by Wilding and Rugg (1996). Participants were presented with a list of words and non-words at study, either in a male or female voice. At test, they were required to make *old/new* recognition judgements to visually presented words, followed by a source judgement about voice gender. There was activity maximal over the left parietal scalp with an onset latency of 400ms post stimulus. This activity was more positive for items for which the study context (voice) could be accurately recalled, in comparison to correctly rejected or correctly recognised (without accurate source judgement) items (Wilding & Rugg, 1996). This indicates that the left parietal *old/new* effect is likely to index retrieval of contextual information, which is associated with the process of recollection rather than familiarity.

There is also evidence that the left parietal *old/new* effect can be dissociated from other potentially confounding ERP effects (Rugg & Curran, 2007). Importantly, Herron, Quayle & Rugg (2003) have shown that the left parietal *old/new* effect is reflective of recollection processes alone, and does not vary with target probability. This is important because the P300 potential has a time course and scalp distribution that overlaps with that of the left-parietal *old/new* effect (Horst, Johnson & Donchin, 1980). In Herron et al.'s study, participants completed recognition memory tasks in which the proportions of *old* and *new* items varied across study/test blocks. The P300 is sensitive to probability changes, but the left parietal *old/new* effect did not differ according to the ratio of *old* and *new* items (Herron et al., 2003). Thus this ERP *old/new* effect can be dissociated from other posterior effects which occur during a similar time-window.

There is now broad support for the view that the left parietal effect is an index of recollection from experiments in which single items were presented at test. Other research has shown that the left parietal *old/new* effect varies in associative recognition tasks. Rugg et al. (1996) conducted a study in which participants performed an *old/new* recognition task for pairs of items. During study, participants were presented with a series of word pairs for which they were asked to form a sentence. At test, participants were presented with single words for recognition. When items were judged as '*old*', participants were asked to retrieve the other word from the study pair. Activity over parietal areas, especially over the left hemisphere, was more positive-going for correct judgments to *old* items compared to *new* items. Items judged '*old*' by participants (for which they were later able to recall the other word from the study pair) were associated with even greater positivity (Rugg et al., 1996). This is strong evidence to suggest that the left parietal *old/new* effect is indeed a correlate of successful recollection, since familiarity is not likely to support associative memory for non-semantically-related pairs of words (Ecker, Zimmer, Groh-Bordin & Mecklinger, 2007; Rhodes & Donaldson, 2007; but see Speer & Curran, 2007).

In a related experiment (Donaldson and Rugg, 1998) participants were presented with a series of word pairs at study. During test the participants were required to indicate whether presented pairs were *old* or *new*, followed by a 'same' or 'rearranged' judgement for pairs they believed to be *old*. There was greater posterior positivity for correctly identified *old* words in comparison with *new*, which is further evidence to support the recollection theory of this ERP effect. This is believed to be the case, since rearranged pairs were found to evoke effects which were smaller in magnitude in comparison with the same test pairs. The authors suggested this was due to the fact that less contextual information would be recalled for the rearranged pairs because neither word was from the same episode, which would therefore lead to less potent recollection and greater reliance on familiarity (Donaldson & Rugg, 1998).

One interpretation of these findings in associative recognition is that the left parietal effect can be graded according to the level of contextual information derived from memory search (see also Smith, 1993; Wilding et al., 1995; Wilding & Rugg, 1996). This is important for the current thesis because this sensitivity is necessary if the effect is to be used to assess the possibility that recollection supports recency judgments in a strength-based manner. Direct evidence in support of this graded account comes from the finding that the level of accuracy in source memory tasks requiring multiple source judgments is linked to the magnitude of the left parietal *old/new* effect (Wilding, 2000). In this experiment, participants were presented with a series of spoken words, either in a male or female voice. For each item participants were cued to make either a passive/active judgement or a pleasant/unpleasant judgement.

During test trials participants were presented with words on a computer screen and were asked to make an *old/new* judgement, followed by a task and voice (source) judgement. ERP recording revealed that the size of the left parietal *old/new* effect increased as a function of increasing levels of contextual retrieval (Wilding, 2000, see also Vilberg & Rugg, 2007). This study suggests that if the left parietal *old/new* effect indexes the volume or amount of contextual retrieval, then this could potentially be utilised by participants in line with a distance theory of recency in the manner outlined in Chapter 1.

The weight of the evidence reviewed above is in support of the idea that the left parietal *old/new* effect is an ERP index of the memory process of recollection. It has been shown that activity between 500-800ms post stimulus is more positive going for recognised *old* compared to *new* items, for which associated contextual information can be recovered. Recollection is likely to be one process that underlies Friedman's (1993) location information because of these contextual and reconstructive memory properties. However, since there is also evidence that recollection can be graded (e.g.

Wilding, 2000), this ERP effect may also provide the basis for a strength-related form of distance information. Thus, measuring how this effect might differ across JORs could provide useful information for understanding memory for recency.

Mid-Frontal Old/new Effect

The mid-frontal *old/new* effect has also been described as the FN400 (Curran, 2000). This negative-going waveform has a typical onset latency of 300ms and has been found to last around 200ms. It takes the form of greater positivity for *old* compared to *new* items (Friedman & Johnson, 2000) that attract correct memory judgments. This ERP effect occurs within the same time-window as the N400 component, which has been linked to semantic processing (Kutas & Hillyard, 1980). The mid-frontal effect differs from the N400 component, since it is usually evident primarily at frontal sites rather than being limited to central regions (Curran & Cleary, 2003).

The earliest study documenting the mid-frontal ERP *old/new* effect, linking it to familiarity, was undertaken by Rugg et al. (1998). Participants completed a standard *old/new* recognition memory task, with the manipulation involving depth of processing at study (shallow vs. deep encoding). The mid-frontal effect was evident for correctly identified *old* items and did not differ according to the encoding manipulation. Rugg et al. (1998) therefore suggested that this was a likely index of familiarity processes, since depth of processing has been shown to influence familiarity to a lesser extent than recollection (for a review, see Yonelinas, 2002).

Curran (2000) also claimed that the mid-frontal *old/new* effect is likely to be a neural correlate of familiarity. In this research, participants studied lists of 40 words and were instructed that their memory would be tested for the words and for their plurality. At test, 60 words were presented, with an equal mixture of *new*, studied and similar (with plurality changed) words. It was expected that '*old*' responses to plurality reversed words would be based on familiarity, since recollection would not permit these types of errors. Curran (2000) found that the left parietal effect was greater for correct responses to correctly identified *old* items in comparison to words for which plurality had been altered at test. In the 300-500ms epoch however, there was no difference in ERP activity across these conditions, but both differed in comparison with correctly rejected *new* items at mid-frontal electrode sites. This research is therefore strong evidence that the mid-frontal effect is an index of familiarity memory processes, since if this effect reflected contextual retrieval, it would be expected to differ across studied and similar '*old*' items.

Other evidence that the mid-frontal *old/new* effect is associated with familiarity comes from a study by Nessler, Mecklinger and Penney (2001). These researchers constructed categories of words and created lists of nouns for each category. After studying the lists of nouns, participants were presented with a recognition memory test that contained studied words from a particular category, non-studied words from the same category, and non-studied words from a different category.

Nessler et al. (2001) found that a mid-frontal *old/new* effect was evident for items correctly classified as *old*, and for items incorrectly classified as *old* that were semantically similar to *old* test items. The researchers also reported that the left parietal *old/new* effect was observed in response to items correctly classified as being *old*, and that this activity was smaller for lures accepted as being *old* (Nessler et al., 2001). These results therefore give further support to dual process theories of recognition memory (Mandler, 1980; Yonelinas, 2002), suggesting that the mid-frontal *old/new* effect is indeed an index of familiarity and that the left parietal effect is an index of recollection.

Curran and Cleary (2003) have provided evidence to suggest that familiarity is indexed by the mid-frontal *old/new* effect using non-verbal stimuli. Participants were required to study a series of sequentially presented line drawn pictures. At test the participants were presented with studied pictures, new pictures and pictures which were mirror reversals of studied pictures. During test the participants were required to make *old* and *new* judgements for each picture. There were mid-frontal *old/new* effects in response to both the *old* and the highly similar but unstudied items. It was suggested that the mirror drawings would invoke a feeling of familiarity, but would not lead to recollection, unlike the *old* items (Curran & Cleary, 2003). This interpretation supports the theory that the mid-frontal *old/new* effect is an index of familiarity.

Further evidence that the mid-frontal *old/new* effect is an electrophysiological index of familiarity comes from an experiment carried out by Woodruff, Hayama and Rugg (2006), in which the researchers utilised confidence judgements to indicate the different levels of familiarity experienced by participants. At study, participants were presented with a list of words to which they were asked to make an animate/inanimate judgement. During a test of recognition memory, participants were required to indicate their form of recognition experience, be it remember (something contextual about the study episode could be recovered), confident *old* (though not able to recall any detail about the study episode), unconfident *old*, unconfident *new* and confident *new*.

An early left frontal *old/new* effect was elicited to a greater extent by items designated as being highly familiar, compared to items categorised as being less familiar (as indexed by the confidence ratings). This effect did not differ in size for recollection (contextual recovery) judgements and highly familiar (confident *old*) judgements. Late left-parietal positivity however, was associated only with items given a recollection response and did not vary across confidence (Woodruff et al., 2006). This study suggests that this frontal *old/new* effect indexes familiarity in a graded fashion. These findings also provide compelling support for dual process accounts of recognition memory (Yonelinas, 2002).

Other related evidence in support of the mid-frontal *old/new* effect and the link to familiarity processes comes from work by Azimian-Faridani and Wilding (2006). They manipulated the response criterion used in an *old/new* recognition paradigm. Participants were required to respond '*old*' to words at test only if they were confident that the item was *old* (the "conservative" condition). In the "liberal" condition, participants were required to respond '*new*' to an item if they were confident that the word was *new*. ERPs elicited by *old* as well as *new* test items at mid-frontal electrodes were more positive-going in the conservative than the liberal condition.

This finding is consistent with the view that the mid-frontal ERP *old/new* effect indexes familiarity if greater positivity equates to greater familiarity, because in the conservative condition a higher level of familiarity should have been associated on average with correct *old* as well as with correct *new* judgments. Given that previous behavioural research suggests that familiarity is more influenced by changes in criterion than recollection (e.g. Yonelinas, 2001; Postma, 1999), this study is evidence in support of the notion that the mid-frontal *old/new* effect is an index of familiarity processes and that this process is graded in nature, in line with the views of Yonelinas (1994), and the data produced by Woodruff et al. (2006) described earlier.

Despite the persuasive evidence in support of a familiarity account of the mid-frontal *old/new* effect, however some theorists remain unconvinced. Instead, these researchers interpret the collated data in terms of conceptual priming – differential processing of presented stimuli following a preceding semantically related event (Paller, Voss & Boehm, 2007). Although convinced that familiarity is an existing memory process, these theorists argue that much previous research has failed to rule out conceptual priming as the basis for the mid-frontal *old/new* effect.

In line with the conceptual priming account, it has been suggested that the mid-frontal ERP *old/new* effect is merely reflective of verbal processing activity (Yovel & Paller, 2004). In their experiment, novel faces (paired with an occupation label) were used rather than words. At test, recollection of faces was indicated by the recovery of additional contextual recovery of occupation label along with a correct *old* judgement, whereas familiarity was associated with *old* judgements alone. Here, both familiarity and recollection were indexed only by parietal activity which differed in magnitude across the conditions (smaller for familiar faces). It was proposed that the mid-frontal activity observed in previous studies arose because the researchers had made use of verbal rather than pictorial stimuli, or pictorial stimuli for which names readily come to mind (Yovel & Paller, 2004). However, other researchers investigating the characteristics of the mid-frontal effect have found it to be elicited when using stimuli such as novel objects, faces and highly diminished visual stimuli (e.g. Curran, Tanaka & Weiskopf, 2002; Jaeger et al., 2006; Johansson, Mecklinger & Treese, 2004; Speer & Curran, 2007), therefore the bulk of the evidence is still in favour of a familiarity account of the mid-frontal *old/new* ERP effect.

Voss and Paller (2006) presented data which they argued ruled out the possibility that familiarity could be the basis of the mid-frontal ERP activity. Participants were presented with famous and non-famous faces directly after presenting them with biographical information. Only some of the famous faces were primed with matching biographical information before the presentation of the face. Participants were required to decide whether the information matched each face. Participants were then tested for explicit memory (familiarity rating of 'very familiar' to 'not at all familiar' on a 5 point scale) and conceptual priming (press button only for famous faces). ERP recordings were taken during the conceptual priming task (Voss & Paller, 2006).

Frontal ERPs for primed famous faces were more positive-going in comparison with un-primed famous faces in the time-window and scalp region of the mid-frontal *old/new* effect. Priming took the form of faster RTs in response to matching biographical face data in the conceptual priming task, compared to mismatching face data trials. When this data was analysed in regard to the explicit memory task, only posterior ERPs in a later time-window differed according to condition (Voss & Paller, 2006). The authors of this study therefore concluded that the mid-frontal ERP activity is selectively associated with conceptual priming, rather than familiarity.

In direct contrast with the account outlined above, other research has found evidence that mid-frontal activity in the 300-500ms time-window varies with familiarity and not with conceptual priming (Ecker, Zimmer & Groh-Bordin, 2007b; Groh-Bordin et al., 2006; Schloerscheidt & Rugg, 2004). For example, Groh-Bordin and colleagues (2006) conducted research where participants studied a list of nonsense figures and real object figures of different colours. Participants were asked to memorise these for a future recognition task. At test, participants were presented with a mixture of *new* items, incongruent colour items and congruent colour items. For each item participants made recognition judgements, followed by a judgement about colour congruency (when an *old* judgement was made). ERPs were recorded during the *old/new* judgements (Groh-Bordin et al., 2006).

Mid-frontal *old/new* effects were present for nonsense figures as well as for drawings of known objects, and were larger when the items were presented in the congruent colour at test. Since the nonsense figures were hard to name and were also meaningless, this research can be taken as evidence in support of a familiarity account of the mid-frontal *old/new* effect since only perceptual, and no conceptual changes, were implemented at test. Stronger evidence supporting this argument was the fact that the effect was still elicited for items rated as 'low' in meaning by participants (Groh-Bordin et al., 2006; see also Ecker, Zimmer & Groh-Bordin, 2007a). Despite this research, and other studies eliciting similar findings, supporters of the conceptual priming account remain unconvinced, suggesting that meaning could have been attributed to the nonsense figures by the participants (Paller et al., 2007).

Although there are arguments both for and against a familiarity basis for the mid-frontal *old/new* effect, it is presumed in this thesis that the ERP effect is an index of familiarity rather than an index of conceptual priming. The weight of available evidence is in line with this view. Rugg and Curran (2007) have reviewed evidence in support of both theories. It was noted that conceptual priming advocates of the mid-frontal effect need to address issues such as: why *new* items falsely identified as *old* still elicit mid-frontal activity; why misses elicit less positive mid-frontal activity than do correctly identified *old* items; and why this effect varies with response criterion (Rugg & Curran, 2007; for an alternative perspective see Paller, Voss, & Boehm, 2007).

In sum, the bulk of the evidence is in favour of the notion that the mid-frontal activity discussed in this section is an ERP index of familiarity. It has been demonstrated in various studies that this activity is related to items that have been mistakenly identified as *old* on the basis of feelings of familiarity and that this ERP effect can be graded. Familiarity is likely to be one process that underlies Friedman's (1993) distance information because of these properties. Thus, if the mid-frontal *old/new* effect does index familiarity, then measuring how this effect might differ across JORs could provide useful information for understanding memory for recency.

Right Frontal Old/new Effect

One of the earliest reports of the late right frontal *old/new* effect was in the mid-nineties, where greater positivity for *old* (compared to *new*) words was evident over right frontal electrodes, from 1100-1400ms post stimuli (Wilding & Rugg, 1996). In this experiment, as described earlier, participants were presented at study with a series of words for which they were asked to make a word/non-word judgement and a male/female voice judgement. For the test part of the experiment, participants were visually presented with a series of new and repeated words and their task was to make an *old/new* discrimination for each word, followed by a male/female voice decision for words given an '*old*' judgment (to indicate original mode of presentation).

Along with a left parietal *old/new* effect in the 500-800ms time-window, the right frontal activity described above was also elicited in this experiment (Wilding & Rugg, 1996). For words which were correctly identified as being *old* and that attracted correct voice gender judgements, the right frontal effect was larger in comparison with correct *old* judgements for which the source judgement was incorrect. The authors argued that since this effect was smaller for non-contextual retrieval, it is likely that it is reflective of retrieval monitoring or organisation of contextual information (Wilding & Rugg, 1996). These cognitive operations working over the products of retrieval have been termed 'post-retrieval operations' and are likely to reflect activity located in the pre-frontal cortex (see Allan et al., 1998).

There is, however, no consensus on the functional role of the right frontal ERP effect. In an experiment by Senkfor and Van Petten (1998), participants studied a series of spoken words, half presented in a male voice and the other half presented in a female voice. There were two types of recognition tests. In one, the participants were required to indicate whether presented stimuli were *old* or *new* words only. In the second recognition test participants were required to judge whether the items were *old* or *new*, and further to decide whether the *old* items had been presented in the same voice as at study, or if the voice was different (source judgements). There was evidence of a frontal *old/new* effect (800-1200ms post stimulus) only during the source task, and the effect was evoked during both accurate and inaccurate voice gender judgements (Senkfor & Van Petten, 1998). The authors argued this suggested that the frontal *old/new* effect is reflective of a source memory retrieval search, since the effect was equivalent for accurate and inaccurate judgements.

In a similar study by Wilding and Rugg (1997), participants were presented with spoken words at study and were asked to perform different encoding tasks depending on the gender of the voice. At test the participants were then required to distinguish between targets (*old* words which had been spoken in a particular gender) and non-targets (*new* items and *old* items that had been spoken in the non-target gender). A right frontal *old/new* effect was elicited in response to target items alone, and this effect was not present for non-targets. This led Wilding and Rugg (1997) to propose that this ERP effect is an index of successful source retrieval monitoring processes, which they suggest are controlled voluntarily by the participants. This is an important paper because it shows that the left parietal effect is dissociated from the right frontal effect, since the left parietal effect was elicited by all accurate *old* responses, whereas the right frontal effect was only elicited when *targets* were correctly identified as being *old* (Wilding & Rugg, 1997; see also Wilding, Fraser & Herron, 2005).

In an experiment by Trott et al. (1999), participants studied sentences from two distinct lists and this was followed by a word recognition test. In addition to their *old/new* judgements, participants were required to make a source judgement for items classified as *old.* Participants elicited similar patterns of right frontal activity regardless of whether their source judgements were correct or incorrect. These researchers also reported that the ERP effect was larger for incorrect source judgements (see also Trott, Friedman, Ritter & Fabiani, 1997). Trott et al. (1999) proposed that a change in voice gender utilised in the Wilding & Rugg (1997) study may have led to a more clearly marked contextual difference in the 'to be remembered' items. Thus, task differences may have led to these disparate findings.

Ranganath and Paller (1999) conducted an experiment involving recognition tests which differed according to retrieval specificity requirements. Participants were presented with study lists of 10 drawings shown twice. At test, some presented drawings were *new*, some *old*, and some similar to *old*. Participants were asked to either endorse only identical items as being *old*, or to endorse identical and similar items as being *old*.

There were late right frontal *old/new* effects between 900 and 1100ms when participants performed the recognition test using lax criteria to classify items as *old* (i.e. when similar and identical items could be accepted as *old*). When adopting more stringent *old* item criteria, a right frontal effect of greater magnitude was observed. These findings led Ranganath and Paller (1999) to conclude that the right frontal *old/new* effect varies with both strategic control and possibly retrieval effort. They argued that more cognitive effort would be required during the test where only identical items could be accepted as *old*, therefore a greater right frontal effect magnitude level would be expected if this ERP effect indexes retrieval effort.

Familiarity is likely to be relied upon for this task when using lax criteria and recollection when using strict criteria (Azimian-Faridani & Wilding, 2006). Thus, although the right frontal *old/new* effect was of increased magnitude in the strict condition compared to the lax or liberal condition, this effect cannot be said to be tied exclusively to judgements of a contextual nature (since familiarity is non-contextual and still elicits the right frontal effect). Further support for this notion comes from the findings of research with R/K judgements, where judgements assumed to be exclusively associated with familiarity were found to elicit late right frontal activity (Duzel et al., 1997).

In a recent study reported by Kuo and Van Petten (2006), the late right frontal effect was classified as indexing a secondary memory search for relationships between stimulus characteristics. Participants saw a series of drawings and for each drawing they were asked to make a size or colour judgement. A mixture of *old* identical, *new*, and *old* incongruent colour drawings were presented sequentially at test. Participants could respond '*old* same', '*old* different' or '*new*' for each item presented at test (Kuo & Van Petten, 2006).

The colour study task was expected to lead to good memory for the test item and its colour attribute, whereas the size study task was not expected to produce such strong colour memory (Kuo & Van Petten, 2006). As was hypothesized by the researchers, the late right frontal *old/new* effect was not present when participants had been asked to focus on colour in the study phase of the experiment, but was present when they had been asked to attend to stimulus size. Attending to size resulted in lower source accuracy and an increased magnitude of the right frontal *old/new* ERP effect, which is consistent with Wilding et al. who also found that the magnitude of this effect was greater in tasks where source accuracy was comparatively lower (2005; see also Kuo & Van Petten, 2008 for a conflicting result).

Finally, Hayama, Johnson and Rugg (2008) aimed to establish whether the right frontal ERP *old/new* effect could be elicited in circumstances where no monitoring of *episodic* retrieval products was necessary, and whether it was present for other types of retrieval monitoring. Participants were presented with a list of nameable pictures of objects to study. For each item presented, they were cued to make one of two different types of semantic judgement. At test, participants were again presented with a list of items and for each item judged to be *old*, they were to make either another type of semantic judgement, or a source memory judgement depending on the test block (Hayama et al., 2008).

Late right frontal *old/new* effects were present in both the episodic and semantic retrieval tasks. These effects were equivalent in terms of latency, magnitude and scalp distribution (Hayama et al., 2008). These researchers also went on to evaluate whether *new* items could also elicit late right frontal activity if participants were required to make the same semantic judgements (instead of making those judgements for *old* items). A greater right-frontal positivity for *new* items requiring a semantic judgement in comparison with *old* items (not requiring any further monitoring) was obtained (Hayama et al., 2008). The researchers argued that these findings are highly suggestive of a monitoring account of the right frontal effect, and one which is not tied exclusively to episodic retrieval.

From this review it is clear that the late right frontal ERP *old/new* effect varies with source accuracy in different ways across experiments. The most recent line of research has created a new pathway for investigating the nature of this effect (Hayama et al., 2008). The most parsimonious account of the right frontal activity to date is that it indexes some form of executive memory processing, likely involving evaluation and monitoring of the outcomes of a retrieval search. If this effect does indeed reflect activity in the frontal lobes as was suggested earlier in this section, it is probable that the late right frontal activity will vary in ERP studies of recency memory, since the frontal lobes are likely to be implicated in temporal memory judgements – and this effect is therefore relevant for this thesis. The inconsistencies outlined above however, make it difficult to make detailed predictions about how the right-frontal *old/new* effect will vary for correct and incorrect recency judgments.

In Summary, the majority of the evidence reviewed in this section is in support of the idea that the left parietal *old/new* effect is an ERP index of the memory process of recollection, and that the mid-frontal *old/new* effect is an ERP index of familiarity. It has also been suggested that the late right frontal ERP *old/new* effect is most likely to index some form of executive memory processing. For these reasons it is proposed that the use of ERP recording is a valid means of assessing whether recollection and familiarity are implicated in recency memory, in a way that is compatible with distance theories of memory for time. Before moving forward however, it is important to determine whether these claims are fitting with other forms of evidence.

Neural Generators of the Mid-Frontal and Left Parietal Old/New Effects

In Chapter 1 it was noted that recollection and familiarity have been widely associated with the hippocampus and perirhinal cortices respectively (see pages 59-60). In terms of ERP data, however, activity over parietal scalp has consistently been linked with the process of recollection. In addition, much evidence has been cited here that would suggest that activity over frontal areas is related to familiarity. How can these ERP findings be reconciled with the wealth of animal, fMRI and neuropsychological evidence of MTL involvement in episodic memory processes (for a review, see: Eichenbaum, Yonelinas & Ranganath, 2007)?

Firstly, as was mentioned early on in this chapter (p70), one limitation of this technology is that ERPs recorded around the surface of the scalp do not have high spatial resolution, unlike fMRI, and therefore it is impossible to be certain about exactly which neural generators are giving rise to a given pattern of electrical activity (Binnie et al., 1996). That being said, there is strong evidence that specific regions in the parietal cortex *are* involved in recollection and familiarity (for a review: Vilberg & Rugg, 2008) and that regions of the frontal lobes are also implicated in familiarity memory processing (e.g. Yonelinas et al., 2005).

There is also evidence that the MTL and parietal cortices are linked via neural pathways (e.g. Vincent et al. 2006). Here it was shown that resting state fMRI bold signal correlated between the hippocampus and parts of the parietal cortex, providing evidence of a physical connection between the two brain regions (Vincent et al., 2006). More recent research has lead to the proposal that this hippocampal-parietal memory network involves the medial section of the parietal region, whereas the lateral parietal cortices are differentially connected to the lateral temporal lobe (Takashi, Ohki & Kim, 2008). These lines of research provide a formal model of how the MTL and parietal areas might be anatomically related.

Why, then, should there be a lack of evidence of episodic memory disturbances resulting from brain injuries in these parietal regions (for a review: Simons & Mayes, 2008)? One reason for this could be that the supposed ERP indices of these memory processes are actually reflecting other non-mnemonic cognitive operations that run downstream of recollection and familiarity – there is indeed support for this in terms of the parietal activity associated with recollection (for a review: Vilberg & Rugg, 2009). However, good evidence is now emerging that parietal disturbances do indeed impair memory processing (e.g. Rossi et al., 2006; Davidson et al., 2008), albeit in subtle ways. For present purposes, however, the key point is that, irrespective of the neural generators of the effect, the parietal old/new effect acts as a robust index of recollection in a graded fashion.

The same argument can be applied to the mid-frontal ERP old/new effect, and at present a specification of the neural generators responsible for it is not more specific than the observation that its focal scalp distribution is consistent with a generator in the prefrontal cortex. The properties of the generators of ERP effects, and the ways in which they propagate to the scalp mean that it is not possible at present to make strong claims about whether this midline maximum effect is in fact generated by brain regions in the right or left hemisphere, or is in fact an combination of activity initiated in both hemispheres. To reiterate, however, these unanswered questions about neural generators do not preclude the use of these ERP old/new effects to investigate memory processing, and how they have been employed in recency tasks is described below.

Memory for recency and ERPs

Researchers have used event-related potential recordings to uncover information about the types of memory processes involved in recency judgements, but these types of studies are rare. In an experiment by Tendolkar and Rugg (1998), participants were presented with two study lists of words, and at test they were asked to identify the most recent item for each presented pair. Test pairs were either both *old* (repeated, one from each list), both *new*, or were made up of one *old* and one *new* item. For pairs where both items were *old*, accurate recency judgements elicited greater positivity over fronto-polar locations in comparison with *new* pairs. This activity was not present when the task required recognition memory judgements, rather than recency judgements. This finding suggests that additional cognitive operations are required in recency memory tasks (Tendolkar & Rugg, 1998). However, the fronto-polar effect reported in this study may not index recency selectively, and is likely to be present in other experiments where source judgements are required. This task is one in which location information is likely to be utilised according to Friedman's (1993) framework, since the list 1 and list 2 divisions act as temporal landmarks which could serve as contextual clues to recency (location information).

In a more recent experiment, Tendolkar et al. (2004) presented participants with two distinct lists of words during study. At test, pairs of words were presented which were either both *new* items, *old* items from the same study list, or *old* items from different study lists. The task required participants to determine which of the items had been presented most recently. Correct recency judgements (both *old* items in the pair) elicited more positive-going activity in comparison to *old/new* judgements. This occurred between 700 and 1000ms post stimulus at fronto-polar sites. This effect did not differ according to whether the task was to compare the recency of items from the same or from different lists. The late fronto-polar effect may be an index of cognitive processes linked to monitoring and implementation of cognitive strategies (Van Petten et al., 2002). If these assumptions about the putative indices of monitoring processes are correct, this study provides evidence that tasks requiring scrutiny of temporal context require a generic executive control process. Why these frontal effects did not differ across classes of recency judgement is unclear, which might be expected since judging the recency of items from the same list could require greater cognitive control or effort.

In another ERP study of recency memory, Curran and Friedman (2003; 2004) employed tasks where location information and distance information might be used in different ways. Participants were asked to study a list of items in a particular environmental context (list 1) and on the following day, they were asked to return to study an additional two lists of items (list 2 in the same context as the previous day, list 3 in a different context). At test, memory was assessed for both recency discrimination based on contextual retrieval (lists 2 vs. 3), and for recency discrimination based on elapsed time (list 1 vs. list 2). The use of distance-based information was encouraged in the day test and location-based information in the context test through use of different instructions (they were told to use their instincts in the day test, and to attempt to retrieve context in the context test).

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Reaction times were slower for recency judgements in the context task, suggesting that making recency judgements based on location information takes longer than judgements based on distance information (Curran & Friedman, 2004). This would fit with the idea that location information is based on recollection and distance information on familiarity, since recollection is thought to be a more effortful and time consuming process (for a review, see Yonelinas, 2002).

No clear ERP *old/new* effects differed across list 1 and list 2 in the day task (Curran & Friedman, 2004), however late right frontal ERPs (800-1800ms) differed between the day and the context tasks; the difference between *old* and *new* items was larger in the context task. This difference across the tasks was attributed to the implementation of cognitive processes which aid reconstruction of location information in memory for the recency judgements (Curran & Friedman, 2003). The results of this study converge with neuropsychological data reviewed earlier (see page 96) suggesting that the frontal lobes are implicated in tasks where location information is utilised by participants, to a greater degree than tasks where distance information is relied upon for recency judgements. A more sensitive test of recency may be required in order to assess whether there are differences in the levels of activation across time in regard to the mid-frontal and left parietal *old/new* effects (linked with familiarity and recollection, see Chapter 2), and whether they map onto differences in recency judgements. This is one issue with which this thesis is concerned, and the thesis aims are outlined below.

General Aims in Conducting this Research

The first three experiments carried out in this thesis involved the use of ERPs and were conducted in order to test whether two possible sources, strength of *familiarity and recollection,* underlie JORs in a manner that would classify them as distance information. Across the three ERP experiments, it was reasoned that if familiarity is utilised in a task where distance information must be relied upon, the mid-frontal *old/new* effect will be larger for short JORs in comparison with relatively longer JORs, regardless of accuracy. Similarly, if recollection is involved in recency judgements and is employed in a strength-based manner, then the left-parietal *old/new* effect will increase in magnitude with decreasing JORs. This argument is key to the designs of Experiments 1-3 described below. The link here is that, for both of these ERP old/new effects, larger (more positive-going) effects index an increase in familiarity or recollection, respectively. If memory strength supports JORs, then increases in strength will result in shorter average JORs. Hence larger ERP old/new effects should be associated with shorter JORs than with longer JORs. The fact that ERPs index recollection as well as familiarity also permits an assessment of how both of these processes, either singly or in combination, might support recency judgments.

The experiments reported in this thesis were all largely based on a task adapted from the work of Yntema and Trask (1963) and of Hintzman (2001; 2003; 2004). In these continuous recency memory tasks, participants are presented with a long list of items (words or famous names), free of contextual landmarks. Items are re-presented within the list after a number of intervening items or lags, which ranged from 5-35 intervening items across experiments. For each item presented, participants were asked to make an *old/new* recognition judgement, followed by a JOR for the items which they identified as being *old*. Critically, in the experiments in which ERPs were acquired, the tasks were designed such that it was possible to analyse neural activity for items from the same repetition lag that were separated according to whether they attracted correct or incorrect judgments. In addition, incorrect judgments were further separated according to whether they were lag under-estimates or over-estimates. This is the critical manipulation that is necessary to assess how ERP indices of specific retrieval processes support recency judgments. Larger old/new effects for shorter than for longer JORs, would be consistent with the view that the memory processes indexed by the effects support recency judgments in a strength-based manner. Conducting a series of experiments using the continuous recency task described here therefore allows several goals to be accomplished:

1 – An electrophysiological assessment of whether, and if so how, familiarity contributes to recency judgments in tasks where distance information is likely to be the form of information that is used for JORs.

2 – An electrophysiological assessment of whether, and if so how, recollection contributes to recency judgments in tasks where distance information is likely to be the form of information that is used for JORs.

3 – An assessment of whether recency judgments elicit electrophysiological signatures of memory processes that differ from those engaged in other kinds of memory tasks.

4 – An assessment of how ERP indices of retrieval monitoring are engaged when recency judgments are required.

These goals were accomplished in Experiments 1-3. Experiment 1 was designed such that a large number of trials at a single lag (15) were presented to participants, in order to obtain sufficient numbers of trials in the conditions of interest, such that shorter JORs (for items with the same lag) could be compared with longer JORs. The possible response options were 10, 20 and 15. In Experiment 2 a wider range of JOR response options was available to participants (5, 15, 25 and 35) and the lags reflected these options, allowing longer distances between them than in the previous experiment. In the final ERP experiment there were equal proportions of items recurring at every possible lag (5, 15 and 25) and participants were aware of this fact. The remaining experiments in this thesis comprise experiments in which recognition and JOR response accuracy were measured. ERPs were not acquired. The intention was to employ a series of behavioural manipulations in order to provide converging evidence for the claims that could be made on the basis of the outcomes of the ERP experiments.

The behavioural experiments all involved continuous recognition tasks with stimuli not previously utilised in other recency research. The stimuli used were famous and non-famous first and last (full) names. The reason for using famous as well as non-famous names was that it was assumed that their pre-experiment strength would vary. Memory strength across experiments was also varied by manipulating the kind of encoding operations and the number of stimulus presentations in study phases that preceded the continuous recency tasks. The encoding manipulations that were employed were intended to load differentially on recollection and familiarity, thereby allowing an assessment (complementing the ERP data) of how these processes contribute to JORs.

A crucial advantage of using famous and non-famous names in this behavioural series of experiments over stimuli used by Hintzman (e.g. high vs. low frequency words, concrete vs. abstract words, pictures vs. words), is that famous names can be used to give a direct assessment of how pre-experimental levels of memory strength can predict lag judgements. This was accomplished in the final experiment reported in this thesis (Experiment 8).

In Experiment 4, famous and non-famous names were used in a continuous recency memory task for the first time in order to assess how a manipulation of fame would influence JORs. Experiment 5 was conducted in order to attempt to elevate the strength of non-famous names prior to the recency task in such a way that familiarity would be the process that was primarily affected. The aim in Experiment 6 was similar to that in the previous experiment, with the intention to use a manipulation that would load primarily on recollection. Toward this end, the non-famous names were presented in a deep encoding task, as this manipulation has been shown to influence recollection to a greater degree than familiarity (Craik & Lockhart, 1972).

The design of Experiment 7 was a departure from that of the previous behavioural experiments in that no famous names were presented. Instead, an attempt was made to pre-experimentally elevate the availability of familiarity for 50% of the non-famous names. This was done in order to assess whether manipulations of familiarity alone would have an influence on subsequent JORs. If studied non-famous names in this experiment were associated with shorter JORs than non-studied names, it could be concluded that familiarity is a strength-based process underlying recency judgements.

Again in this way, familiarity would fall under the bracket of distance information. Finally, Experiment 8 was carried out in order to deduce whether increasing the availability of recollection (through deep encoding) for famous names in a study session prior to the continuous recency task would have a subsequent effect on JORs within the later continuous task. If the amount of contextual information associated pre-experimentally for famous names was related to JOR, it would suggest that recollection is utilised as a form of distance information under these circumstances. In summary, the behavioural experiments will:

4 – Enable an assessment of how recollection and familiarity contribute to recency judgments, in a manner complementary to that employed in the preceding electrophysiological experiments.
5—Generalise the broad pattern of findings described by Hintzman to a different stimulus set.
6 – Extend Hintzman's work to circumstances where the 'strength' manipulation is within the experiments, rather than being a function of the attributes if the stimuli employed (e.g. high versus low frequency words).

Summary of Aims

As described above, the chief objective in conducting the research reported in this thesis was to address some important issues relating to memory for recency. Hintzman's (2005) data suggests that there is more than one memory process underlying memory for recency. The research in this thesis involving continuous recognition memory was expected to enforce reliance on the strength subcomponent of *distance information*, since there are no temporal landmarks to act as location information. Furthermore this task was expected to allow only very limited reliance on relative information, since the list of items is very long, with regular test intervals. Use of a continuous recognition and recency memory paradigm adapted from Yntema and Trask (1963) allowed for a comparison of neural activity associated with short and long JORs, which has not been analysed in other recency memory imaging studies. Briefly, if the level of familiarity and or recollection experienced is one basis for distance information, then neural activity associated with long and short recency judgements should vary in a graded fashion. If the frontal lobes are involved in recency memory processing in a task in which a reliance on distance information is likely, then it might be the case that the late right frontal ERP effect varies across JORs.

Finally, another aim in this thesis was to replicate previous findings that JOR alters as a function of memory strength (Hintzman, 2003; 2004, 2005) with a new set of stimuli, namely famous (high strength) and non-famous (low-strength) names. It was reasoned that if the key findings reported by Hintzman could be replicated with this set of stimuli, then some of the properties of famous names could be used to explore further recency memory issues in an interesting and novel way. In particular, since participants are likely to have different levels of pre-experiment experience with each famous name, then JORs may vary in accordance with this. For names where participants possessed a high level of associated contextual information (as in the case of famous names), it was expected that JORs would be short, in comparison to names where the level of associated contextual information was lower (as in the case of non-famous names). This stimulus set therefore provided an innovative way to assess the contributions of these kinds of memory contents to recency judgments.

The following three chapters describe the ERP experiments conducted in light of the literature reviews and experimental aims reported in this thesis. Chapters 3 to 5 describe the verbal recency experiments in which ERP data were gathered alongside behavioural measures, and the experiments based on famous and non-famous names are described in Chapter 6. At issue throughout is the nature and number of memory processes that support recency judgements in tasks where the use of information in a strength-based manner is encouraged by the task designs. These chapters are preceded by a short section that outlines the general experimental methods. Critically for the first three experiments, ERPs provide indices of recollection and familiarity. As a result, acquiring ERPs during recency tasks provides the opportunity to assess the contributions that these two processes might make, as well as the ways in which they make them. At issue is the nature and number of memory processes that support recency judgements in tasks where the use of information in a strength-based manner is encouraged by the task designs.

General ERP Methods

The following methods were employed in all ERP experiments in this thesis.

Participants

All were right handed with normal or corrected to normal vision. All were undergraduates at Cardiff University. The participants reported speaking English as their native language and none were taking any psychotropic medication, or reported having a diagnosis of dyslexia. All participants gave informed consent prior to the experiment. All experiments in this thesis were approved by the ethics committee of the School of Psychology, Cardiff University.

Stimuli and Design

Low frequency words taken from the MRC Psycholinguistic database (4-9 letters, Kucera-Francis written frequency 1-7 per million, imageability rating 300-700, concreteness rating 400-700; www.psy.uwa.edu.au/MRCDataBase/uwa_mrc.htm) were used within the tasks. Stimuli were presented on a computer monitor located 1m away from participants. All stimuli were presented in uppercase size 40 Times New Roman font in white, set against a black background. They subtended maximum visual angles of 0.6° (vertical) and 5° (horizontal).

Procedure

Participants were fitted with an elasticated electrode cap prior to the experiment. They were seated in a sound attenuated booth facing a monitor with their fingers resting on a keypad. The participants read through an instruction sheet and the instructions were then relayed verbally. Recency-related continuous recognition memory tasks were employed, where the items were presented sequentially in long lists. Most presented items were repeated at some later point in the list. The repetition intervals are referred as *lags*. Participants were required to make an *old* (i.e. repeated) or *new* (i.e. first presentation within this task) recognition judgement in response to every presented item in the list. For those items which they identified as being *old*, the participants were also required to make a lag (or recency) judgement, indicating how many intervening items that were believed to have intervened between first and second presentations of the item at hand.

Electrophysiological Recording Procedure

Electroencephalogram (EEG) readings were recorded from 25 silver/silver chloride electrodes housed in an elastic cap. The sites were located at midline (Fz, Cz, Pz), as well as at left and right hemisphere locations (FP1/FP2, F3/F4, F5/F6, F7/F8, C3/C4, C5/C6, T7/T8, P3/P4, P5/P6, P7/P8, O1/O2; Jasper, 1958). Additional electrodes were placed on the left and right mastoids. Electrooculogram (EOG) readings were recorded from above and below the right eye (VEOG) and from the outer canthi (HEOG). Trials containing large EOG artefacts were rejected, as were trials containing A/D saturation or baseline drift (difference between first and last data point) exceeding ± 80μV. Other EOG blink artefacts were corrected using a linear regression estimate (Semlitsch, Anderer, Schuster, & Presslich, 1986).

EEG was recorded continuously at 200Hz (5ms per point) with Fz as the reference electrode, and was re-referenced computationally off-line to the equivalent of a linked mastoid reference into baseline corrected epochs of 1280ms (256 data points), each including a 100ms pre-stimulus baseline. The data from Fz were reclaimed. EEG and EOG were recorded with a bandwidth of 0.03-40Hz (-3 dB). Participants were excluded from analysis if not contributing at least twelve trials after EOG artefact rejection to the categories of interest. These categories are described in the ERP results section. The averaged ERPs underwent a 7-point binomially weighted smoothing filter prior to analysis.

Experimental Condition Terminology

Correct *new* responses to items presented for the first time in each experiment are referred to as *correct rejections (CR)*. Correct *old* responses to items presented for the second time in the experiments are referred to as *hits (H)*. Incorrect *old* responses to items presented for the first time in the experiments are referred to as *false alarms (FA)*. JORs are referred to in terms of the actual lag presented combined with the *lag response (R)* – so for example, hits that were presented at lag 15 and that attracted a JOR of 10 will be referred to as H15R10.

Analysis Strategy

The key behavioural findings for each experiment are presented in tables or in graphs. All tables and figures are presented in the text. The following flow charts briefly describe the ERP analysis strategy taken for Experiments 1-3 as a useful guide. The three time-windows included in these analyses are 300-500ms, 500-800ms and 800-1100ms. In the a priori analyses F3,Fz,F4 (300-500ms) and P3,Pz,P4 (500-800ms) are examined. Non-significant trends are defined as p values under .1 but greater than .05. Reaction times (RTs) are measured from stimulus onset.

EXPERIMENT 1

Global Old/New Analysis ↓

H15R15 compared with CRs. Carried out in order to identify whether there was evidence of any old/new ERP differences.

A Priori Planned Old/New Comparisons ↓

H15R15 compared with CRs at anterior and then posterior sites. Carried out in order to identify whether there is evidence of any old/new ERP differences that reflect previously identified ERP old/new effects.

Single Lag Global Analyses ↓

H15R10; H15R15; and H15R20 are compared. Carried out in order to determine whether there was evidence that differences in JORs are reflected in the electrical record.

Paired Global Single Lag Analyses ↓

H15R10; H15R15; and H15R20 are compared in pairs, in all three possible combinations. Carried out in order to determine whether there was evidence that differences in JORs are reflected in the electrical record in a way that would support a distance account of recency.

Single Lag A Priori Planned Comparisons ↓

All possible paired contrasts involving the conditions H15R10;H15R15 and H15R20 were conducted. Carried out to determine whether previously identified electrical activity varies with JOR in a way that might support a distance account of recency.

EXPERIMENT 2
Global Old/New Analysis ↓
H15R15 and H25R25 compared with CRs. Carried out in order to identify whether there was evidence of any old/new ERP differences.
Paired Global Old/New Analysis ↓
H15R15 compared with CRs, then H25R25 compared with CRs. Carried out in order to identify whether there is evidence of any old/new ERP differences *for each individual lag*.
A Priori Planned Old/New Comparisons ↓
CRs and hits attracting correct JORs were compared *in pairs* as in the stage above, at anterior and then posterior sites. Carried out in order to identify whether there is evidence of any old/new ERP differences that reflect previously identified ERP old/new effects.
Paired Global Hit Comparisons ↓
H15R15 and H25R25 were compared. Carried out in order to determine whether there was evidence that differences in lag are reflected in the electrical record. Followed by the appropriate a priori comparisons.
Single Lag Global Analyses ↓
H25R15, H25R25 and H25R30. Carried out in order to determine whether there was evidence that differences in JORs are reflected in the electrical record.
Paired Global Single Lag Analyses ↓
H25R15; H25R25 and H25R30 compared in pairs in all possible combinations. Carried out to determine whether previously identified electrical activity varies with JOR in a way that might support a distance account of recency. Followed by appropriate a priori comparisons.
Global Over-estimate Comparison ↓
H15R15 vs H15R25 comparison was conducted. Carried out in order to determine whether there was evidence that differences in JORs are reflected in the electrical record. Followed by the appropriate a priori comparisons.

EXPERIMENT 3
Global Old/New Analysis ↓
H5R5, H15R15 and H25R25 compared with CRs. This was carried out in order to identify whether there was evidence of any old/new ERP differences.
Paired Global Old/New Analysis ↓
H5R5 compared with CRs; H15R15 compared with CRs; and H25R25 compared with CRs. This was carried out in order to identify whether there was evidence of any old/new ERP differences *for each individual lag*.
A Priori Planned Old/New Comparisons ↓
CRs and hits attracting correct JORs were compared *in pairs* as in the stage above, at anterior and then posterior sites. Carried out in order to identify whether there is evidence of any old/new ERP differences that reflect previously identified ERP old/new effects.
Paired Global Hit Comparisons ↓
H5R5, H15R15 and H25R25 were compared. Carried out in order to determine whether there was evidence that differences in lag are reflected in the electrical record. Followed by the appropriate a priori comparisons.
Global Over-Estimate Comparison ↓
H5R5 and H5R15 were compared. Carried out in order to determine whether there was evidence that differences in JORs are reflected in the electrical record in a way that supported the idea that distance information was being used. Followed by the appropriate a priori comparisons.
Global Under-Estimate Comparison ↓
H25R15 and H25R25 were compared. Carried out in order to determine whether there was evidence that differences in JORs are reflected in the electrical record in a way that supported the idea that distance information was being used. Followed by the appropriate a priori comparisons.

CHAPTER 3 – EXPERIMENT 1

Introduction

The first ERP experiment was conducted in order to establish whether ERPs vary according to JOR. The main objective of this experiment was to assess whether ERP activity varies with judgements of recency and if so, whether it does in a strength-based manner. As outlined in the previous chapters, familiarity and recollection are two memory processes with purportedly known electrophysiological indices. If these are involved in supporting recency judgements, they will differ according to the type of JOR given. Furthermore, if these memory processes are involved in memory for recency in a way that falls into a distance category of memory processing, their electrophysiological correlates should increase in magnitude as a function of decreasing JORs.

In recency-related continuous recognition memory tasks, items are typically presented sequentially in long lists. Every presented item is repeated at some later point in the list. The repetition interval is referred to in this thesis as the 'lag'. It is the task of the participant to make an *old/new* recognition judgement in response to every presented item in the list. For those items which they identify as being '*old*', the participant must also make a 'lag' or recency judgement, indicating how many intervening items they thought there were between first and second presentations of items.

Experiment 1 was devised in order to maximise the number of trials at one single lag (15) in order to have sufficient numbers in the categories of interest, which were lag under-estimates, correct lag judgments, as well as over-estimates. If familiarity is employed in a strength-based manner in this task, the mid-frontal *old/new* effect will be larger for under-estimated lag judgements, in comparison with correct and over-estimated lag judgements. Similarly, if recollection is involved in lag judgements and is employed in a strength-based manner, then the left-parietal *old/new* effect will increase in magnitude with decreasing JORs.

Finally, the literature reviewed in Chapter 1 has shown that the frontal lobes are implicated in memory for recency (e.g. Eyler-Zorilla et al., 1996; Mangels, 1997; Tendolkar et al., 2004). No ERP studies have been conducted using distance-based tasks such as the continuous recency memory paradigm introduced by Yntema and Trask (1963; although for a somewhat different task, see Curran & Friedman, 2003), so there is little knowledge about how late-right frontal *old/new* effects vary with the accuracy of recency judgments. A subsidiary aim in this experiment was to explore how ERP activity varies with JORs in late time-windows over anterior scalp locations.

Method

Participants

There were 25 participants aged between 18 and 28 years (mean age 21 years) in the experiment. Two participants were excluded on the basis of excessive EOG artefact. A further 5 participants were excluded because they did not contribute sufficient trials to the categories of interest (specified below). Of those included, 15 were female, each being paid £20.

Stimuli

These were 330 low frequency words. Each participant took part in three experiment blocks (480 trials in total). Within each block there were 100 words, sixty of which were repeated after a lag of 15 intervening words. No words appeared in more than one block. The 100 words in each block were divided into 5 mini-blocks, each containing 20 words. 3 of the 5 mini-blocks were designated as repeated words, and 2 as *new* (not to be repeated) words. This procedure was repeated a further four times, yielding 5 lists per block in total, such that across lists each word was designated as a repeated word on 3 lists, and a *new* word on 2 lists. 30 *new* words, 10 of which were repeated, were used in an initial practice block. Words within each list were organised pseudo-randomly for each block, with *new* words acting as fillers among *new* to-be-repeated words.

Procedure

Each experiment block began with a 'Ready' signal, lasting 5000ms. Each trial began with a fixation mark (*) which lasted 500ms, followed by a blank screen (100ms). Words were then presented for 300ms, followed by a blank screen during which participants decided whether the word was *old* or *new* via key press (*old* or *new* with left or right thumb – counterbalanced across participants). Once this judgement had been made, a blank period of 1000ms passed before participants were presented with the words 'How Far Back?'. If the participant had indicated the word was *new*, they were instructed to press the same key again at this point to carry on to the next trial. If they had indicated that the word was *old*, they were instructed to judge whether the word had initially been presented 10, 15, or 20 intervening words previously.

The three judgement of recency (JOR) options were made via three key buttons, three on one hand, with the hands used for responses balanced across participants (with the middle three fingers of the left or right hand being used for responses - 10,15,20 or 20,15,10). The JOR was followed by a 500ms blank screen before the next trial. Participants were able to remind themselves of which keys to press throughout the experiment through a display on the floor, which they were advised they could look at when, but not before, the 'How Far Back?' signal was displayed.

An equal number of participants completed each of the 5 lists of three blocks (n=5) except for lists 4 and 5 (which n=3 participants completed). An equal number of participants were presented with each of the block presentation orders (b1,b2,b3; b2,b3,b1; or b3,b1,b2). Response hands, list and block order were counterbalanced so that each person conducted the experiment with a unique combination of these three. There was a short practice session before the first block was presented, and a break of approximately five minutes between blocks. Participants were instructed to balance speed and accuracy equally. Participants were not informed of the ratios of repeated items presented at each lag. The individual blocks took 15-20 minutes to complete. Participants were debriefed at the end of the experiment and the minor deception concerning the lag judgment was explained to them.

Behavioural Results

The mean probability of a correct rejection (CR) was .96 (SD =.03), and of a correct response to an *old* item regardless of JOR was .96 (SD =.05). *Old/new* discrimination (p[hit] – p[false alarm]) was reliably greater than chance ($t(17) = 89.11; p < .001$). The mean RT for CRs was 775ms (SD =132ms). The conditional probabilities and the RTs for recency judgements are provided in Table 1 (p114). A one way ANOVA involving the three different classes of hits (H15R10, H15R15, H15R20) revealed a main effect ($F(2,51) = 16.0; p < 0.001$). Follow-up paired t-tests showed that H15R10 and H15R20 responses were less likely than H15R15 responses ($t(17) > 5.00; p < .01$ in each case), and that the probabilities of H15R10 and H15R20 responses were not reliably different. A one-way ANOVA showed that the mean reaction times did not differ across the three classes of hit.

Table 1. Mean Probabilities (p) and Reaction Times (RT) of each lag judgment (10, 15 & 20), conditional on a correct old judgment (n=18) §.

	p	RT
JOR		
10	.29 (.11)	892 (159)
15	**.43 (.05)**	**883 (131)**
20	.28 (.10)	896 (158)

§SD reported in brackets.
Correct JOR highlighted in Bold.

ERP Results

ERP Analysis Strategy

The analyses were conducted using ANOVAs. Degrees of freedom are shown with epsilon corrected degrees of freedom for non-sphericity where appropriate (Greenhouse & Geisser, 1959). Only the highest order interactions obtained in each case are described in the text (unless indicated otherwise), but all reliable effects involving category are shown in tables. No references to main effects and interactions that do not involve the factor of response category are made here. The data were analysed over three separate time-windows, which were 300-500ms, 500-800ms and 800-1100ms, since these largely span the recording epoch and these correspond to the time-windows that have been employed in previous recognition memory and source memory studies (Allan et al., 1998).

Initial global analyses included the factors of response category (CC), anterior/posterior (AP) dimension (three levels: anterior: F3/F4/F5/F6/F7/F8, central: C3/C4/C5/C6/T7/T8, and posterior: P3/P4/P5/P6/P7/P8), hemisphere (HM; two levels: left/right), and site (ST; three levels: inferior: F7/F8/T7/T8/P7/P8, mid-lateral: F5/F6/C5/C6/P5/P6, and superior: F3/F4/C3/C4/P3/P4). In addition to the global ANOVAs, focused analyses were conducted involving the parts of the electrical record in which ERP indices of familiarity and recollection have been identified previously (e.g. Mecklinger, 2000; Nessler et al., 2005; Rugg et al., 1998). For familiarity, these were F3, Fz, F4 during the 300-500ms time-window (e.g. Curran, 2000). For recollection these were P3, Pz, P4 during the 500-800ms time-window (e.g. Rugg et al., 1998).

Figure 4 (p116) supports the decision to analyse the data within three separate time-windows. The figure shows the scalp distributions of neural activity that differentiates items attracting correct lag judgements (H15R15) from correct judgements to *new* items at lag 15 over the 300-500ms, 500-800ms and 800-1100ms epochs. As with all scalp maps in this thesis, for each epoch and contrast the amplitudes are scaled over the colour range according to the maximum and minimum amplitude values within that epoch. These values are shown below each scalp map. The scalp maps show marked differences in the distributions of the *old/new* effects across the three recording epochs. The ways that these distributions change with time correspond broadly with the ways in which ERP *old/new* effects have varied in previous studies (e.g. Allan et al., 1998). In the 300-500ms epoch, there is a central maximum positivity. The anterior activity diminishes after 500ms, with the distribution moving toward the back of the head with a left lateralised maximum. The distribution then begins to move anteriorly in the 800-1100ms time-window.

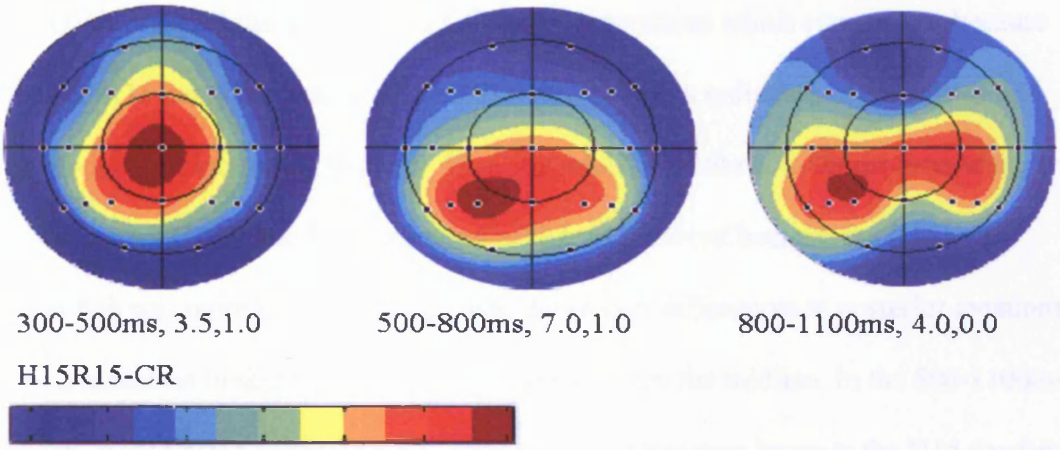

Figure 4. Topographic maps showing the scalp distributions of the neural activity associated with correct lag judgments for the 300-500ms, 500-800ms and 800-1100ms time-windows. The maps were calculated on differences scores obtained by subtracting mean amplitudes within each time-window for correct rejections from amplitudes associated with correct lag 15 judgments (n=18).

The ERPs elicited by correctly identified *old* items (H15R15) were first compared with those elicited by correct rejections. Critical follow-up comparisons to these global analyses of *old/new* effects were between the different recency judgements given to the items, to assess whether differences in JOR are reflected in the electrical record, and if so, whether these differences can be tied to recollection or familiarity. This follow-up comparison is important, as any differences in JOR can be attributed to recency memory processes, since actual lag does not differ across these categories. The mean number of trials (range in brackets) contributing to the correct rejection category for the analysis was 255 (216-286). For the other categories, the values were: H15R15 = 58 (37-75), H15R10 = 40 (24-76), H15R20 = 37 (16-66).

Global Old/new Analyses

The outcomes of the global analysis involving the categories CR and H15R15 for the 3 critical epochs are shown in Table 2 (p118). The table shows that in all cases, there were interactions involving category and scalp locations. In the 300-500ms epoch, the ANOVA revealed that there was a CC by ST interaction which came about because the H15R15 condition was more positive-going, with a reduction in the size of this positivity with increasing distance from the midline. In the 500-800ms time-window, there was a CC, AP and ST interaction which came about because the H15R15 condition was more positive-going, with the largest differences at posterior locations and a reduction in size with increasing distance from the midline. In the 800-1100ms epoch, the ANOVA revealed a CC, HM and ST interaction because the H15 condition was more positive than CR, with larger differences over the left hemisphere than over the right, at mid-lateral and inferior sites. In this epoch, there was also a CC, AP and ST interaction which came about because the differences between categories were largest at posterior-superior electrode locations.

Table 2. The outcomes of the global analyses of the ERP old/new effects for words attracting correct old/new judgements (n=18) §.

	300-500ms	500-800ms	800-1100ms
CC (1,17)	48.96***	105.00***	23.82***
CC x AP (1.1,19.5)	-	15.92**	4.20*
CC x ST (1.2,20.5)	41.06***	50.64***	3.77•
CC x AP x ST (2.8,47.2)	-	9.45***	7.55**
CC x HM x ST (1.2,21.2)	-	3.80•	5.01*

§ The factors are Condition (CC), Anterior-Posterior Dimension (AP), Hemisphere (HM) and Site (ST). Conditions = CR; H15R15
Full degrees of freedom are shown.
•trend
*p<0.05
**p<0.01 ***p<0.001

A Priori Planned Comparisons

In the 300-500ms time-window a focused analysis (F3,Fz,F4) was conducted for the CR and H15R15 conditions (Figure 5, p120). The ANOVA revealed a CC by ST interaction ($F(1.8,31.2) = 7.82; p<0.01$), which came about because the H15R15 condition was more positive-going, with the largest differences at Fz. There was also a main effect of CC $(1,17) = 34.62; p<0.001$). The second planned comparison was carried out in the 500-800ms time-window at posterior locations (P3,Pz,P4) (Figure 6, p120). The ANOVA comparing CR and H15R15 revealed a main effect of CC also ($F(1,17) = 75.51; p<0.001$), and a CC and ST interaction ($F(1.9,32.3) = 5.60; p<0.01$). The interaction came about because the H15R15 condition was more positive-going, with the largest differences at P3.

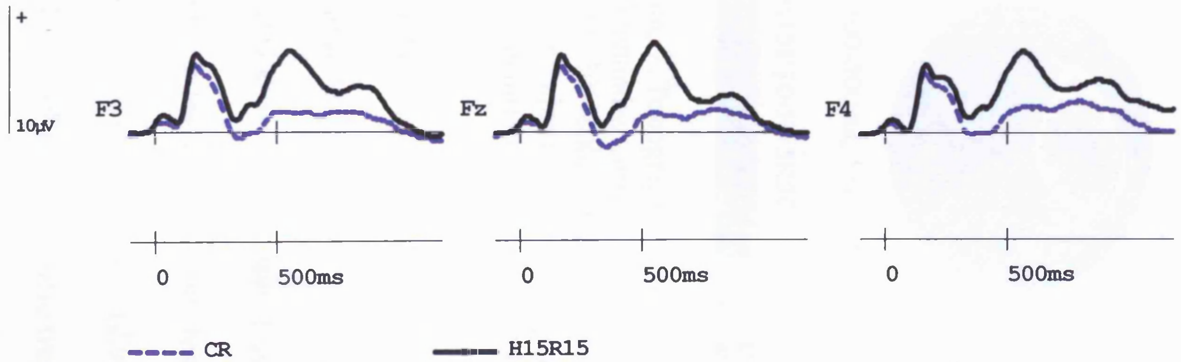

Figure 5. Grand average ERPs associated with correct JORs and correct rejections at selected anterior electrodes (n=18).

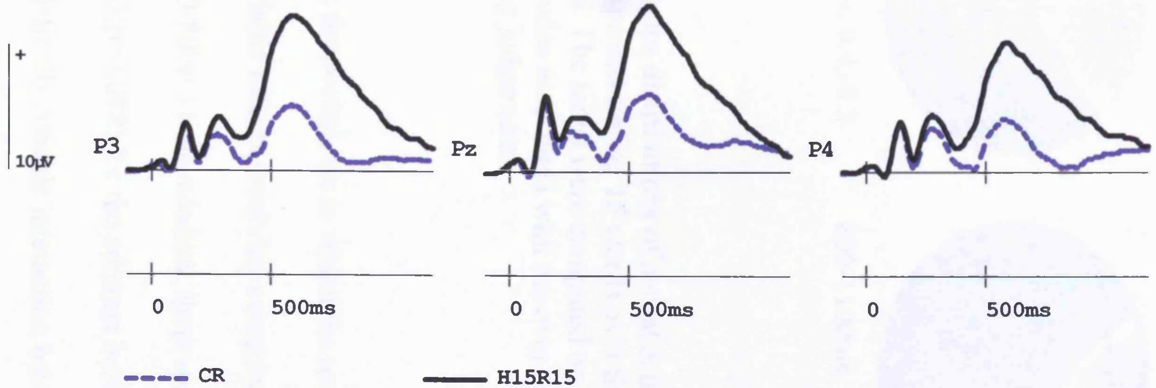

Figure 6. Grand average ERPs associated with correct JORs and correct rejections at selected posterior electrodes (n=18).

Single Lag Global Analyses

Of principal interest for addressing the experiment hypothesis was whether any differences are present between the H15R15, the H15R10 (under-estimates) and the H15R20 (over-estimates) conditions (see Figure 7). All reliable effects involving condition in these analyses are reported in the text. In the 300-500ms epoch, no reliable effects between the conditions were detected. In the 500-800ms time-window, there was a trend for a CC, AP and HM interaction ($F(3.1,52.9) = 2.39; p=0.078$). In the 800-1100ms time-window, there was also a trend the same interaction term ($F(3.2,55.2) = 2.57; p=0.06$).

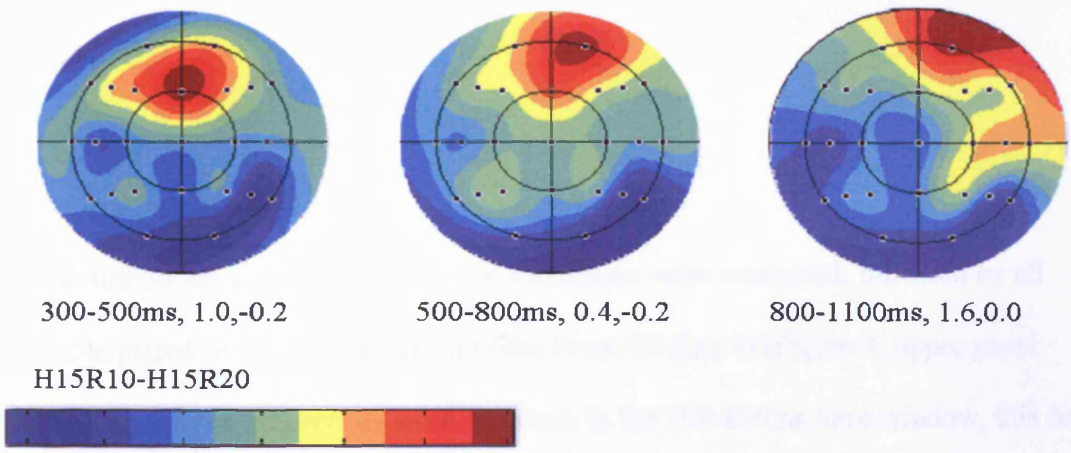

Figure 7. Topographic maps showing the scalps distributions of neural activity differentiating correct and incorrect lag judgments for lag 15 words over the 300-500ms, 500-800ms and 800-1100ms epochs. The maps were computed on difference scores obtained by subtracting mean amplitudes associated with the over-estimated lag judgements from the under-estimated lag judgements.

Paired Global Single Lag Analysis

These paired contrasts were restricted to the time-windows in which the trends reported above were revealed. Again, all reliable effects involving category in the ANOVAs are reported in the text. In the 500-800ms time-window, there was a trend for a four way interaction ($F(2.9,49.8) = 2.33; p=0.088$) for the contrast between H15R15 and H15R10. There was also a statistically reliable interaction between

H15R10 and H15R20 involving the factors CC, AP and HM, ($F(1.9,32.1) = 3.88; p<0.05$), which came about because the under-estimate condition was more positive-going than the over-estimate condition, with larger differences over the right hemisphere than the left, at frontal and central locations. In the 800-1100ms epoch, there was a trend for a CC, AP and HM interaction for the contrast between the H15R15 and the H15R20 conditions ($F(1.8,29.9) = 3.03; p=0.07$). There was also a statistically reliable CC, AP and HM interaction between the under-estimate and the over-estimate conditions ($F(2.0,33.9) = 3.52; p<0.05$), which came about because the H15R10 condition was more positive-going, with the largest differences over right frontal and central locations. There were no reliable effects in the analyses from 300-500ms.

A Priori Planned Comparisons

In the 300-500ms epoch, the three JOR conditions were compared, followed by all possible paired contrasts at the front of the head (F3,Fz,F4) (Figure 8, upper panel p123). No reliable differences were detected. In the 500-800ms time-window, this set of analyses was also performed including posterior electrodes (P3,Pz,P4) (Figure 8, lower panel p128). Again no reliable differences were observed across JORs for lag 15 items.

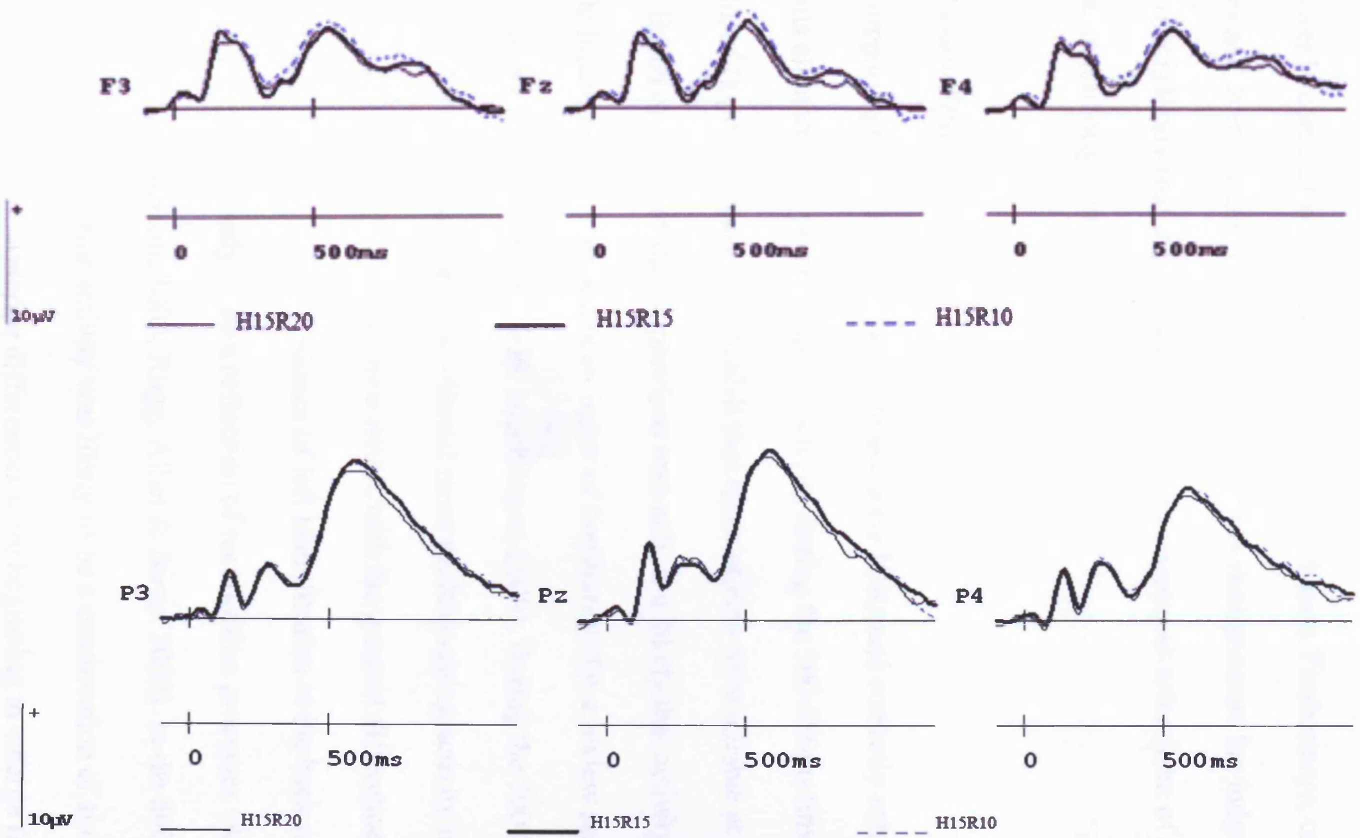

Figure 8. Grand average ERPs associated with correct JORs and incorrect JORs for lag 15 words at selected anterior (upper panel) and posterior (lower panel) electrodes (n=18).

Discussion

One aim of this experiment was to establish whether ERPs might be useful for use in a task where participants are required to make a long series of recognition and recency judgements. The primary aim was to explore whether ERPs vary in line with JORs in a task where lag remained constant and only JORs varied. Recognition memory performance was at ceiling in the current experiment. The accuracy of the JORs was much lower in comparison, though this was above chance. Furthermore, under-estimates and over-estimates of lag were less likely than accurate lag judgments. Therefore it is likely that the participants did have access to some form of recency information (although see p127).

ERP Old/new Effects

When comparing the hits associated with accurate JORs and correctly rejected *new* items, hits elicited more positive-going activity during the 300-500ms time-window. The focused (a priori) analyses revealed that these effects were reliable at sites F3, Fz and F4. Based on the findings of previous research, it is likely that activity at frontal electrode locations in this epoch is an index of familiarity (for a review see Curran, DeBuse, Woroch & Hirshman, 2006; Mecklinger, 2000). During the 500-800ms time-window, the H15R15 category also elicited more positive-going activity in comparison with correctly rejected *new* items, with the greatest differences over posterior areas. There was also evidence of left lateralisation at the back of the head. This differentiation is likely to be a reflection of recollection processes (Allan et al., 1998; Friedman & Johnson, 2000; Rugg, Allan & Birch, 2000). In the 800-1100ms epoch the reported posterior activity was likely to be a continuation of activity from the earlier time-window. Anterior differences were beginning to emerge (as was indicated by the scalp maps, Figure 4, p116), suggesting that some form of executive processing was in the process of initiating by the end of the recording epoch.

As outlined earlier, the critical comparisons in this experiment were between the ERPs elicited by correct lag judgments, and those elicited by under-estimates and over-estimates for the same lag. If the ERP activity associated with these conditions varied such that larger *old/new* effects were associated with shorter lag judgements, this would comprise evidence that distance information is utilised for making recency judgements. Analysing the JORs across a single lag means that there is no confound with actual lag and could therefore provide evidence to suggest that the memory processes associated with these ERP effects are utilised by participants when making recency judgements.

Single Lag Comparisons

Experiment 1 did not reveal any strong evidence that ERPs varied with judgements of recency. Though visual inspection of the waveforms shows that hits accompanied by shorter JORs elicit more positive-going activity during the time-window previously associated with familiarity (Figure 7, p121) compared to longer JORs, there was no statistical support for this impression. In the 500-800ms time-window, over-estimated lag judgements were associated with comparably more negative-going ERPs compared to under-estimated lag judgements. However, the fact that the activity predicting differences in lag judgements did not have a distribution reminiscent of the left parietal *old/new* effect makes these differences difficult to interpret. A discussion of these null results will be conducted later in this section.

A late right frontal effect was associated with type of lag judgement in the current study, being more positive-going for under-estimates than over-estimates (Figure 7, p121). Late effects with a similar distribution have been reported in previous studies (e.g. Wilding & Rugg, 1996). It was reported in the study by Wilding and Rugg as being a greater positivity for items for which the correct source was determined, in comparison with items for which the source was not retrieved. As outlined in Chapter 2 in this thesis, late right frontal memory related activity has been associated with monitoring and other executive processes. However, if this is the case, why under-estimates should require greater involvement of this type of processing than over-estimates is unclear. In line with the evidence accrued by Hayama et al. (2008), it could be that late right frontal activity is related to monitoring the products of retrieval and if this is the case, perhaps a greater level of monitoring takes place for items of greater strength, potentially since a greater volume of information is likely to have been recovered for strong items.

This study builds on previous behavioural research into memory for time concerning recency judgements. Hintzman (2001; 2003; 2004) has shown over a number of behavioural studies that strength manipulations can influence JORs, and these findings support the notion that distance theories could contribute to the debate over how recency decisions are formed. This is because the current research has shown that three known ERP signatures can be recorded in a continuous recency memory task adapted from that of Hintzman and Yntema and Trask (1963) and these effects can therefore be measured in order to answer further questions about memory for recency. The use of ERP recording during a continuous recency memory task is apparently novel and an interesting way to investigate these issues in that it may capture any decrements in ERP amplitudes with increasing time or JORs.

As mentioned earlier, there was little statistical evidence in the current experiment in support of the view that ERP indices linked to familiarity and recollection varied in a manner consistent with a distance-based account. One possible reason for the lack of ERP amplitude variance across JORs in the time-windows associated with these memory processes is that strength differences do not support recency judgements. If this was the case, it would rule out a strength account of recency memory in the framework put forward by Friedman, at least in the way that it is presented in Figure 2 (p56), however drawing this conclusion on the basis of the current experiment is premature.

Another potential source of the null results reported here is the possible criticism of this study is that participants did not base their JORs on any reliable memory processes and instead, participants were encouraged to respond 10, 15 or 20 simply as a consequence of being given these options. However, evidence to the contrary can be seen in the behavioural performance which showed that they were more likely to judge items correctly as being presented after 15 intervening items, rather than giving JORs that were too short or too long. This result is consistent with the view that participants had access to at least some recency information, although this does not mean that on all trials participants relied upon recency information. It is also possible that the increased likelihood of a lag 15 response is in whole or part a consequence of bias to choose the middle value, i.e. as a normal distribution of data might suggest that the middle value would be the one most commonly observed, however evidence to the contrary was obtained during initial piloting of this task, as when four response options were available to participants (10,15,20,25) a 15 response was still the most frequent JOR. Regardless, future studies will not use this design so it is not anticipated that this possible criticism will be an issue.

One other possible reason for the absence of statistically reliable effects in Experiment 1 in terms of the JORs is that there were insufficient distances between the lag judgement response options - the result being that the ERPs were not sufficiently sensitive to detect differences according to the judgements participants gave. The scalp map in Figure 7 (p121) is encouraging, however at least for the 300-500ms epoch, where it can be seen that a focal frontal positivity differentiates between the neural activity associated with under- and over-estimates of lag.

The distribution of the ERP differences across lag, alongside some evidence for differences according to lag judgements in later epochs, motivated the design of Experiment 2, in which an attempt was made to make a larger separation between the neural activity associated with the critical classes of a wider range of lag judgement options to participants. The possibility that insufficient distances between the lag judgement response options led to a lack of statistically reliable effects in Experiment 1 was addressed in the second ERP experiment via changes in the experiment design. In addition, the potential criticism of this study that participants did not base their lag judgements on any meaningful mnemonic information was also addressed by the inclusion of four actual lags in the second experiment, rather than including one lag as in Experiment 1. Further consideration of the findings in Experiment 1 can be found in the General Discussion (Chapter 7).

CHAPTER 4 – EXPERIMENT 2

Introduction

The second ERP experiment was also designed in order to explore recency-related memory processing. The task used here was altered from that employed in the previous experiment in order to increase the number of intervening items between the available JOR response options. Instead of having one repetition interval, four were used here (5, 15, 25 and 35). This increased the spacing between possible JORs relative to Experiment 1, with a minimum of 10 intervening items to a maximum of 30. Experiment 2 was devised in order to maximise the number of trials at lags 15 and 25 in order to have sufficient numbers in the categories of interest, specifically under-estimated, correct and over-estimated lag judgements for each of these lags.

The key predictions concerning specific elements of the electrical record are the same as for Experiment 1. If familiarity is employed in a strength-based manner in this task, the mid-frontal *old/new* effect will be larger for under-estimated lag judgments, in comparison with correct and over-estimated lag judgements. Similarly, if recollection is involved in lag judgements and is employed in a strength-based manner, then the left-parietal *old/new* effect will increase in magnitude with decreasing JORs.

Method

Participants

Twenty-nine participants aged between 18 and 25 years (mean age 20 years) took part in the experiment. Four participants were excluded on the basis of excessive EOG artefact and one was excluded due to a computer malfunction. Of those included, 16 were female and each participant was paid £20 for taking part.

Stimuli and Design

The stimuli were 824 low frequency words. There were four blocks in each complete task list. Each block comprised 196 stimuli, which included 116 words, 80 of which were repeated. The repeated words were presented after 5, 15, 25 or 35 intervening words. Ten were repeated at lag 5 and ten at lag 35. Thirty were repeated at lag 25 and thirty at lag 15. Order of presentation of lag 5, 15, 25 and 35 items was determined pseudo-randomly. Five words which were not repeated were presented at the start of the block to act as buffer items. ERPs were not formed for these stimuli. A further 31 words (different in each block) were presented only once. These were filler items that were presented towards the end of each list in order to ensure that items from each lag were distributed relatively evenly throughout each list. One further list was created from each initial block, such that all words at lag 5 and 35 were encountered at lags 35 and 5, respectively, in the second alternate list. The same procedure was followed for Lag 25 and 15 words. This procedure resulted in the creation of four pairs of blocks. A further 25 words, 15 of which were repeated, were used in an initial practice block.

Procedure

Each experiment block began with a 'Ready' signal, lasting 5000ms. Each trial began with a fixation mark (*) which lasted 500ms, followed by a blank screen (100ms). Words were then presented for 300ms, followed by a blank screen during which participants decided whether the word was *old* or *new* via key press (left thumb for *old*, right thumb for *new* – counterbalanced across participants). Once this judgement had been made, a blank period of 1000ms passed before participants were presented with the words 'How Far Back?'.

If the participant had indicated the word was *new*, they were instructed to press the same key again at this point to carry on to the next trial. If they had indicated that the word was *old*, they were instructed to judge whether the word had initially been re-presented after 5, 15, 25 or 35 intervening words. The four JOR options were made via four key buttons, two on each hand (either 5, 15 or 25, 35) with the middle and index fingers, with the hands used for responses balanced across participants. The JOR was followed by a 500ms blank screen before the next trial. Participants were able to remind themselves of which keys to press throughout the experiment by means of a display on the floor, which they were advised they could look at when but not before the 'How Far Back?' signal was displayed.

An equal number of participants completed each of the two lists, and the order of block presentation was rotated evenly across participants. There was a short practice session before the first block was presented, and a break of approximately five minutes between blocks. Participants were instructed to balance speed and accuracy equally. Participants were not informed of the numbers of repeated items presented at each lag. The individual blocks took 15-20 minutes to complete.

Behavioural Results

Table 3 (p133) shows the probabilities of correct *old/new* judgments to *new* words and to *old* words separated according to lag. Also shown in the table are the reaction times for these classes of response. Discrimination (p[hit] – p[false alarm]) was reliably greater than chance at each lag ($t(23) > 40.00$, $p<0.001$ in each case). A one-way ANOVA contrasting these four discrimination measures revealed a main effect ($F(2.02,46.41) = 8.42$, $p<0.01$) and follow-up paired t-tests revealed that *old/new* discrimination deteriorated between lag 5 and 25 and between lag 5 and 35 ($t(23) > 3.00$, $p<0.01$, in each case). Discrimination also deteriorated between lag 15 and 25, and between lag 15 and 35 ($t(23) > 2.80$, $p<0.01$, in each case).

Table 3. Probabilities of correct old and new judgments and associated reaction times (RT), separated according to lag (n=24) §.

	New	Lag 5	Lag15	Lag25	Lag35
p(correct)	0.95 (0.04)	0.86 (0.11)	0.85 (0.11)	0.81 (0.11)	0.77 (.17)
RT	814 (168)	1003 (228)	977 (211)	969 (208)	1013 (246)

§ SDs are in brackets.

Table 4. Probabilities of each lag judgment (JOR 5, 15, 25, 35), conditional on a correct old judgment and separated according to lag (n=24) §.

Lag:	Lag5	Lag15	Lag25	Lag35
JOR5	**0.44 (.18)**	0.08 (.06)	0.03 (.03)	0.02 (.03)
JOR15	0.37 (.13)	**0.48 (.10)**	0.28 (.10)	0.19 (.15)
JOR25	0.15 (.14)	0.36 (.10)	**0.48 (.09)**	0.43 (.12)
JOR35	0.03 (.03)	0.09 (.06)	0.21 (.10)	**0.36 (.18)**

§ Correct lag judgments are in bold.

SDs are in brackets.

A one-way ANOVA comparing the RTs associated with correct *old* judgments at each lag (but regardless of JOR) shown in Table 3 revealed a main effect of condition ($F(3.03,69.61) = 24.329; p<0.001$). Follow up t-tests showed that RTs for CRs were faster than hits at all lags ($t(23)>7.80; p<0.001$, in each case). Paired sample t-tests also confirmed that there were significant RT differences between hits at lags 15 and 35, and between hits at lags 25 and 35 ($t(23)>-2.40; p<0.05$, in each case), with participants being faster to respond in the shorter lag condition in each pair.

Table 4 (p133) shows the probabilities of each lag judgment (JOR 5, 15, 25, 35), conditional on a correct *old* judgment and separated according to lag and JOR. The bold values on the diagonal are the probabilities of a correct lag judgment and in each case, this was above chance ($t(23)>9.50; p<0.001$). Paired sample t-tests revealed that correct lag 15 judgements were more likely than a lag 25 judgement ($t(23) = 3.18; p<0.01$) for words re-presented at lag 15. Paired sample t-tests also revealed that correct lag 25 judgements were more likely than an under-estimate ($t(23) = -5.67; p<0.001$) or an over-estimate ($t(23) = 8.34; p<0.001$) for words presented at lag 25. These are the critical conditions for which ERPs can be formed, and which are described in detail below. A one-way ANOVA showed that there was a trend for a main effect of RT for hits associated with correct lag judgements ($F(1.77,35.30) = 2.99; p<0.07$). The mean RTs for correct lag judgements were 955, 951, 975 and 1026ms for lags 5, 15, 25 and 35, respectively.

ERP Results

ERP Analysis Strategy

Here the global *old/new* effects will be reported first, followed by paired contrasts between hits at lags 15 and 25 that attracted a correct JOR. By design, there were insufficient trials to complete these analyses for lag 5 and lag 35 items. The critical contrasts between different JORs at single lags will ensue. Figure 9 (p136) supports the decision to analyse the data within three separate time-windows. The figure illustrates the ERP *old/new* effects for items attracting correct lag judgements (separated according to lag) for a subset of sites encompassing the spatial extent of the electrodes included in the analysis described below. Figure 9 shows the scalp distributions of neural activity that differentiates items attracting correct lag judgements from correct judgements to *new* items at lags 15 and 25 over the 300-500ms, 500-800ms and 800-1100ms epochs. The scalp maps show marked differences in the distributions of the *old/new* effects across the three recording epochs in the same way as was described in Experiment 1.

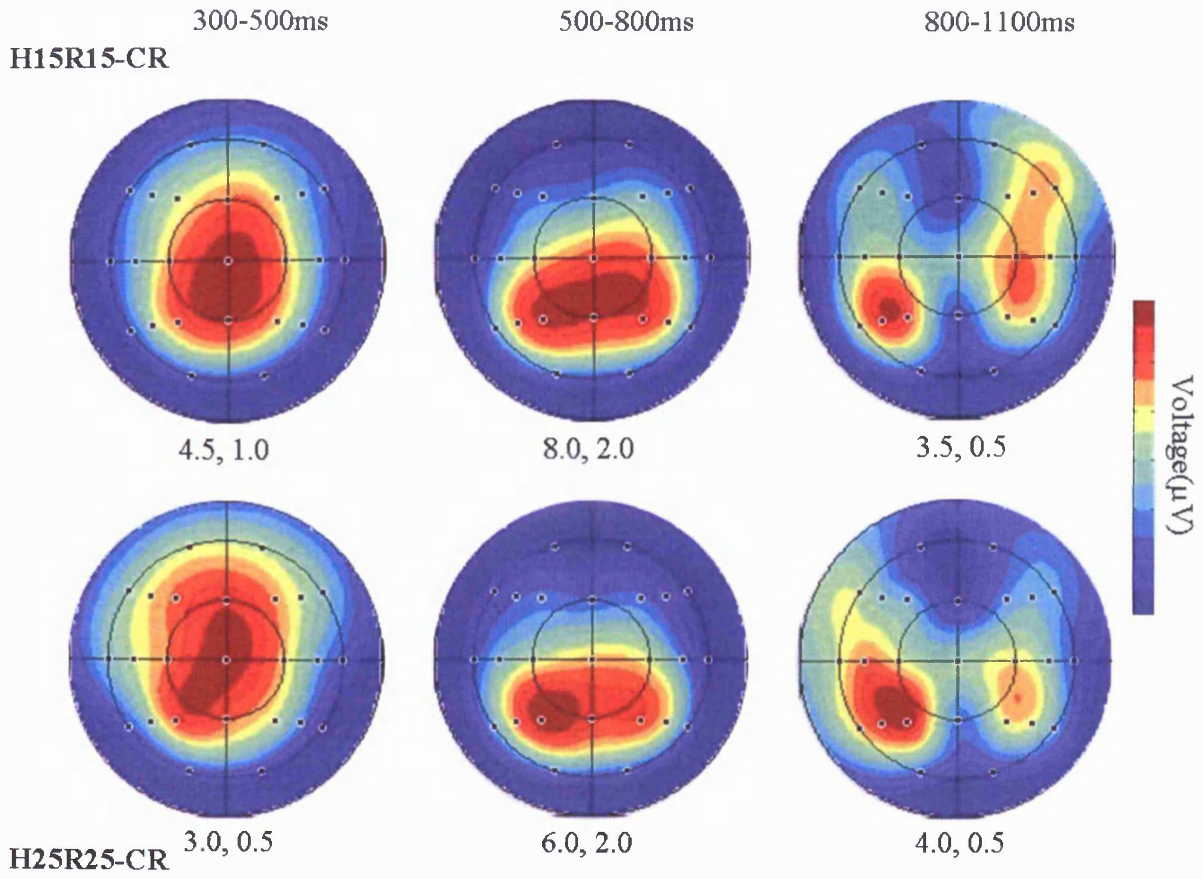

Figure 9. Topographic maps showing the scalp distributions of the neural activity associated with correct lag judgments for the 300-500ms, 500-800ms and 800-1100ms time-windows. The maps were calculated on differences scores obtained by subtracting mean amplitudes within each time-window for correct rejections from amplitudes associated with correct lag 15 and 25 judgments, respectively (n=24).

Only ERPs elicited by correctly rejected *new* items and correctly identified *old* items at lags 15 and 25 were analysed. These are the critical conditions that allow for a potential comparison of both under- and over-estimations of lag. The inclusion of lags 5 and 35 with lower trial numbers precluded formation of reliable averaged ERPs of interest for these lags. First, an analysis of the *old/new* effects for correct lag judgments was conducted. 24 participants were included in these analyses. Figure 9 shows that the scalp distributions of the ERP *old/new* effects in the 500-800ms epoch differ primarily in magnitude, with the effects decreasing in magnitude with increasing lag. For the earlier (300-500ms) epoch, the maxima of the scalp distributions of the ERP *old/new* effects move posteriorly with increasing lag. The principal reason for this shift is the progressive attenuation of the ERP *old/new* effects at anterior sites with increasing lag, alongside a less pronounced degree of attenuation at posterior scalp locations. From 800-1100ms, there is an extension of the posterior positivity from the earlier epoch. Here there is an emerging anterior effect which is lateralised to the left hemisphere for the H15R15 condition, and is over the right for the H25R25 condition.

Secondly a comparison of single lag judgements was conducted, involving lag 25 hits associated with a correct JOR (H25R25), an under-estimated lag judgement (H25u) and an over-estimated lag judgement (H25o). 17 participants were included in these analyses. Finally, for lag 15 items, hits associated with a correct JOR (H15R15) were contrasted with those associated with an over-estimated JOR (H15o). All 24 participants were included in these analyses. For the analyses of the *old/new* effects at each lag, no follow-ups are conducted when the outcomes of paired ANOVAs revealed interactions involving scalp locations, as the intention is to characterise the broad distributions of the *old/new* effects before focussing on the critical contrasts, which are between *old* items separated according to the accuracy of lag judgments. For the direct contrasts between correct or incorrect responses to *old* items at each lag, however, follow-up analyses at anterior and posterior locations are conducted where necessary in order to elucidate the specific distributions of differences between these critical conditions. The mean number of trials (range in brackets) contributing to the correct rejection category for the analyses including 24 participants was 365 (range = 213-444). The corresponding value for H15R15 was 43 (19-61), for H25R25 this was 40 (17-59) and for H15o this was 36 (14-59). For the 17 participant subset, the mean number of trials for CRs was 356 (213-443). For H25R25 the mean number of trials was 39 (17-55), for H25u this was 26 (12-47) and for H25o this was 19 (12-30). In the analyses below, the reports of the outcomes of the ANOVAs for the *old/new* effects (both global and planned comparisons) precede the reports of the direct contrasts between the ERPs associated with correct lag judgments.

Global Old/new Analyses

The outcomes of the global analysis involving the categories CR, H15R15 and H25R25 for the 3 critical epochs are shown in Table 5 (p139). The table shows that in all cases, there were interactions involving condition and scalp locations, and in light of this, follow-up paired contrasts were conducted for all possible pairs for each epoch.

Table 5. The outcomes of the global analyses (F-values and significance levels) of the ERP old/new effects for words attracting correct old/new and correct lag judgements for the 3 selected time-windows. Experiment 1 (n=24)§.

	300-500ms	500-800ms	800-1100ms
CC	36.55***	71.24***	26.60***
CCxAP	-	13.76***	-
CCxHM	-	-	3.52*
CCxST	30.27***	47.26***	-
CCxAPxST	5.13**	12.41***	3.49**
CCxHMxST	-	-	-
CCxAPxHMxST	-	-	1.95•

§ The factors were Condition (cc), Hemisphere (hm), Anterior-Posterior Dimension (ap) and Site (st). Conditions = H15R15, H25R25, CR.
*p<0.05
**p<0.01
***p<0.001 (epsilon corrected)
•trend

Table 6. The outcomes of the global paired analyses (F-values and significance levels) of the ERP old/new effects for words attracting correct old/new and correct lag judgements for the 3 selected time-windows. Experiment 1 (n=24)§.

Epoch	300-500ms		500-800ms		800-1100ms	
Lag	15	25	15	25	15	25
CC	79.31***	47.27***	104.70***	70.03***	26.60***	28.69***
CCxAP	-	2.86•	25.28***	16.64***	-	-
CCxHM	-	4.70*	-	-	3.52*	-
CCxST	75.54***	25.57***	62.09***	42.24***	-	-
CCxAPxST	7.48***	5.96**	15.88***	17.26***	3.49**	4.62**
CCxHMxST	-	-	-	-	-	-
CCxAPxHMxST	-	2.60•	-	3.02*	1.95•	3.46*

§ The factors were Condition (cc), Hemisphere (hm), Anterior-Posterior Dimension (ap) and Site (st). Conditions = H15R15vsCR; H25R25vsCR.
*p<0.05
**p<0.01
***p<0.001 (epsilon corrected)
•trend

Paired Global Old/new Analyses

For the 300-500ms time-window, a global ANOVA was conducted to assess whether there were differences between CR and H15R15 (Table 6, p139). For this analysis, the CC, AP and ST interaction came about because the H15R15 condition was more positive-going, especially over central and posterior locations, with differences in amplitude diminishing with increasing distance from the midline, as Figure 9 (p136) shows. The same interaction term was reliable for the same reason for the paired contrast between CR and H25R25.

For the 500-800ms time-window, the ANOVA for the H15R15 versus CR contrast also revealed a CC, AP and ST interaction, which came about because the H15R15 condition was more positive-going, with the largest differences over the back of the head at the midline. In the contrast between H25R25 and CR, the ANOVA revealed a CC, AP, HM and ST interaction. This came about for similar reasons to those for the H15R15 contrast. In addition there was a degree of lateralisation, with larger differences between conditions over the left hemisphere at posterior locations.

For the 800-1100ms time-window, the H15R15 versus CR ANOVA revealed a CC, AP and ST interaction which came about because the H15R15 condition was more positive-going, with the largest differences across posterior locations, and a reduction in size with increasing distance from the midline. In this time-window, an ANOVA comparing H25R25 and CR revealed that there was a CC, AP, HM and ST interaction and this came about for the same reason as the four-way interaction term for this pairing in the earlier epoch.

A Priori Planned Comparisons

For these analyses, reliable outcomes are reported in the text. In the 300-500ms time-window a focused analysis (F3,Fz,F4) was conducted with the CR, H15R15 and H25R25 conditions (Figure 10, upper panel p142), since this region is of interest in terms of the pre-experiment hypotheses. There was a trend for a CC and ST interaction ($F(3.1,71.4) = 2.64; p=0.055$) and a main effect of condition ($F(1.8,41.4) = 37.65; p<0.001$). This was followed up with all possible paired contrasts. The CR and H15R15 comparison revealed a main effect of condition ($F(1,23) = 62.38; p<0.001$) and a CC by ST interaction ($F(1.5,35.3) = 5.41; p<0.05$), which came about because the hit condition was more positive-going, with the largest differences at Fz. The CR and H25R25 comparison revealed a main effect of condition ($F(1,23) = 66.52; p<0.001$), which also came about because the hit condition was more positive-going than the CR condition.

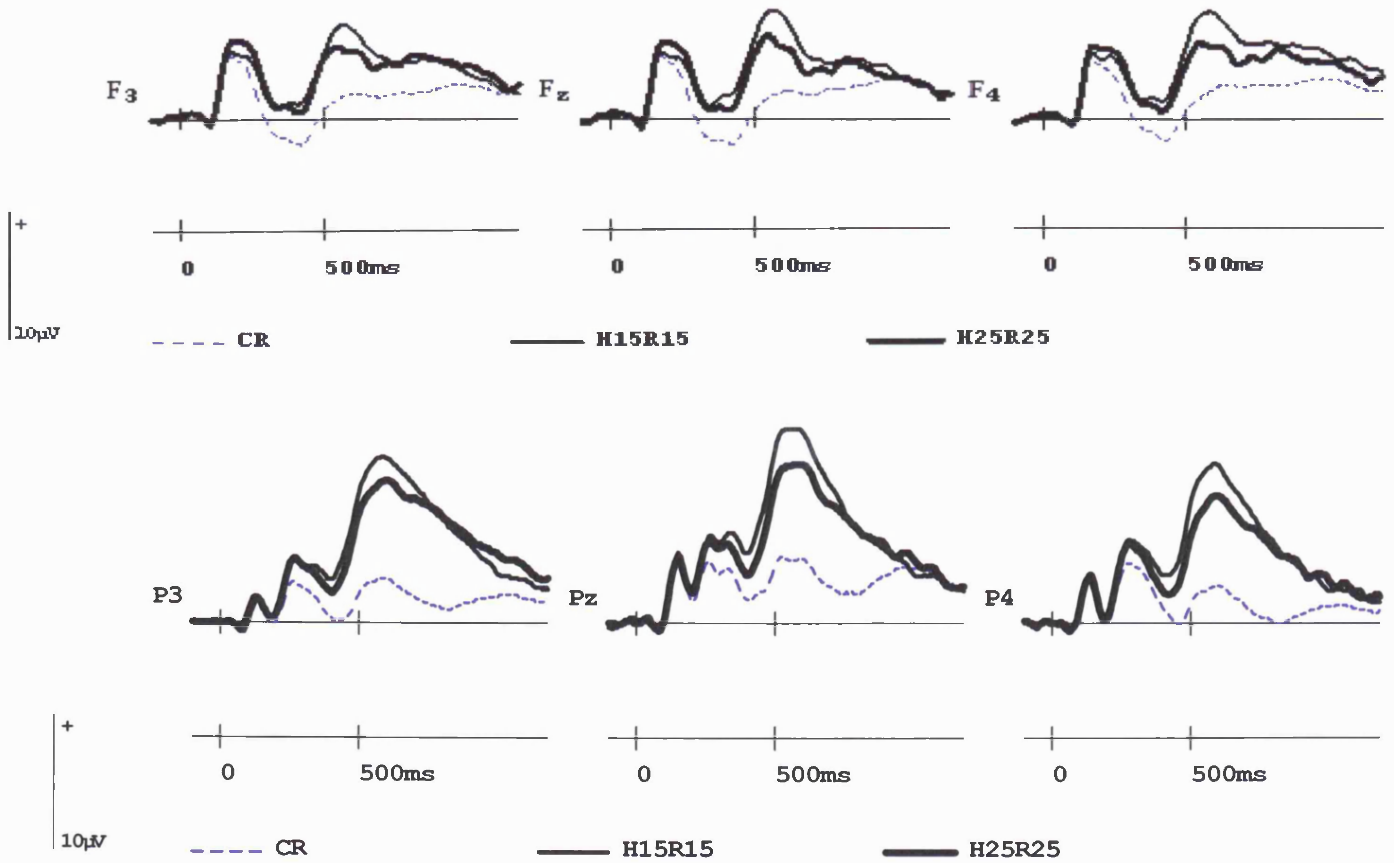

Figure 10. Grand average ERPs associated with correct JORs for lag 15 words and for lag 25 words at selected anterior and posterior electrodes (n=24).

The second planned comparisons were carried out in the 500-800ms time-window at posterior locations (P3,Pz,P4) (Figure 10, lower panel p142). The ANOVA comparing CR, H15R15 and H25R25 revealed a main effect of condition ($F(1.5,35.4) = 87.80; p<0.001$), which came about because the CR condition was the most negative-going. This finding was also true for the ANOVA comparing CR and H15R15 ($F(1,23) = 121.41; p<0.001$) and for that comparing CR and H25R25 ($F(1,23) = 80.84; p<0.001$).

Paired Global Hit Contrasts

These comprised follow-up contrasts for the H15R15 and H25R25 conditions only for each epoch. The ANOVA from 300-500ms revealed a trend for a CC, AP and ST interaction ($F(2.2,51.2) = 2.45; p=0.091$). Furthermore there was a CC and ST interaction ($F(1.1,26.4) = 5.63; p<0.05$), which came about because the H15R15 condition was more positive-going than H25R25, with the a reduction in the size of the differences with increasing distance from the midline. For the 500-800ms time-window, there was an interaction between CC, AP and ST ($F(2.1,48.2) = 3.55; p<0.05$) which came about because the H15R15 condition was more positive-going and largest over central and posterior superior locations, as Figure 9 (p136) shows. In this time-window there was also a CC and ST interaction ($F(1.2,28.4) = 12.22; p<0.01$) and a main effect of condition ($F(1,23) = 11.47; p<0.01$). In the 800-1100ms time-window, the ANOVA revealed a CC and HM interaction ($F(1,23) = 5.02; p<0.05$), which came about because the H15R15 condition was more positive-going over the right hemisphere, whereas the H25R25 condition was more positive-going over the left hemisphere.

A Priori Planned Comparisons

In the 300-500ms time-window a focused analysis (F3,Fz,F4) was conducted with the H15R15 and H25R25 conditions. While both hit conditions were more positive-going than CR (as described above), they did not differ reliably from each other. In the 500-800ms epoch, a second focused set of analyses was performed (P3,Pz,P4) where a main effect of condition was revealed ($F(1,23) = 12.29; p<0.01$), which came about because the H15R15 condition was again more positive-going than the H25R25 condition.

Additional Analyses

Based on inspection of the waveforms, an ANOVA was also conducted with these conditions over P3, Pz and P4 in the 300-500ms epoch. This revealed a main effect of condition ($F(1,23) = 5.62; p<0.05$) which came about because the ERPs associated with the H15R15 condition was more positive-going than the H25R25 condition.

Single Lag Global Analyses

Of principal interest for addressing the experiment hypothesis was whether any differences are present between the H25R25 condition, the H25 under-estimates (H25u) and the H25 over-estimates (H25o) (Figure 11, p146). The analysis strategy for this comparison followed that of the *old/new* effect analyses reported above (with the exception that the CR condition was not included here). Appendix 1 (p309-311) shows the scalp distributions of the *old/new* effects for these two categories (see Figures AP1-AP3), as well as the outcomes of the analyses of the *old/new* effects in each case (see tables AP1 and AP2). All reliable effects involving condition in these analyses are reported in the text. For the analysis involving all electrode sites of interest (specified above) for the H25R25, lag 25 under-estimate (H25u) and lag 25 over-estimate (H25o) conditions between 300-500ms, an interaction was revealed between CC, AP and ST ($F(4.2,67.4) = 2.94; p<0.05$). From 500-800ms, the highest order interaction was between CC, HM, and ST ($F(2.9,46.6) = 3.12; p<0.05$. There was also an interaction between CC, AP, and ST ($F(3.7,58.8) = 3.95; p<0.01$). The global analysis for 800-1100ms showed that the highest order interaction was between CC and AP ($F(2.2,35.2) = 4.19; p<0.05$). There was also a main effect of condition in this epoch ($F(1.6,25.3) = 9.05; p<0.01$).

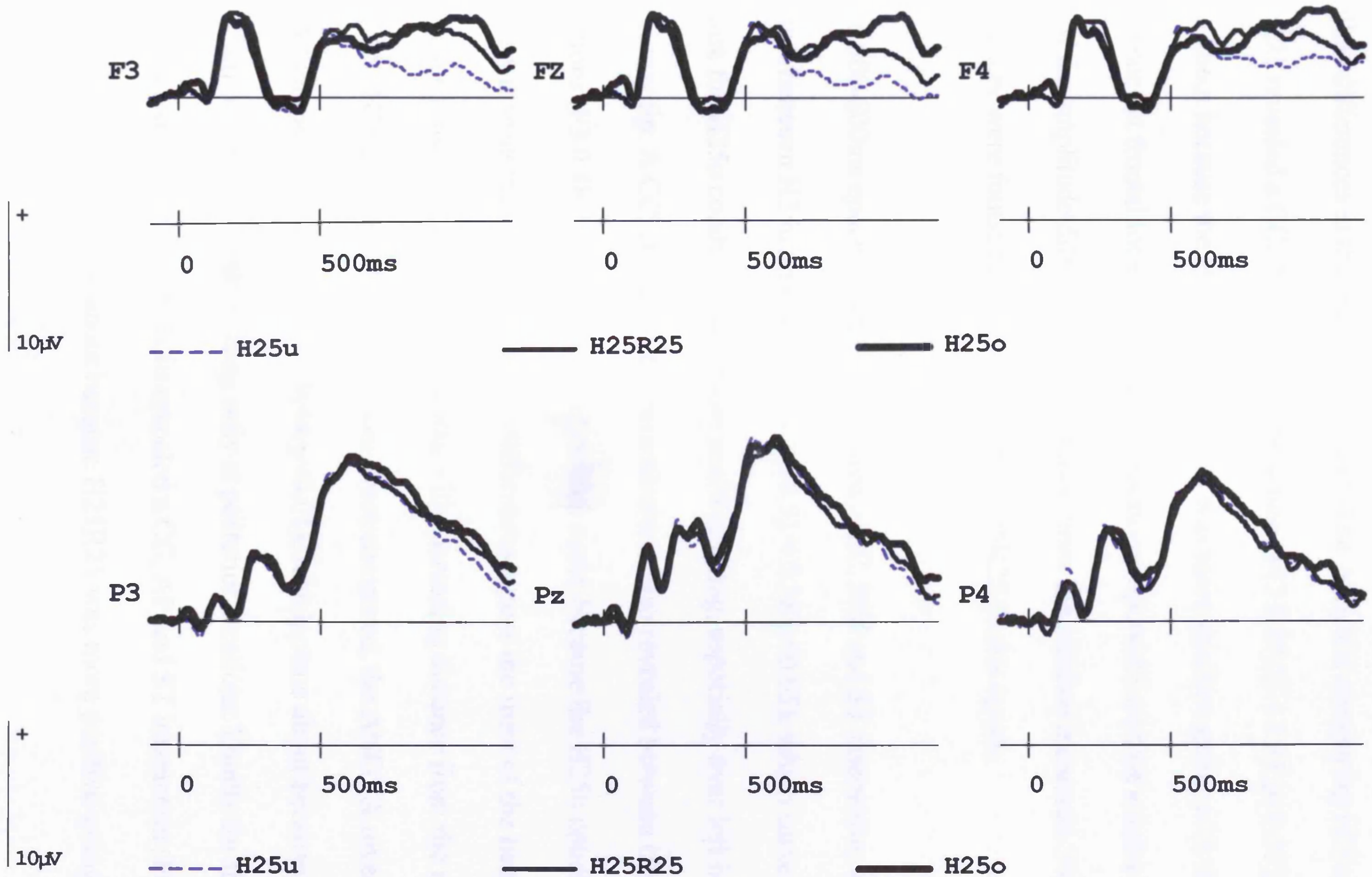

Figure 11. Grand average ERPs associated with correct JORs for lag 25 words and with under- and over-estimated lag judgements for words at this lag, at selected anterior and posterior electrodes (n=17).

Paired Global Single Lag Analyses

Here all possible paired contrasts were computed for lag 25 items that attracted either correct or incorrect lag judgements. All reliable effects involving condition in the ANOVAs are reported in the text. In the 300-500ms time-window, there was a CC, AP and ST interaction ($F(2.8,45.4) = 3.52; p<0.05$), for the contrast between H25u and H25o. This came about because the H25o condition was more positive-going, with the smallest differences at the back of the head. The ANOVA comparing H25o and H25R25 revealed a CC, AP and ST interaction ($F(2.3,37.2) = 3.37; p<0.05$), which came about because the H25R25 condition was more positive-going with the largest differences at frontal locations. Both interactions reported involved a reduction in the size of the amplitude differences as distance from the midline increased. No differences were found between H25u and H25R25 in this epoch.

In the 500-800ms epoch, ANOVA revealed a CC, HM and ST interaction for the contrast between H25u and H25o ($F(1.8,28.5) = 5.38; p<0.05$), which came about because the H25o condition was more positive going, especially over left hemisphere superior scalp. A CC, AP and ST interaction was also revealed between these conditions ($F3.0,48.7) = 4.26; p<0.01$), which came because the H25o condition was more positive-going, with the largest differences across the front of the head. Both interactions involved a reduction in size with increasing distance from the midline. When the H25u and H25R25 conditions were compared, the ANOVA revealed a CC and AP interaction ($F(1.3,20.8) = 9.44; p<0.01$), which came about because the H25u condition was more positive-going only at posterior locations. Finally for this epoch, a comparison of H25R25 and H25o revealed a CC, AP and ST interaction ($F(2.1,33.4) = 5.88; p<0.01$). This came about because H25R25 was more positive-going at frontal and central locations, with a general reduction in size with increasing distance from the midline.

In the 800-1100ms epoch, there was a CC and AP interaction between H25u and H25o ($F(1.3,20.2) = 7.95; p<0.01$), which came about because the H25o condition was more positive-going, with the largest differences at frontal locations. There was also a main effect of condition between H25u and H25o ($F(1,16) = 12.80; p<0.01$), which came about because the H25o condition was more positive-going. The ANOVA comparing H25u and H25R25 revealed a CC and HM condition ($F(1,16) = 4.79; p<0.05$), which came about because the H25R25 condition was more positive-going, with larger differences over the left hemisphere than over the right. A CC and AP condition was also revealed ($F(1.2,19.9) = 6.34; p<0.05$) which came about because the H25R25 condition was more positive-going, with a reduction in size with distance from the front of the head. Finally, the ANOVA comparing H25R25 and H25o revealed a CC, AP and ST interaction ($F(2.1,34.3) = 4.05; p<0.05$), which came about because the H25o condition was more positive-going, with the smallest differences at posterior sites. Differences between the conditions decreased in size with increasing distance from the midline. Mean ERP amplitudes in this time-window increased with rising JOR (Figure 11, p146).

In summary, there were differences in all epochs concerning the under- and over-estimate categories, but not in a way that is consistent with the psychological theories set out in the introduction, since the over-estimate conditions were somewhat larger in amplitude in most cases. The contrasts between correct lag judgements and over-estimates however showed that the correct lag judgements elicited greater ERP amplitudes than over-estimates in the 300-500ms and the 500-800ms epochs.

A Priori Planned Comparisons

No reliable effects involving condition were obtained in the frontal analysis in the 300-500ms epoch or the posterior analysis in the 500-800ms epoch (Figure 11, p146).

Global Over-estimate Comparison

Also of interest for addressing the experiment hypothesis was whether any differences are present between the H15R15 condition and the H15 over-estimates (H15o). All 24 participants contributed sufficient trials to these categories (Figure 12, p150). The analysis strategy for this comparison followed that of the *old/new* effect analyses reported above (with the exception that the CR condition was not included here). In the 300-500ms time-window, no differences were found when directly comparing these two conditions using a global ANOVA. In the 500-800ms epoch, the global ANOVA revealed that there was a trend for a main effect of condition ($F(1,23) = 4.13; p<0.055$), which came about because the H15R15 condition was of moderately larger amplitude than the H15o condition. In the 800-1100ms epoch, the global ANOVA revealed no differences across the two conditions.

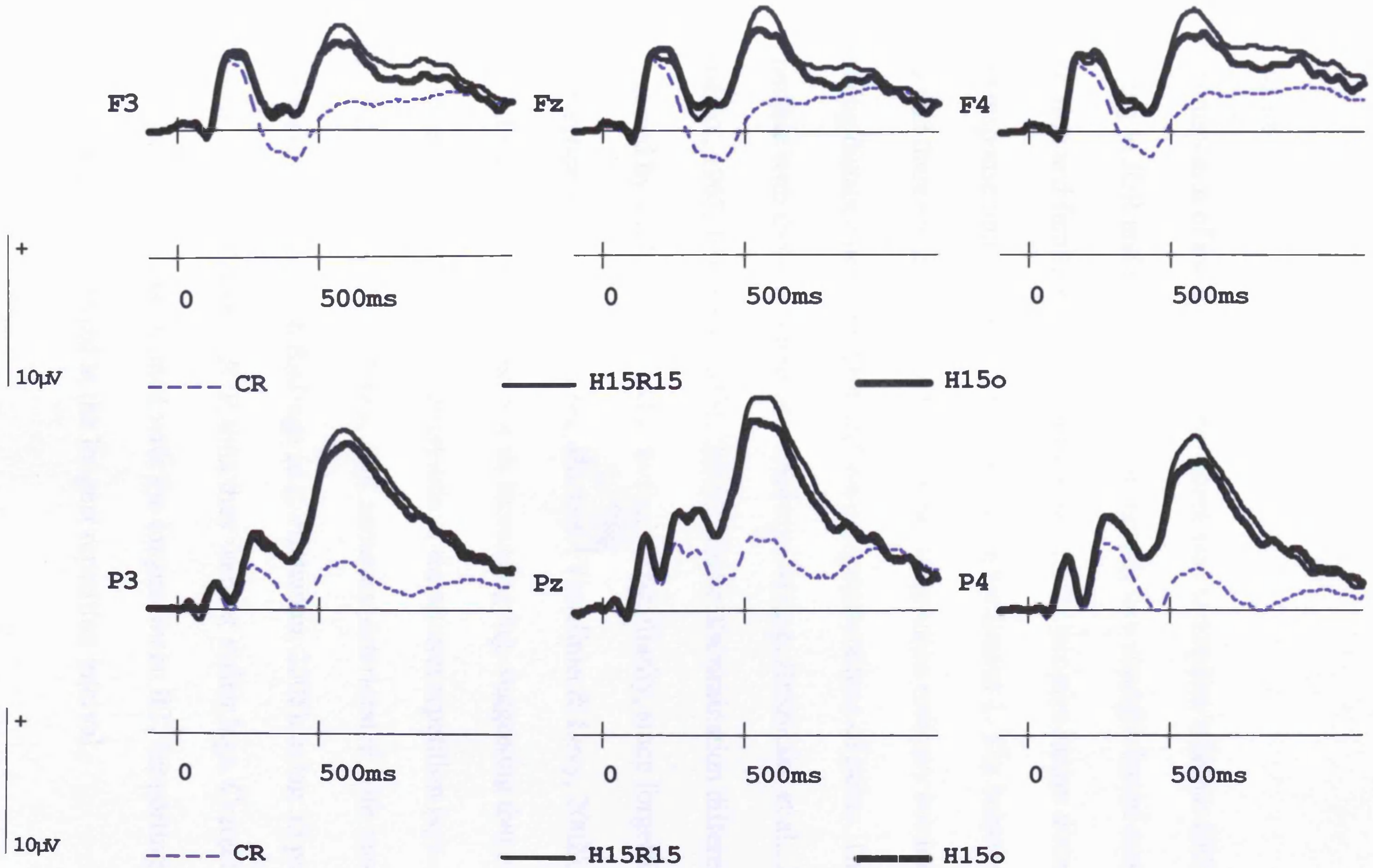

Figure 12. Grand average ERPs associated with correct lag judgements and over-estimated lag judgements for lag 15 words at selected anterior and posterior electrodes (n=24).

A Priori Planned Comparison

No effects were found in the 300-500ms time-window in the outcome of the planned comparisons (F3,Fz,F4). Finally, a focused analysis was conducted during the 500-800ms time-window at the back (P3,Pz,P4) of the head. The posterior ANOVA revealed an effect of condition ($F(1,23) = 4.98; p<0.05$), which came about because the H15R15 condition was more positive-going than the H15o condition.

Discussion

The primary aim of the current experiment was to explore whether ERPs vary according to JOR and if so, whether this occurs in a strength-based manner in terms of recollection and familiarity. An attempt was made to make longer distances between the lag response options in comparison with Experiment 1. The behavioural data shows that there are decrements in *old/new* recognition memory accuracy with increasing distance between first and second presentations of items. These results are comparable with those in some previous reports (e.g. Brozinsky et al., 2005; Hinrichs & Buschke, 1968; Hintzman 2001; 2003). These discrimination differences are likely to be carried by a reliance on and a decline in familiarity, since forgetting rates for this memory process are faster than recollection (Yonelinas & Levy, 2002). There was some evidence that RT increased with increasing lag, suggesting that *old/new* discrimination was easier for participants at the shorter repetition lags. When the data were separated according to JORs, JOR accuracy deteriorated with increasing lag in line with previous research findings (e.g. Hintzman, 2005): at lag 35 participants were less likely to make a correct JOR than they were at earlier lags. Correct lag 35 judgements were also associated with the longest mean RT, supporting the suggestion that task difficulty increased at the longest repetition interval.

ERP Old/New Effects

The ERP *old/new* effects are consistent with previous research in terms of their changes over time, and are comparable with those in Experiment 1 (Figure 4, p116). The ERPs elicited by correct rejections were the most negative-going condition in all three selected time regions in comparison with those elicited by hits. The scalp distributions of these ERP *old/new* effects correspond largely with those previously reported in studies of episodic retrieval (e.g. Mecklinger, 2000; Nessler et al., 2005; Rugg et al., 1998). These comprised a broadly distributed positivity in the 300-500ms epoch, a more posterior distribution in the 500-800ms time-window and a lateralised anterior positivity in the 800-1100ms epoch. There is some evidence from the outcomes of the analyses in this experiment to suggest that the sizes of the *old/new* effects diminished with increasing lag. This kind of repetition effect has been reported in some previous studies but not in others (e.g. Curran & Friedman, 2004; Rugg & Nagy, 1989; Wolk, et al., 2006). This shall be discussed further in the General Discussion (Chapter 7, pages 256-258).

The main reason for conducting this experiment was to determine whether known ERP correlates of memory processes distinguish between different recency judgements. Figure 10 (p142) shows that very small anterior and posterior differences in activity make a distinction between lag 15 and 25 hits which were associated with correct JORs in the 300-500ms time-window. This justified focused analyses between these conditions in this early time-window. *Old/new* effects were found at the front of the head as well as at the back in this epoch. On the basis of previous research it is likely that the anterior effect is distinct from the posterior activity, and that the anterior effect is related to familiarity, whereas the posterior activity may be related to implicit memory (see Azimian-Faridani & Wilding, 2006; Rugg et al., 1998).

The link between the anterior effect in this epoch and familiarity has been described extensively in Chapter 2 (see pages 78-85). The link between posteriorly related activity and implicit memory operations is somewhat weaker, with the suggestion having been made initially on the basis of the finding that the effect is in fact a repetition effect: it indexes the *old/new* status of test items but does not vary with the accuracy of memory judgments. Demonstrations of this insensitivity to response accuracy, and the fact that anterior and posterior memory modulations in the 300-500ms epoch can be dissociated, can be seen in Rugg et al. (1998) and in the scalp maps provided by Azimian-Faridani & Wilding (2006). Stronger evidence for a link between this early posterior effect and implicit memory would arise from changes in this effect in combination with a behavioural index of implicit memory. Priming manipulations are perhaps the most obvious candidate to consider here, because if the effect is in fact an index of implicit memory operations, then either the time course or the size of the effect should vary with reaction times. The key point here however, is that irrespective of the accuracy of the implicit memory account of the posterior effect, it is functionally dissociable from the anterior effect in this epoch (since the anterior effect is sensitive to response accuracy).

There was no statistical evidence in this study to suggest that the anterior *old/new* effect differed across lags 15 and 25 for words that were associated with correct JORs. There was however, statistical evidence to show that a parietal *old/new* effect was elicited in this task and that it diminished with increasing lag. The outcomes of the analyses demonstrated that correctly rejected *new* items were the most negative-going condition in 500-800ms epoch and that hits associated with correct JORs at lag 15 were more positive-going at posterior electrodes than their lag 25 equivalent. The scalp maps indicate a left lateralisation for this *old/new* ERP effect (Figure 9, p136), a pattern identified in previous recognition studies (e.g. Wilding, 2000; Wilding & Rugg, 1996). This was not supported by the statistical analysis for lag 15 hits, but there was evidence for lateralization at lag 25 which was provided by an interaction involving hemisphere as well as condition. These findings provide support for the notion that recollection differed across lag. The 800-1100ms ERP *old/new* effects revealed again that the hit conditions were more positive-going than the CR condition, with the greatest differences at posterior electrode locations. There was also evidence to suggest that the H15R15 condition was more positive-going over the left hemisphere, whereas the opposite was true for the H25R25 category. Perhaps the posterior activity in this time-window is a continuation of the same effect that differentiates these classes of ERPs from 500-800ms.

One possible reason for the lack of a difference in the magnitude of the mid-frontal ERP *old/new* effect across lags 15 and 25 is that the effect did differ across these lags but not sufficiently so to make this a statistically reliable difference. Perhaps if more trials or participants contributed to the data set then this would have come out in the analysis. It may also be the case that familiarity *does not* diminish over these short distances in time (a difference of only ten intervening items) and if so it would suggest that this memory process would be an unlikely contributor for distance information in these task types. The finding that the parietal *old/new* effect did differ in magnitude across these lags lends support against this second possibility, since familiarity is said to have a faster level of deterioration than recollection (Yonelinas & Levy, 2002).

As was outlined in the introduction to this experiment, a key contrast was between under-estimates and over-estimates for a single lag. If the ERP activity associated with these conditions was found to vary systematically with JOR in the early and middle time-windows, this could indicate changes in memory strength and in turn would suggest that distance information is utilised for making these types of memory judgements. Although confidence and error related processing could also account for ERP activity associated with these kinds of memory judgements, this interpretation is unlikely in that it is difficult to conceive of a confidence or error related effect that will vary in a graded way, according to whether shorter or longer lag judgements (relative to a correct judgment) are made. Presumably many incorrect lag judgements will be accompanied by high confidence, so an ERP index of confidence would be unlikely to vary in the same systematic way as an ERP index of the strength of familiarity and recollection. Further discussion of these issues is presented in the General Discussion (Chapter 7, pages 263-264).

Single Lag Comparisons

The main ERP activity of interest is that which differentiates between correct and incorrect recency judgments, and also activity that differentiates between shorter and longer judgements of recency. For lag 25 items identified correctly as being *old*, the ERPs associated with under-estimates, over-estimates and correct lag judgements were compared across the three selected time-windows.

The lag 25 ERPs are illustrated in Figure 11 (p146), where the ERP waveforms are shown for H25R25, H25o and H25u. In the 300-500ms time-window, there was no evidence to suggest that distance based information was being utilised for JORs in the way outlined in the introduction. In the 500-800ms time-window, there was mixed evidence to suggest that recollection was utilised for JORs in a strength-based manner. In the global paired hit analysis, under-estimated lag 25 hits were associated with greater posterior positivity than lag 25 hits attracting correct JORs, although this was not supported in the follow up analysis. However, other findings (e.g. that over-estimated lag judgements had greater positivity over the left hemisphere than under-estimates) do not fit with the idea that posterior-related activity predicted lag judgements. Finally, in the late time-window, differences between the conditions were largest over the front of the head. The level of positive-going activity increased as JOR increased at lag 25 (see Figure 13, p157). This is an interesting finding, because it could suggest that executive memory processes associated with late frontal activity also contribute to JORs in a way that parallels distance theory. This pattern of activity was however, not seen in Experiment 1 for lag 15 items. One possible reason for this is task structure, whereas having only a single lag in Experiment 1, whilst providing 3 possible response options confused participants, and that this led to variance in the late time-window, that was not related to memory related processing. Conducting another ERP experiment where there is a range of actual lags may shed light on these issues (see also the General Discussion, Chapter 7).

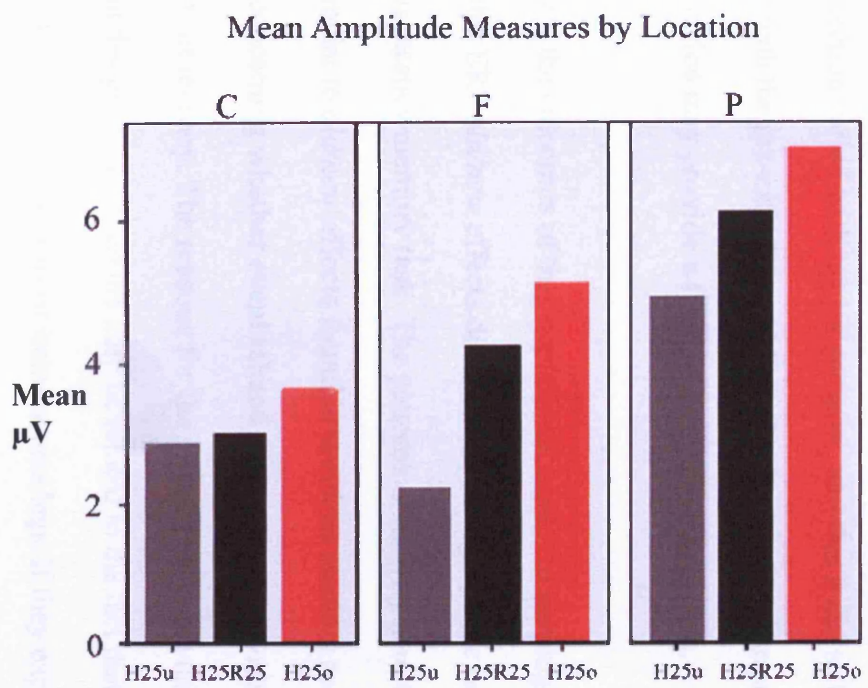

Figure 13. 800-1100ms. Mean ERP amplitude measures are collapsed across central (C) (T7,C5,C3,C4,C6,T8), frontal (F)(F7,F5,F3,F4,F6,F8) and posterior (P)(P7,P5,P3,P4,P6,P8) locations. The bars represent under-estimated (grey), correct (black) and over-estimated (red) lag judgements for words presented at lag 25. This figure demonstrates that amplitudes increase as a function of JOR increase (n=17).

There were sufficient trials to permit a statistical comparison of lag 15 hits associated with over-estimated and correct lag judgements. There were no effects of interest in the 300-500 or 800-1100ms time-windows involving these conditions. In the 500-800ms epoch there was some evidence to suggest that the hits attracting an over-estimated lag judgment were less positive-going than those associated with correct JORs. This fits with the idea that recollection processes are used in making JORs in a strength-based manner, since there is evidence here that the ERP effect associated with recollection varied with lag judgements, and that it did so in a direction consistent with the pre-experimental hypothesis. These findings support the notion that recollection may provide a form of distance information.

In summary, the outcomes of this experiment have – in keeping with Experiment 1, revealed that ERP *old/new* effects differ across three separate time-windows in a continuous recency memory task. The patterns of activity here were found to be broadly similar to *old/new* effects found in previous memory research. There is mixed evidence concerning whether event related potentials vary systematically with judgements of recency. The reasons for the mixed results are unclear, but in this experiment design the null results may be related to the fact that participants were not told of the differing proportions of items across lags. If they expected an equal number of items to be re-presented at each lag, it could have affected the JORs they gave to the stimuli. When participants have an expectation that there is an equal number of words presented at each lag (when in fact there is not), then on at least some occasions they may distribute their responses in line with that expectation rather than relying on mnemonic information (for a discussion, see Postma, 1999).

Another possible reason for the lack of differences in the 300-500ms time-window across lag judgements is that the memory process of familiarity is not utilised for making recency judgements in tasks of this type. This null result adds to that reported in the previous experiment, and these findings may give some weight to the notion that familiarity-related strength accounts of recency memory are insufficient under these circumstances. The findings across the first two experiments in this thesis give some support for the idea that recollection can be utilised for recency judgements, however there is still a possibility that some of the activity in the 500-800ms epoch may be related to lack of confidence related processing. One argument against the confidence viewpoint can be based on the findings of Hintzman (2003) who demonstrated that confidence ratings are less sensitive to lag than are judgements of recency, in that iso-JOR curves drop off much more rapidly than iso-confidence curves as a function of lag. In terms of the current findings, this means it is more likely that the ERP activity that varies in accordance with lag is more likely to be based on recency-related processing. Future studies might be important in ascertaining whether this is indeed the case.

If this is a reasonable account, then ERPs separated according to response accuracy may not provide a clear separation between ERPs that are in fact associated, to different degrees, with signals indexing mnemonic information that supports recency judgments. Conducting an experiment where there are equal proportions repeated at every lag is one way of addressing this concern. This was done in Experiment 3, which is described below. Further comment on the findings in this experiment can be found in the General Discussion (Chapter 7).

CHAPTER 5 – EXPERIMENT 3

Introduction

At issue in this experiment is the ways in which two classes of retrieval process, in isolation or in combination, support judgments for when events occurred. This experiment was designed to address the same issues that were outlined in Experiments 1 and 2, using a design that may not be prone to some of the problems that were identified in the discussions of Experiments 1 & 2. In Experiment 1, the data permit the claim that electrical activity associated with *old/new* judgements in typical recognition tasks is also present in continuous recency memory tasks. Experiment 1 provided little evidence that this activity varied across JORs, however. Experiment 2 provided a demonstration that the *old/new* effects decreased in magnitude with increasing lag, but the evidence in terms of these effects varying meaningfully with JOR was mixed.

In the third ERP experiment, an attempt was made to decrease the complexity of the task, by reducing the number of lags from four to three. The longest lag (35) included in Experiment 2 was not used in Experiment 3, since participants were least accurate for this lag in terms of their JORs. Most importantly in Experiment 3, the proportion of repetitions was equal across the three lags that were used. The idea was to improve on the design of Experiment 2, in order to have proportions of items in line with the likely expectations of participants.

The three repetition lags used in this experiment were 5, 15 and 25 and these were also the three JOR response options. This meant that the spacing across the JOR options was at least 10 intervening items and a maximum of 20, which is wider than in Experiment 1. The rationale for these changes to the method was that they might lead to a cleaner separation between correct responses, under-estimates and over-estimates by virtue of reducing the possibility that lag judgements will be based upon task expectations, and by incorporating a reasonable gap between items presented after different lags.

Method

The method was different from that for Experiment 1 in the following ways.

Participants

There were forty-two participants (12 male) aged between 18 and 24 years (mean age = 20), and they were paid £7.50/hr. The data sets from 36 participants (9 males) were included in the initial analyses described below. Three participants did not complete the entire experiment due to technical problems, and for the remaining 3, there were insufficient trials in critical conditions after artefact rejection (see below), in part because of low levels of correct lag judgments.

Materials and Design

The stimuli were 235 low frequency words. Each complete task list comprised two blocks. Each block contained 109 words, 90 of which were repeated, with an equal number (30) after 5, 15 and 25 intervening words. The order of re-presentation of words at each lag was determined pseudo-randomly for each block. The 19 words in each block that were not repeated were presented towards the end of each block, ensuring that words repeated at each lag were distributed relatively evenly throughout blocks. Five further lists were created from the initial list, such that across lists all items were encountered at each lag, and each block within each list occurred at the start of the list. A further 17 words, 13 of which were repeated, were used in an initial practice block. In total, participants saw 428 stimuli (199 per block, 30 in the practice phase).

Procedure

Each experiment block began with a 'ready' signal, lasting 5000ms. Each trial began with a fixation mark (*). This was visible for 500ms and was followed by a blank screen (100ms). Words were then presented for 300ms, followed by a blank screen during which participants indicated whether the word was *old* or *new* via key-press using left and right thumbs. The screen was blanked for 1000ms after the response and then the words 'How Far Back?' were shown. Participants were instructed that, if they had indicated a word to be *new*, then pressing any key would initiate the next trial. For words judged to be *old*, they were instructed to indicate whether the word had been re-presented after 5, 15 or 25 intervening words.

The three JOR options were made via three key buttons on one hand, with lag 5, 15 and 25 judgments made with index, middle and fourth fingers, respectively. This response was followed by a 500ms blank screen before the next trial commenced. An equal number of participants completed each task list, and an equal number completed the experiment for the four possible combinations of left/right hand responses for the *old/new* judgment and the second response. There was a break of approximately five minutes between blocks. Participants were asked to balance speed and accuracy equally, and each test block took on average 18 minutes to complete.

Behavioural Results

Table 7 (p164) shows the probabilities of correct *old/new* judgments to *new* words and to *old* words separated according to lag. Also shown in the table are the reaction times for these classes of response. Discrimination (p[hit] – p[false alarm]) was reliably greater than chance at each lag ($t(35) > 30.00; p<0.001$ in each case). A one-way ANOVA contrasting these three discrimination measures revealed a main effect ($F(1.77,62.10) = 8.56; p<0.01$) and follow-up paired t-tests revealed that *old/new* discrimination deteriorated with increasing lag ($t(35) > 2.00; p<0.05$, for each contrast). A one-way ANOVA on the RT categories for which the means are shown in Table 7 also revealed reliable differences across the categories ($F(1.86,65.13) = 7.03; p<.001$). While not differing reliably from each other, RTs for all classes of hit were slower than RTs for correct rejections ($t(35) > 3.00; p<.01$ in each case).

Table 8 (p164) shows the probabilities of each lag judgment at each lag for words judged correctly to be *old*. The bold values on the diagonal are the probabilities of a correct lag judgment. For each lag, the likelihood of a correct lag judgment was above chance (0.33) ($t(35) > 7.00; p<.001$). Paired contrasts between the likelihoods of a correct response at each lag revealed only that correct lag 15 judgments were made more often than correct lag 25 judgments ($t(35) = 3.47; p<.01$), although the advantage for lag 5 over lag 25 judgments approached significance ($p = 0.06$). The mean reaction times for items attracting correct lag judgments were 924, 923 and 946ms for lags 5, 15 and 25, respectively. A one-way ANOVA on these RTs revealed no significant differences according to lag.

Table 7. Probabilities of correct old and new judgments and associated reaction times (RT), separated according to lag (n=36) §

	New	Lag5	Lag15	Lag25
p(correct)	0.95 (0.05)	0.88 (0.10)	0.85 (0.12)	0.83 (0.13)
RT(ms)	841 (204)	961 (242)	925 (211)	906 (203)

§ Standard deviations are in brackets

Table 8. Probabilities of each lag judgment (lag5, 15, 25) conditional on a correct old judgment and separated according to lag (n=36) §

	Actual Lag		
	Lag5	Lag15	Lag25
Judgment			
Lag5	**0.57 (.15)**	0.14 (.09)	0.06 (.04)
Lag15	0.36 (.13)	**0.60 (.11)**	0.45 (.12)
Lag25	0.07 (.05)	0.26 (.12)	**0.48 (.14)**

§ Correct lag judgments are in bold, standard deviations are in brackets

ERP Results

ERP Analysis Strategy

The analysis strategy was the same as that outlined in Experiment 1. Figures 14-16 support the decision to analyse the data within three separate time-windows. Figure 15 (p166) shows that the scalp distributions of the ERP *old/new* effects in the 500-800ms epoch differ primarily in magnitude, with the effects decreasing in magnitude with increasing lag. For the earlier (300-500ms) epoch (Figure 14, p165), the maxima of the scalp distributions of the ERP *old/new* effects move posteriorly with increasing lag. The reason for this is the continuing reduction of the ERP *old/new* effects at anterior sites with increasing lag, with a lesser reduction at posterior scalp locations. In the 800-1100ms epoch (Figure 16, p166), the scalp maps reveal that the activity begins to subside at posterior electrodes, with a right lateralised anterior effect beginning to emerge. Figure 17 (p167) shows the ERP *old/new* effects for items attracting correct lag judgments (separated according to lag) for a subset of the sites encompassing the spatial extent of the electrodes included in the analyses described below. The mean number of trials (range in brackets) contributing to the correct rejection ERP response category was 179 (121-204). The corresponding values for correct lag 5, 15 and 25 judgments were 26 (12-30), 28 (12-41) and 21 (12-37), respectively.

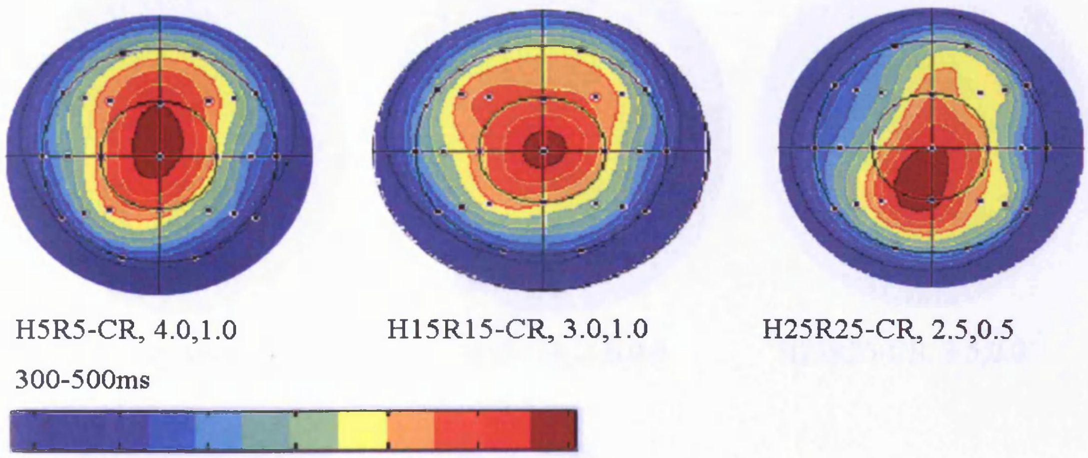

Figure 14. Topographic maps showing the scalp distributions of the neural activity associated with correct lag judgments for the 300-500ms time-window. The maps were calculated on differences scores obtained by subtracting mean amplitudes within each time-window for correct rejections from amplitudes associated with correct lag 5, 15 and 25 judgments, respectively (n=36).

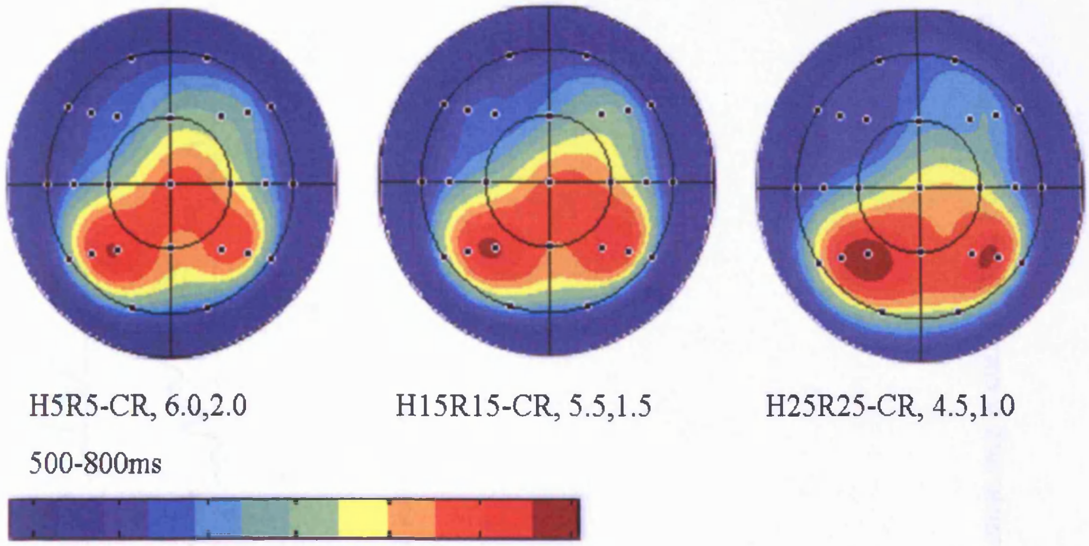

Figure 15. Topographic maps showing the scalp distributions of the neural activity associated with correct lag judgments for the 500-800ms time-window. The maps were calculated on differences scores obtained by subtracting mean amplitudes within each time-window for correct rejections from amplitudes associated with correct lag 5, 15 and 25 judgments, respectively (n=36).

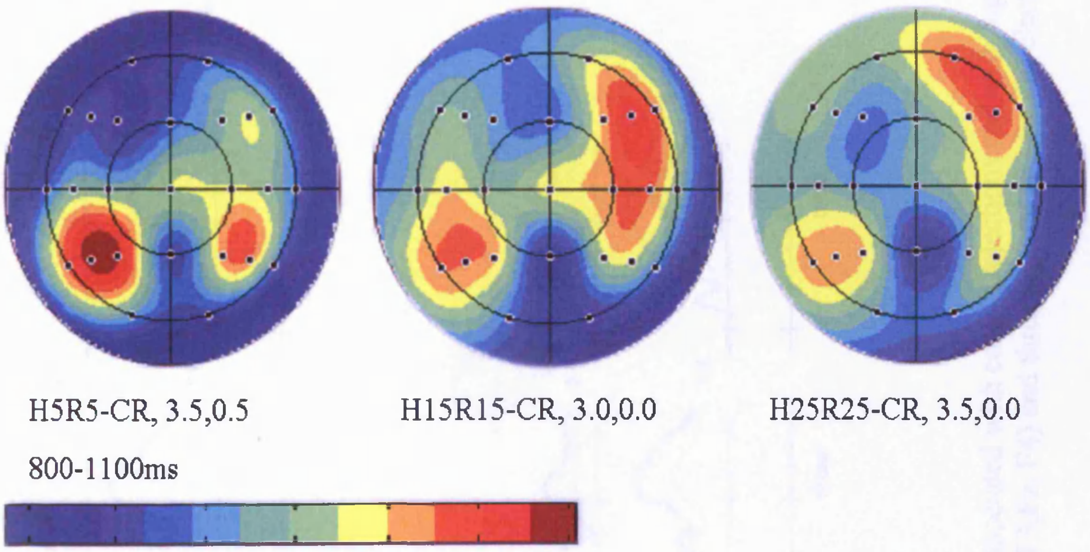

Figure 16. Topographic maps showing the scalp distributions of the neural activity associated with correct lag judgments for the 800-1100ms time-window. The maps were calculated on differences scores obtained by subtracting mean amplitudes within each time-window for correct rejections from amplitudes associated with correct lag 5, 15 and 25 judgments, respectively (n=36).

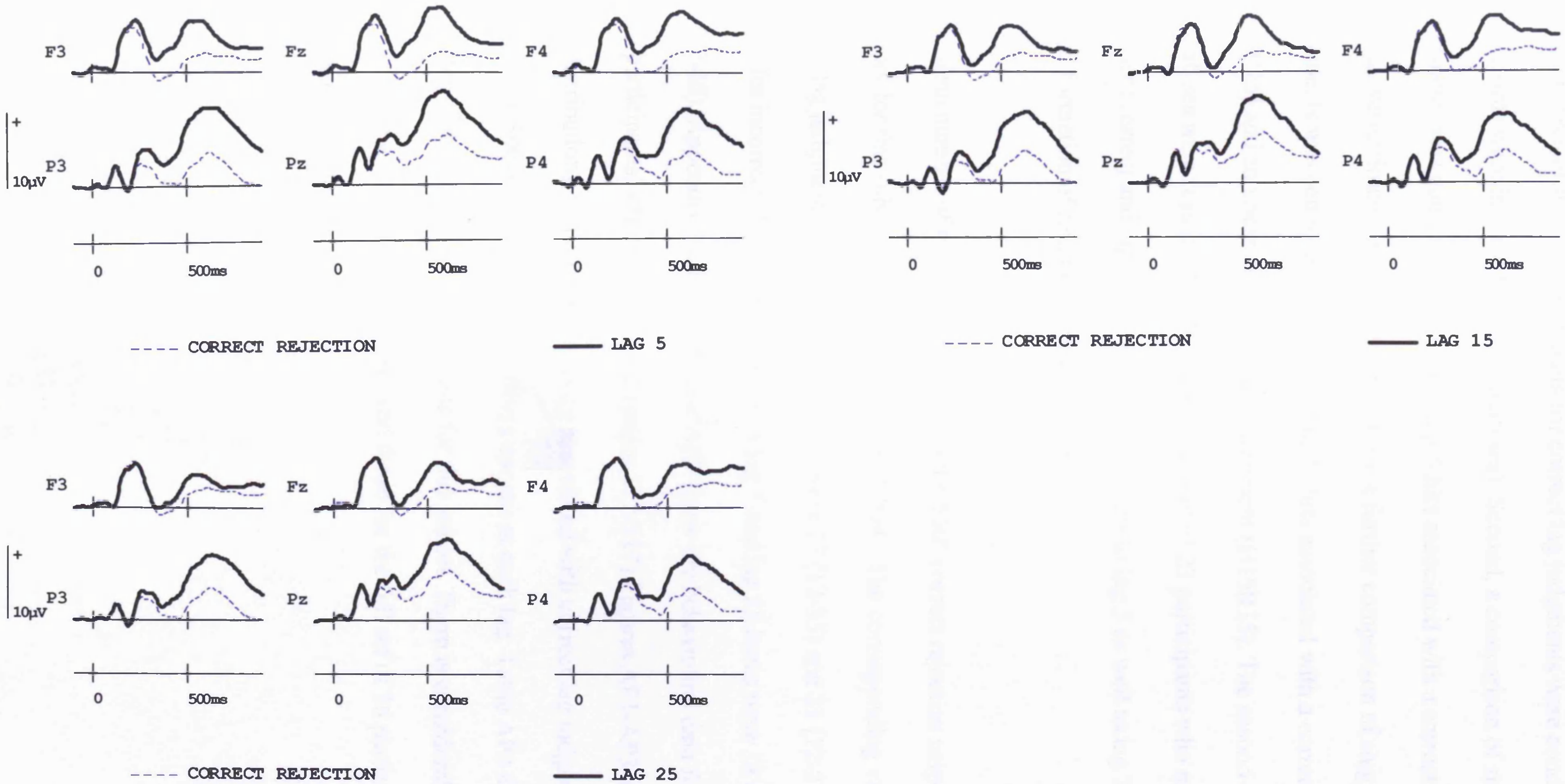

Figure 17. Grand Average ERPs associated with correct rejections and with lag 5, 15 and 25 items attracting accurate JORs. For each lag, the ERPs are shown for three frontal (F3,Fz, F4) and three parietal (P3,Pz,P6) electrodes (n=36).

First, analyses of the *old/new* effects for correct lag judgments were conducted (36 participants were included in these analyses). Second, a comparison of single lag judgements was conducted, involving lag 5 hits associated with a correct JOR (H5R5) and an over-estimated JOR (H5R15). Third, a further comparison of single lag judgements was conducted, involving lag 25 hits associated with a correct JOR (H25R25) and an under-estimated lag judgement (H15R15). The second and third set of analyses were restricted to data from a subset of 23 participants who made sufficient correct and lag 15 (incorrect) responses to lag 5 as well as lag 25 items to permit formation of reliable averaged ERPs.

The mean number of trials contributing to the ERP correct rejection response category for this subset was 190 (range = 154-204). The corresponding values for correct lag judgments to lag 5 and 25 items were 27 (12-35) and 23 (12-37), while the values for incorrect (lag 15) judgments to lag 5 and lag 25 items were 18 (12-35) and 22 (12-40). Appendix 2 tables AP1 and AP2 show the behavioural data for this subset of 23 participants, while Appendix 2 (pages 312-317) Figures AP1-AP3 show the scalp distributions of the neural activity associated with correct lag judgments for the 300-500ms, 500-800ms and 800-1100ms epochs at each lag. Table AP3 shows the outcomes of the ERP *old/new* contrasts for this subset. There is considerable overlap between the outcomes for this subset and those for the full set of 36 participants that are shown in Table 9 (p169).

Table 9. The outcomes of the global ANOVA Performed for the Mean Amplitude Measures (n=36) §

	300-500ms		500-800ms		800-1100ms	
	df	F	df	F	df	F
cc	2.5,88.5	29.67***	2.9,101.1	39.52***	2.9,102.3	12.96***
cc x ap	3.2,113.6	3.84*	3.4,119.2	9.62***	-	-
cc x hm	-	-	-	-	-	-
cc x st	3.1,109.8	17.85***	3.2,111.2	22.41***	3.0,105.7	5.98***
cc x ap x hm	-	-	-	-	3.9,136.8	4.25**
cc x ap x st	-	-	7.6,264.9	5.02***	-	-
cc x hm x st	3.3,116.4	.55*	3.8,134.2	5.01**	3.5,120.8	4.20**

§ The factors were Condition (cc), Hemisphere (hm), Anterior-Posterior Dimension (ap) and Site (st). Conditions = H5R5, H15R15, H25R25, CR.
*p<0.05
**p<0.01
***p<0.001 (epsilon corrected)

Global Old/new Analyses

The outcomes of the global analysis involving the categories CR, H5R5, H15R15 and H25R25 for the 300-500ms, 500-800ms and the 800-1100ms epochs are shown in Table 9 (p169). The table shows that, in all cases, there were interactions involving condition and scalp locations, and in light of this, follow-up paired contrasts were conducted for all possible pairs for each epoch.

Paired Global Old/new Analyses

As in previous chapters, only the highest order interaction terms are reported in the text. In the 300-500ms time-window, a global ANOVA was conducted to assess whether there were differences between CR and H5R5 (see Table 10, p172). For this analysis there was a CC, AP and ST interaction, which came about because the H5R5 condition was more positive-going, with the largest differences over frontal scalp, with differences in amplitude diminishing with increasing distance from the midline, as Figure 14 (p165) shows. There was also an interaction involving the CC, AP and HM categories, which came about because the positive-going differences are moderately larger over the right hemisphere at frontal and central locations. In the same epoch, the comparison between CR and H15R15 revealed a CC, HM and ST interaction, which came about because the hit condition was more positive-going, with larger differences over the left hemisphere and a reduction in the size of the differences with increasing distance from the midline. This ANOVA also revealed a CC, AP and ST interaction, which came about because there were larger differences at the front of the head, in addition to the reasons mentioned for the previous interaction. Finally in this epoch, in the CR and H25R25 comparison, a CC, HM and ST interaction was revealed because the hit condition was more positive-going, with differences that were largest over left inferior and mid-lateral sites. A CC, AP and ST interaction was also found, because differences are larger over posterior sites.

Table 10. The outcomes of the global paired analyses (F-values and significance levels) of the ERP old/new effects for words attracting correct old/new and correct lag judgements for the 3 selected time-windows (n=36)§

Epoch	300-500ms			500-800ms			800-1100ms		
Lag	5	15	25	5	15	25	5	15	25
CC	64.80***	77.98***	20.89***	83.93***	71.14***	38.33***	29.91***	20.54***	23.58***
CCxAP	5.37*	4.26*	-	15.87***	15.80***	18.30***	-	-	-
CCxHM	3.55•	3.15•	-	-	-	-	-	-	-
CCxST	46.62***	33.03***	26.69***	45.26***	37.67***	32.54	4.34*	-	-
CCxAPxHM	3.85*	-	4.32*	5.09*	-	-	7.47**	6.56**	6.18**
CCxAPxST	4.19*	2.97*	2.90*	8.22***	7.16***	12.31***	-	-	3.16*
CCxHMxST	-	3.89*	4.88*	-	5.43*	16.88***	-	5.79*	13.22***

§ The factors were Condition (cc), Hemisphere (hm), Anterior-Posterior Dimension (ap) and Site (st). Conditions = H5R5vsCR; H15R15vsCR; H25R25vsCR.
*p<0.05
**p<0.01
***p<0.001 (epsilon corrected)
•trend

In the 500-800ms time-window, the ANOVA for the H5R5 versus CR contrast also revealed a CC, AP and ST interaction, which came about because the H5R5 condition was more positive-going, with the largest differences over the back of the head at the midline (Figure 15, p166). There was also a CC, AP and HM interaction, because additionally the differences were largest over the left hemisphere at posterior locations, whereas there was less marked lateralisation at the front of the head. In the contrast between H15R15 and CR, the ANOVA revealed a CC, HM and ST interaction. This came about because the H15R15 condition was more positive-going than CR, with the differences being largest over the right hemisphere at superior and mid-lateral sites. There was also a CC, AP and ST interaction, because differences were largest over the back of the head, with a reduction in size with increasing distance from the midline. Finally, the ANOVA comparing CR and H25R25 revealed a CC, HM and ST interaction as well as a CC, AP and ST interaction, which both came about for the same reasons as for the terms revealed in the CR vs. H15R15 comparison.

In the 800-1100ms time-window (Figure 16, p166), the H5R5 versus CR ANOVA revealed a CC, AP and HM interaction which came about for the same reasons as this comparison in the 500-800ms epoch. In this same time-window, an ANOVA comparing H15R15 and CR revealed that there was a CC, HM and ST interaction and this also came about for the same reasons as this interaction in the earlier epoch. There was also a CC, AP and HM interaction which came about because the H15R15 response category was more positive-going and the largest differences were over the right hemisphere at frontal locations. Finally, the ANOVA comparing CR and H25R25 in this epoch revealed a CC, HM and ST interaction, which came about because H25R25 was more positive-going, with the largest differences being over right superior and mid-lateral sites. There was also a CC, AP and ST interaction, because additionally, the largest differences were over posterior locations. Furthermore, there was a reliable CC, AP and HM term, which came about because the differences were largest over right frontal sites.

A Priori Planned Comparisons

In the 300-500ms time-window a focused analysis (F3,Fz,F4) was conducted with the CR, H5R5, H15R15 and H25R25 conditions, since this region is of interest in terms of the pre-experimental hypothesis. There was a CC and ST interaction ($F(4.4,153.7) = 2.44; p<0.05$), which came about because the CR condition was the most negative-going, with an increase in hit positivity as lag decreased and with the largest difference at Fz (H5R5). There was also a main effect of condition ($F(2.6,89.5) = 26.02; p<0.001$). This was followed up with all possible paired contrasts (Figure 17). The CR and H5R5 comparison revealed a main effect of condition ($F(1,35) = 88.53; p<0.001$) and a CC by ST interaction ($F(1.7,58.4) = 6.78; p<0.01$), which came about because the hit condition was more positive-going, with the largest differences at Fz. The CR and H15R15 comparison revealed a main effect of condition ($F(1,35) = 51.15; p<0.001$), which also came about because the hit condition was more positive-going than the CR condition. Finally, the CR and H25R25 ANOVA revealed a main effect of condition ($F(1,35) = 11.68; p<0.01$), which came about for the same reasons as the previous two main effects. There was also a trend for a CC and ST interaction ($F(2.0,70.0) = 2.96; p=0.06$).

The second planned comparisons were carried out in the 500-800ms time-window at posterior locations (P3,Pz,P4). The ANOVA comparing CR, H5R5, H15R15 and H25R25 revealed a main effect of condition ($F(2.6,91.3) = 41.30; p<0.001$), which came about because the CR condition was the most negative-going, and because the hit conditions increased in positivity with decreasing lag. This was followed up with all possible paired contrasts involving the CR response category (Figure 17). All three ANOVAs revealed main effects of category ($F(1,35) > 53.36; p<0.001$, in each case), which came about because the hit conditions were more positive-going than the CR condition in every contrast. In the CR and H5R5 comparison there was a CC and ST interaction ($F(2.0,69.8) = 3.42; p<0.05$), which came about because the hit condition was more positive-going, with the largest differences over P3. In the CR and H15R15 comparison, there was also a trend for a CC and ST interaction ($F(1.7,58.3) = 2.76; p<0.082$), which came about for the same reason.

Global Hit Paired Contrasts

These comprised follow-up paired contrasts for the H5R5, H15R15 and H25R25 conditions only for each epoch (thus CR is not included in this set of analyses). Only the highest order interactions are detailed in the text (see Table 11, p177, for results in full). The ANOVA from 300-500ms comparing the H5R5 and H15R15 conditions revealed a trend for a CC, HM and ST interaction, which came about because the H5R5 condition was more positive-going, with differences that were largest over the left hemisphere at superior sites. In the contrast between H5R5 and H25R25 in this early epoch the same interaction was revealed by the ANOVA, with the shorter lag eliciting greater positivity and larger differences over left superior and mid-lateral sites. In the same epoch, the comparison involving H15R15 and H25R25 revealed a

CC and AP interaction, which came about because the ERPs associated with the shorter lag were more positive-going, with the largest differences at the front of the head.

Table 11. The outcomes of the global paired hit analyses (F-values and significance levels) of the ERP activity for words attracting correct old and correct lag judgements for the 3 selected time-windows (n=36)§

Epoch		300-500ms			500-800ms			800-1100ms	
Lag	5 vs 15	5 vs 25	15 vs 25	5 vs 15	5 vs 25	15 vs 25	5 vs 15	5 vs 25	15 vs 25
CC	-	23.52***	7.61**	-	14.44**	5.87*	-	-	-
CCxAP	-	6.68**	5.10*	-	-	-	5.66*	3.72•	-
CCxST	-	6.12*	-	-	6.92**	-	-	-	-
CCxHMxST	4.15*	3.43*	-	-	3.50*	-	-	3.79*	-
CCxHMxAPxST	-	-	-	-	-	-	-	-	2.201•

§ The factors were Condition (cc), Hemisphere (hm), Anterior-Posterior Dimension (ap) and Site (st). Conditions = H5R5vsH15R15; H5R5vsH25R25; H15R15vsH25R25.
*p<0.05
**p<0.01
***p<0.001 (epsilon corrected)
•trend

In the 500-800ms epoch, the ANOVA revealed no differences between the H5R5 and H15R15 conditions. There was a CC, HM and ST interaction between H5R5 and H25R25, which came about because the shorter lag was associated with greater positivity, with the smallest differences over left inferior sites. In the H15R15 and H25R25 contrast, the ANOVA revealed a main effect of condition, which came about because the H15R15 condition was more positive-going.

Finally, in the 800-1100ms time-window, there was a CC and AP interaction between H5R5 and H15R15, which came about because the H15R15 condition was more positive-going at frontal locations, but not at posterior locations. There was a CC, HM and ST interaction between the H5R5 and H25R25 conditions, because the H5R5 condition was more positive-going, except over left inferior sites. Finally, there were no statistically reliable differences revealed between the H15R15 and the H25R25 conditions in this epoch.

A Priori Planned Comparisons

In the 300-500ms time-window a focused analysis (F3,Fz,F4) was conducted with all possible paired contrasts between the ERPs associated with correct lag judgments and separated according to lag. In the ANOVA, a trend for a main effect of condition was revealed involving the H5R5 and H15R15 conditions ($F(1,35) = 3.65; p<0.066$), because the H5R5 condition was moderately more positive-going. There was also a trend for a CC and ST interaction with these conditions ($F(1.6,56.5) = 2.53; p<0.1$). In this epoch, there was a main effect of condition when comparing H5R5 and H25R25 ($F(1,35) = 27.70; p<0.001$), because the H5R5 condition was associated with greater positivity. Finally in the 300-500ms epoch, when comparing H15R15 and H25R25, there was a main effect of condition ($F(1,35) = 5.74; p<0.05$), which came about because the ERPs associated with the shorter lag were more positive-going. There was also a trend for a CC and ST interaction with these categories ($F(1.8,62.2) = 2.61; p=0.089$).In the planned 500-800ms follow-ups, there were no reliable differences between H5R5 and H15R15, or between H15R15 and H25R25. An ANOVA did reveal a main effect of condition in the H5R5 and H25R25 comparison ($F1,35) = 7.23; p<0.05$), which came about because the ERPs associated with the shorter lag were more positive-going.

Global Over-Estimate Comparison

Of primary interest for addressing the experiment hypothesis was whether any differences are present between the H5R5 condition and the H5R15 (over-estimate) condition (Figure 18, right hand side, p181). The scalp maps showing the activity in all 3 epochs differentiating between H5R15 and CR are shown in Figure 19 (p182). The analysis strategy for this comparison followed that of the *old/new* effect analyses reported above (with the exception that the CR condition was not included here). All reliable effects involving condition in these analyses are reported in the text. For the analysis involving all electrode sites of interest (specified above) for the H5R5 and H5R15 (over-estimate) conditions between 300-500ms, an interaction was revealed between CC, AP and ST ($F(2.8,60.5) = 2.95; p<0.05$). This interaction came about because the H5R5 condition was more positive-going (except at posterior sites), with the largest differences at anterior electrode locations, and with amplitude differences falling from superior to inferior locations. There was also a CC and AP interaction ($F(1.4,29.7) = 6.02; p<0.05$). In the 500-800ms epoch, there was a trend for a main effect of condition ($F(1,22) = 3.74; p=0.067$), because the H5R5 condition was moderately more positive-going compared with the over-estimate condition. In the 800-1100ms epoch, there were no reliable differences across these conditions.

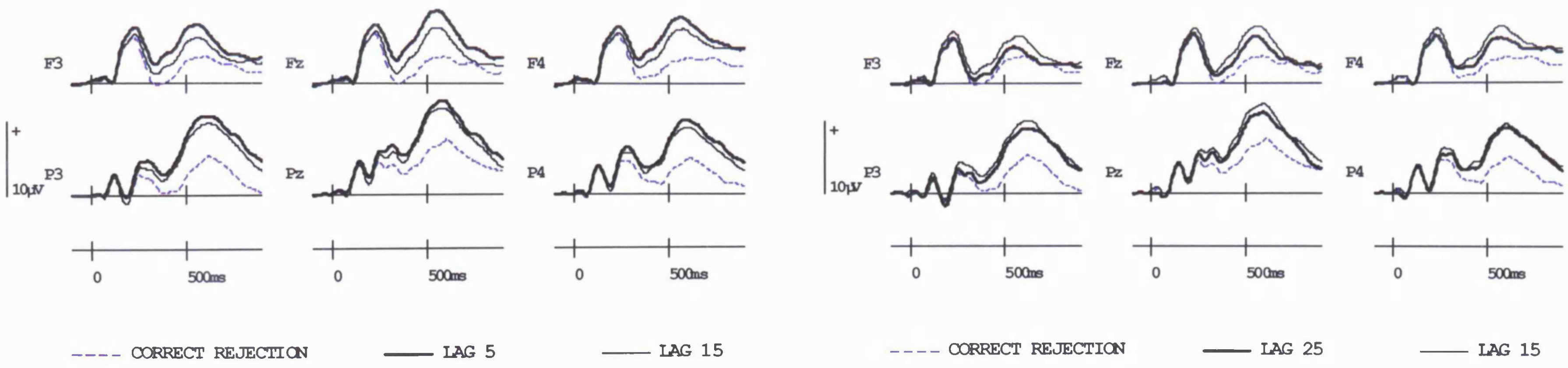

Figure 18. Grand Average ERPs associated with correct and incorrect JORs (n=23). The left panel constitutes waveforms associated with items presented at lag 5, the right panel items presented at lag 25. Waveforms associated with lag 15 JORs in both panels are incorrect. For each lag, the ERPs are shown for three frontal (F3,Fz, F4) and three parietal (P3,Pz,P6) electrodes.

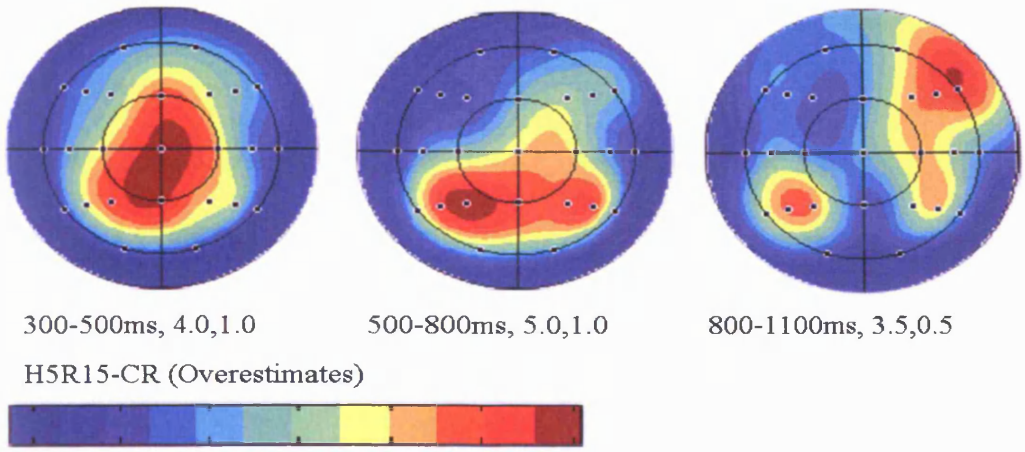

Figure 19. Topographic maps showing the scalp distributions of the neural activity associated with incorrect lag judgments for the 300-500ms, 500-800ms and 800-1100ms time-windows. The maps were calculated on differences scores obtained by subtracting mean amplitudes within each time-window for correct rejections from amplitudes associated with incorrect lag 15 judgments for words presented at lag 5, respectively (n=23).

A Priori Planned Comparisons

In the 300-500ms time-window a focused analysis was again conducted for critical paired contrasts. In a departure from the approach in the previous experiments, these focused analyses comprised one-tailed t-tests on mean amplitudes across sites F3, Fz and F4. The tests were one-tailed because they were based on the prediction that larger (more positive-going) effects would accompany shorter lag judgments, with the findings in Experiments 1 & 2 providing tentative support for this prediction. The one-tailed t-test revealed reliably more positive-going activity for correct compared to incorrect JORs at this lag ($t(22) = 2.04; p<0.05$). In the 500-800ms time-window, the t-test analysis revealed no differences between the critical conditions on mean amplitudes across sites P3, Pz and P4.

Global Under-Estimate Comparison

Also of primary interest for addressing the experiment hypothesis was whether any differences are present between the H25R25 condition and the H25R15 (under-estimate) condition across the same 23 participants contributing sufficient trials to the categories of interest (Figure 18, right hand side, p181). The scalp maps showing the activity in all 3 epochs differentiating between H25R15 and CR are shown in Figure 20 (p184). The analysis strategy for this comparison followed that for the over-estimate analyses described above. Again, all reliable effects involving condition in these analyses are reported in the text. For the analysis involving all electrode sites of interest (specified above) for the H252R5 and H25R15 (under-estimate) conditions between 300-500ms, an interaction was revealed between CC, AP and ST ($F(2.5,55.3) = 3.12; p<0.05$). This came about because the under-estimated lag judgements were associated with more positive-going activity, with the largest differences over frontal superior sites. This interaction was also revealed by the ANOVA in the 500-800ms time-window ($F(3.0,66.9) = 3.91; p<0.05$), which came about for the same reasons. In the 800-1100ms epoch, there was a CC, AP and ST interaction ($F(3.7,80.4) = 3.50; p<0.05$), because the under-estimate condition was more positive-going (except at posterior inferior sites), with the largest differences over central locations. Finally in the 800-1100ms epoch, there was a four-way interaction CC, AP, HM and ST ($F(3.1,67.8) = 3.14; p<0.05$), which came about for the same reasons as the three-way interaction, with the additional reason that there were larger differences over the right hemisphere.

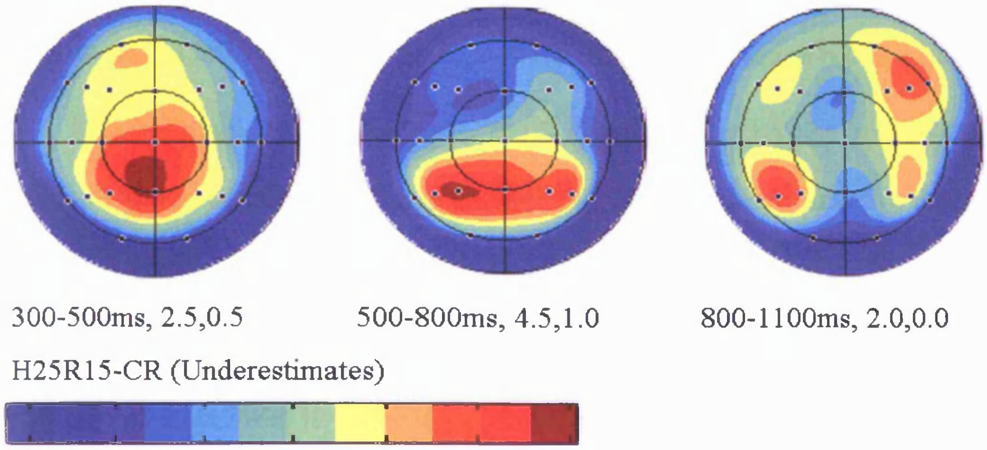

Figure 20. Topographic maps showing the scalp distributions of the neural activity associated with incorrect lag judgments for the 300-500ms, 500-800ms and 800-1100ms time-windows. The maps were calculated on differences scores obtained by subtracting mean amplitudes within each time-window for correct rejections from amplitudes associated with incorrect lag 15 judgments for words presented at lag 25, respectively (n=23).

A Priori Planned Comparisons

In the 300-500ms time-window a more focused analysis (F3,Fz,F4) was again conducted with a one-tailed paired t-test – this time comparing mean amplitudes associated with H25R15 and H25R25. There were no reliable effects. In the 500-800ms epoch, across the electrode sites (P3,Pz,P4), this was also the case.

In summary, the results of the Global Paired Contrasts revealed patterns of reliable effects that indicated that positive –going effects with different distributions in the 300-500 and 500-800ms epochs predicted shorter recency judgments. The follow-up (a priori) analyses revealed support for the view that aspects of the electrical record linked with familiarity responded in this way.

Discussion

The aim of this experiment was to investigate the ways in which recollection and/or familiarity memory processes could support judgments for when events occurred. The behavioural data in this experiment showed that *old/new* discrimination declined with increasing lag, as did the accuracy of JORs, a pattern of performance consistent with that obtained in previous comparable studies (Hinrichs & Buschke, 1968; Hintzman, 2004; 2005). In relation to Experiment 2 in this thesis, the JOR accuracy reported here is improved and this may be due to decreasing the complexity and length of the experiment. The fact that there was a greater overall likelihood of a lag 15 judgment in this experiment (see Table 8, p164) might be interpreted as a tendency to default to this response option when uncertain, but attributing aspects of the pattern of behavioural data to response bias is complicated by the fact that for both lag 5 and lag 25 items, a lag 15 judgment is temporally closer to the correct response than the other incorrect alternative.

ERP Old/new Effects

The sizes of the *old/new* effects decreased as lag increased (Figure 17, p167) – this is largely consistent with the findings of Experiment 2. The scalp distributions of the ERP *old/new* effects corresponded broadly with the effects reported previously in ERP studies of episodic retrieval, comprising a more posterior and left-lateralised distribution in the 500-800ms than in the 300-500ms epoch (Azimian-Faridani & Wilding, 2006; Curran, 1999; 2000; Wilding, 1999). These findings are consistent with the view that at least two distinct memory processes were engaged in the first 800ms following stimulus presentation.

Figures 14-16 (pages 165-166) show the distributions of these ERP *old/new* effects, and how they change with lag. For the 300-500ms time-window, the progressively posterior maximum of the *old/new* effects with increasing lag is consistent with the view that the amplitude of the mid-frontal *old/new* effect – the putative index of familiarity – became smaller as lag increased. In the 500-800ms epoch, the *old/new* effects diminished but the shapes of the distributions remained the same. In keeping with the findings in Experiments 1 and 2, in the late time-window (800-1100ms), the scalp maps revealed emerging anterior activity that was right lateralised. In this late epoch, the *old/new* effects associated with the three lags did not vary in a way that was consistent with the earlier experiments. This pattern of findings will be discussed in more detail in the General Discussion (Chapter 7).

Single Lag Comparisons

As with the previous two experiments, the main ERP activity of interest in Experiment 3 is that which differentiates between correct and incorrect recency judgments. In this experiment it was possible to measure lag 15 JORs to lag 5 items (over-estimates), and to measure lag 15 JORs to lag 25 items (under-estimates). Critically, for these incorrect lag judgments, ERPs were formed only for those items attracting lag 15 judgments. The central findings in this set of analyses are shown in Figures 21-23 (pages 187-189), which illustrate the mean amplitudes of the waveforms across the 3 epochs (separated across the anterior, central and posterior electrodes), for hits associated with correct JORs (lag 5 and 25), along with hits associated with incorrect (lag 15) JORs.

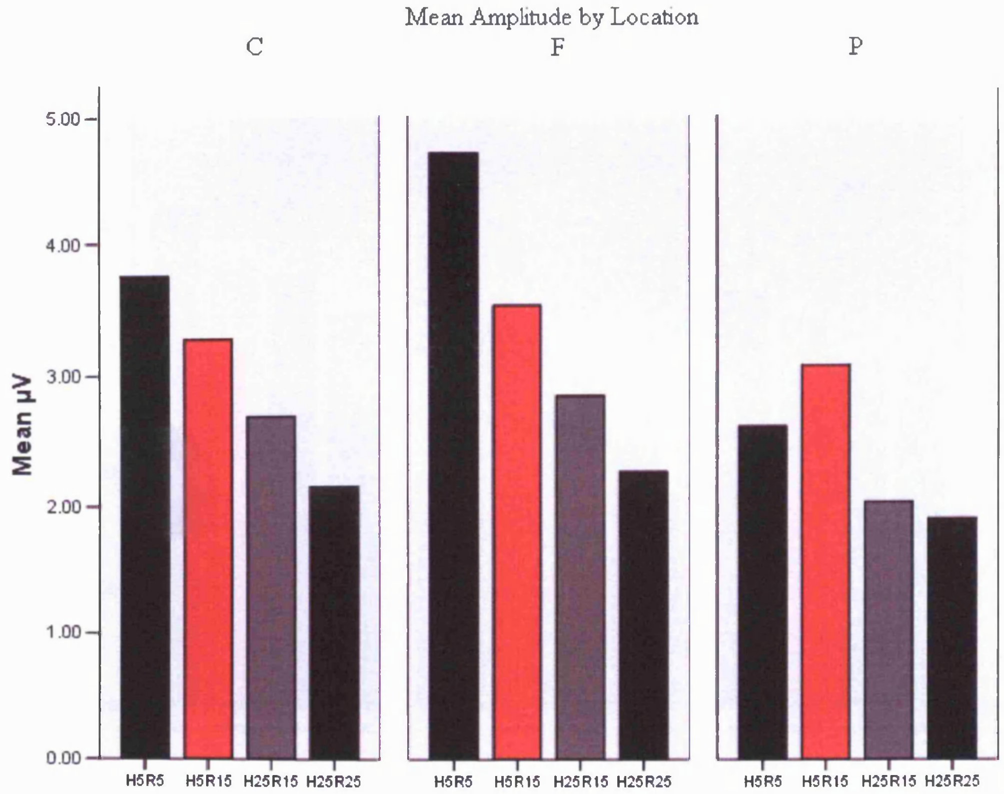

Figure 21. Mean amplitude of the 300-500ms electrical activity associated with correct JOR lag 5 and 25 hits (black bars); lag 5 hits attracting over-estimated lag judgements (red bars) and lag 25 hits attracting under-estimated lag judgements (grey bars). (n=23). There are separate graphs for each AP dimension: Central (C) electrodes (collapsed across T8,C6,C4,T7,C5,C3), Frontal (F)(F8,F6,F4,F7,F5,F3) and Posterior (P)(P8,P6,P4,P7,P5,P3).

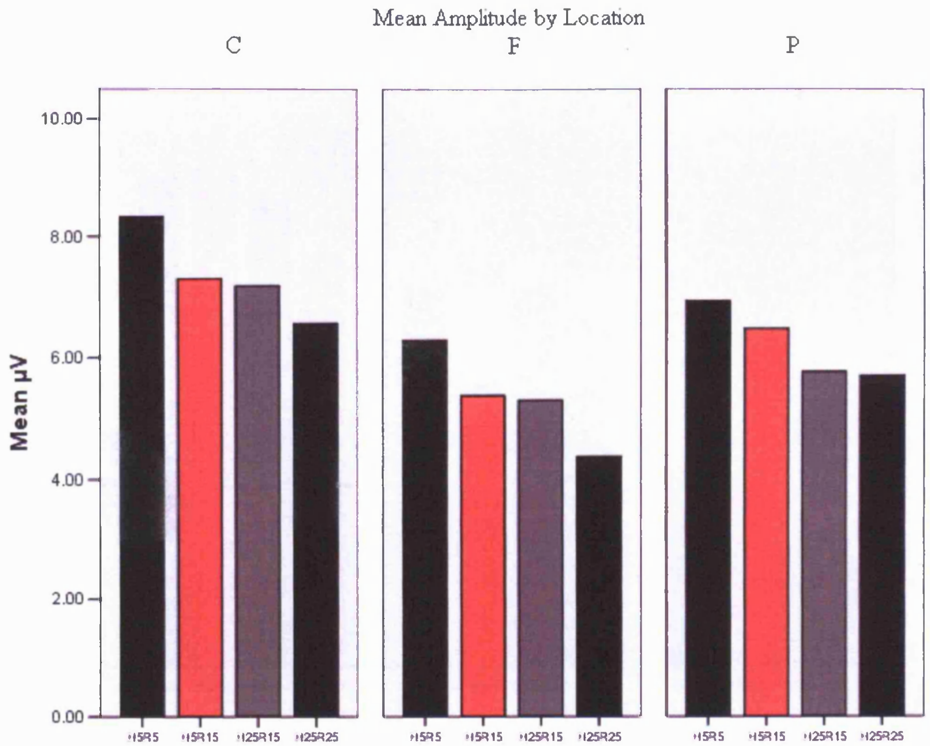

Figure 22. Mean amplitude of the 500-800ms electrical activity associated with correct JOR lag 5 and 25 hits (black bars); lag 5 hits attracting over-estimated lag judgements (red bars) and lag 25 hits attracting under-estimated lag judgements (grey bars). (n=23). There are separate graphs for each AP dimension: Central (C) electrodes (collapsed across T8,C6,C4,T7,C5,C3), Frontal (F)(F8,F6,F4,F7,F5,F3) and Posterior (P)(P8,P6,P4,P7,P5,P3).

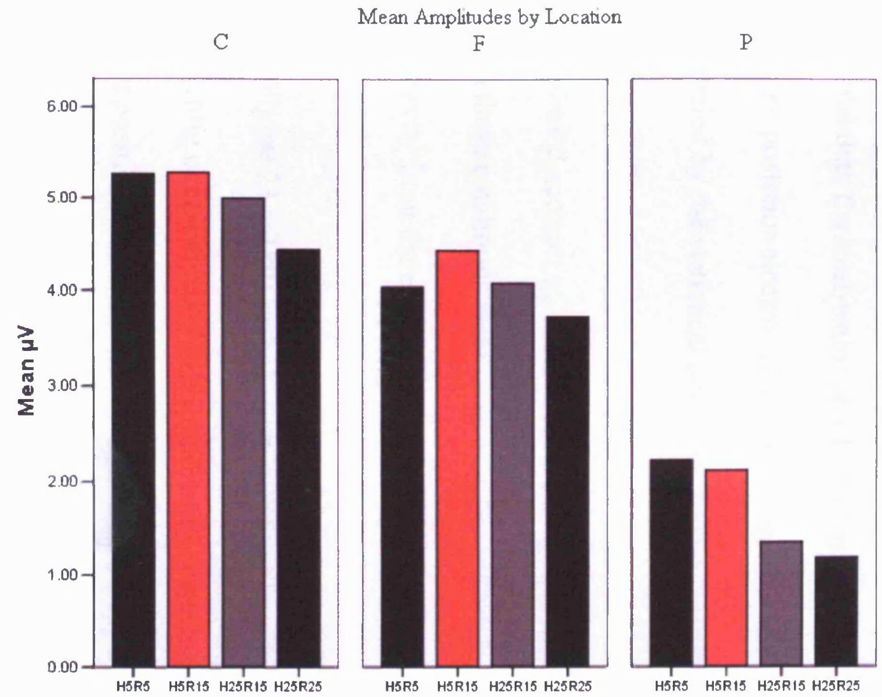

Figure 23. Mean amplitude of the 800-1100ms electrical activity associated with correct JOR lag 5 and 25 hits (black bars); lag 5 hits attracting over-estimated lag judgements (red bars) and lag 25 hits attracting under-estimated lag judgements (grey bars). (n=23). There are separate graphs for each AP dimension: Central (C) electrodes (collapsed across T8,C6,C4,T7,C5,C3), Frontal (F)(F8,F6,F4,F7,F5,F3) and Posterior (P)(P8,P6,P4,P7,P5,P3).

In the 300-500ms epoch, the bar graph (Figure 21, p187) reveals that at frontal electrodes, correct JORs for lag 5 items elicit more positive-going activity than incorrect (over-estimated) lag judgements. This is also the case at the central electrodes, but less so at posterior ones. Under-estimated lag 25 hits were associated with more positive going activity than correct lag 25 judgements in this epoch, especially over anterior locations. In the 500-800ms epoch, the bar graph (Figure 22, p188) reveals that the correct JOR lag 5 hits were associated with more positive-going waveforms than the over-estimated JORs for lag 5. This was the case at the anterior, central and posterior electrode locations, but only moderate support for differences was revealed by the statistical analyses. Under-estimated lag 25 hits were associated with more positive going activity than correct lag 25 judgements, consistent with a strength-based account of JORs. There was an indication that the largest differences between these conditions were over anterior electrode sites, suggesting an extension of the activity from the early epoch into the 500-800ms time-window.

Finally, Figure 23 (p189) reveals that at frontal locations in the 800-1100ms epoch, hits attracting over-estimated lag judgements were actually associated with marginally increased positivity, in comparison with accurate lag 5 judgements. This is not the case at posterior electrode sites, where once again correct lag 5 judgements were the most positive. However there was no support for differences across conditions in the statistical analyses. The under-estimated lag 25 condition was associated with more positive going waveforms than the correct 25 lag condition, which was held up by the statistical analysis.

In the 300-500ms epoch, the magnitude of frontally distributed ERP *old/new* effects varied inversely with the lag judgment that was made to test items. In previous studies, greater relative positivity for *old* than for *new* items attracting correct judgments in recognition memory tasks has been interpreted as an index of familiarity (e.g. Azimian-Faridani & Wilding, 2006; Curran, 2000). By this account, the greater positivity for *old* in comparison to *new* items signals the increase in familiarity for this stimulus class that is engendered by exposure in a study phase. The sensitivity of this effect to a range of manipulations thought to change the familiarity of items is consistent with this account, and of particular importance here are findings that ERP *old/new* effects in this time-window at anterior locations vary according to perceived memory strength (Azimian-Faridani & Wilding, 2006; Woodruff et al., 2006). Alongside other data points (Curran, 2004; Curran et al., 2006), the findings of Azimian-Faridani et al. (2006) as well as Woodruff and colleagues (2006) support the view that ERPs at anterior scalp sites in the 300-500ms time-window index familiarity in a graded manner.

Hintzman has suggested that one of the processes that support recency judgments is the same strength-based process – familiarity – that also supports *old/new* recognition memory judgments (Hintzman, 2003). Familiarity is assumed to provide a basis for recency judgments in so far as the familiarity strength signal is employed heuristically, with high levels of familiarity signalling more recent events than low levels of familiarity. If the magnitude of the mid-frontal ERP *old/new* effect does in fact index familiarity in a graded manner, then the findings in this experiment – an inverse relationship between the magnitude of this *old/new* effect and the associated recency judgment – are consistent with Hintzman's account, and at the same time provide data consistent with the familiarity account of the mid-frontal ERP *old/new* effect. Previous research demonstrating that familiarity declines more rapidly than recollection (Yonelinas & Levy, 2002) makes familiarity an especially strong contender for providing distance information over the short-term.

In line with the early time-window, there was some tentative support for the notion that larger ERP *old/new* effects in the 500-800ms epoch predicted shorter lag judgments than did smaller *old/new* effects. Positive-going ERP *old/new* effects, often with a left-parietal maximum, have been associated with the process of recollection (see Chapter 2, Wilding, 2000; Wilding & Rugg, 1996; Wilding & Sharpe, 2003). Evidence for this account comes from findings that the magnitude of the left-parietal ERP *old/new* effect varies according to the either the quality or quantity of task-relevant information that is retrieved (Vilberg et al., 2006; Wilding, 2000). This suggests that recollection may also be employed in a strength-based manner to support JORs. However, stronger support for this would have been to demonstrate statistically that activity in posterior regions varied with JORs in this epoch.

The results of this experiment also suggest that recollection could be employed as a source of distance information, which is inconsistent with the suggestion by Curran and Friedman (2003; 2004) that recollection is associated solely with location-based processes. If recollection had been the basis of location information in this task, larger parietal *old/new* effects would be expected to uniformly accompany correct, rather than incorrect, lag judgments (a finding that has been obtained in some experiments where the focus has been on recovery of forms of contextual information other than time: e.g. Wilding, 1999; Wilding & Rugg, 1996). The data reported here are more consistent with the possibility that, if recency judgements are supported by recollection, then this is in a strength-based manner, which would correspond to the use of distance information according to Friedman's (1993) framework. This is because activity in the time-window associated with this effect varied in magnitude across JORs, and since the magnitude of the left parietal *old/new* effect varied across time.

In one important study relevant to these views, Hintzman (2001) explored judgements of recency using a continuous recognition memory task where low frequency words were repeated after lags of 10, 20, 30, 40, 50, 60, 70 and 80 intervening items. Participants were required to make *old/new* recognition judgements in response to word stimuli in the continuous list. For items judged to be *old* (i.e. those recognised as being repeated in the experiment by participants), numerical JORs were also required. Before making the JORs, participants were also required to make an R/K judgement in order to report whether their *old* judgement had been based on recollection or familiarity (as in the R/K procedures identified in Chapter 1, p62).

In Hintzman's study (2001), mean JOR decreased as a function of increasing lag, as did the proportion of accurate '*old*' judgements. JORs for items judged familiar (as indexed by 'know', or 'K' responses) were longer on average than those judged to be recollected ('remembered', or 'R'). Hintzman argued that this data suggests that uni-dimensional strength does not account for recency judgements. However, the fact that participants were asked to make R/K judgements prior to making their JORs could have led to this result, in that participants adapted their numerical JORs in accordance with their R/K judgements (Hintzman, 2001). The current ERP experiment has the advantage of negating any requirement for participants to indicate whether they are recollecting or experiencing familiarity and so avoids the criticism that this prior judgement could influence subsequent JORs. The data reported in the current experiment provides additional support for the notion that both familiarity and recollection may underpin JORs in a continuous recency task.

Again a confidence or error related processing account for these ERP findings is thought to be unlikely in that a confidence effect that varies in a graded way, according to whether shorter or longer lag judgements (relative to a correct judgment) are made would suggest that confidence (or indeed error checking) would decrease with increasing lag. There is no reason to expect that greater errors or less confidence would be associated with items thought to be *recently* experienced. Further discussion of these issues is presented in the General Discussion (Chapter 7).

In summary, the data presented in this experiment has provided further evidence that ERP *old/new* effects in the early and middle epochs diminish with increasing lag, and that in all time-windows, the activity associated with shorter JORs was largely more positive-going, compared to activity associated with longer JORs. These findings will be discussed further in the General Discussion (Chapter 7). The following chapter contains a report of the outcomes of a series of behavioural experiments that were conducted to uncover further information regarding these issues. Experiment 3 revealed that familiarity and recollection are likely to be utilised by participants for their JORs, but a limitation of this experiment is that ERPs were formed for an under-estimation of a lag (25) or an over-estimation of a lag (5), and not both for the same lag. Another limitation is that only tentative support for the fact recollection varied inversely with increasing JORs was obtained in Experiment 3 – possibly because ERPs are not sensitive enough to capture the very small differences in this kind of strength that may exist between memories formed very close together in time. Attempts to form ERP waveforms for correct, under- and over-estimates for a single lag in Experiments 1 and 2 did not lead to findings that were easily interpreted (for possible explanations, see Chapters 3 and 4). For these reasons, it was decided that a fruitful approach would be to conduct several behavioural experiments, in order to provide more evidence for the ways in which different memory processes and types are used by participants when making recency judgments.

CHAPTER 6 – BEHAVIOURAL STUDIES

Famous Experiments Introduction

As discussed in Chapter 1, when making judgements about the recency of an item in memory, it could be that participants utilise what Friedman (1993) referred to as distance information. This kind of information is obtained via processes that occur following memory encoding, the most prominent of which is the fact that memory traces decay. As a result, the strength of a memory might be employed as a basis for recency judgments (Hinrichs, 1970). Hintzman (2001; 2003; 2005) has conducted a series of studies on recency judgements, which all involved a continuous memory task adapted from that of Yntema and Trask (1963). In these tasks, participants are usually presented with a long list of items one at a time. Items are represented in the list after different numbers of intervening items. After each item is presented, participants make a recognition judgement (i.e. *new* or *old* item), followed by a judgement of recency for items they had classified as being repeated.

Typical continuous recency tasks are thought to be free of contextual landmarks (Hintzman, 2001), unlike tasks that involve study list1/list2 divisions, which would provide information relating to source that people could use to make judgements about time under different circumstances. In a task where there are two study phases, followed by a test phase, participants could make recency judgements based on location information (contextual retrieval), e.g. they might know that 'SPATULA' occurred before 'SPIDER' simply because they knew study list 1 occurred before study list 2. In a long continuous list of words like that of the continuous recency task employed by Hintzman, it is less likely that people would make broad contextual associations such as these for JORs.

Furthermore, since continuous memory tasks comprise a single long list of words (typically between 400-800 items) with lags of up to 80 items, it is also unlikely that participants are using relative information to chronologically reorganize the items studied (for a full discussion of this topic, see Chapter 1). For example, when presented with the word 'SPATULA', in making a recency judgement it is unlikely participants recall each item between first and second presentation. Hintzman's (2004) research supports the idea that any form of re-ordering or reference to a large number of intervening items is unlikely. In this study participants performed the continuous memory task under 'fast' and 'slow' conditions, where the time duration between trials was varied between 500ms and 2500ms. Time passage, rather than the number of intervening items, was the basis of recency decisions in this task (since the number of intervening items was constant across blocks, but JORs varied between them). This suggests that carrying out chronological re-organization is unlikely to be the basis of recency judgements in continuous memory tasks of this type, because performance did not depend upon the number of items to be ordered but on the time between presentation and re-presentation.

It is probable that, in this type of continuous memory task, distance information (in the form of a strength assessment of memory traces) is available to participants and that this is the form of information utilised when making JORs. This notion is supported by previous work conducted by Hintzman. In 2003, employing the continuous memory task with lags of 5, 10, 15, 20, 25 and 30 intervening items, Hintzman showed that low frequency words attracted shorter JORs than high frequency words. Hintzman also demonstrated that pictures attracted shorter lag judgements than words (2005). Both types of stimuli attracting the shorter lag judgments in these studies were also the categories associated with more accurate recognition performance and were therefore thought to have greater memory strength. Figure 24 shows how patterns of JOR might differ across strong and weak items. The key idea is that 'stronger' memories attract shorter lag judgements, and in this example this is evident at each lag – although this may not always be the case.

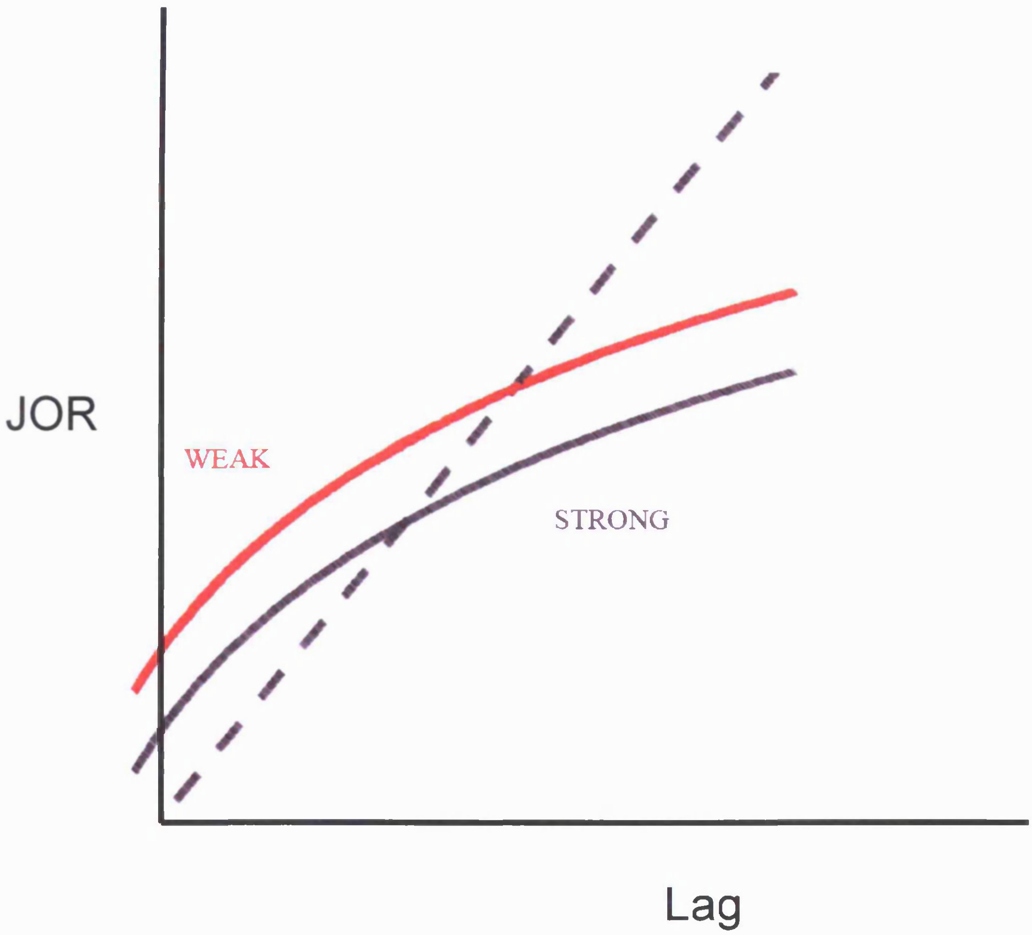

Figure 24. JOR as a function of lag, based on memory strength (adapted from Hintzman, 2005).

Previous research (Chapter 5) implementing the continuous recency task and using ERPs to investigate the nature of JORs over lags of 5, 15 and 25, supports the idea that the strength of a memory trace is linked to the JOR it will attract. When items at lag 5 were over-estimated (attracting a JOR of 15), they were accompanied by less positive-going waveforms in comparison with accurate lag 5 judgements. Furthermore, when lag 25 items were under-estimated, the waveforms were more positive-going than when the lag 25 items attracted a correct response. These results were found in both the 300-500ms (anterior locations) and the 500-800ms (anterior and posterior locations) time-windows. Neural activity in these time-windows and at these scalp locations has been associated with familiarity and recollection memory processes respectively. The results of this study suggested that both recollection and familiarity could be utilised when making JORs, and if so, they are both likely to be employed in a strength-based manner. The greater level of familiarity experienced, and/or the more information recollected, the shorter the JOR.

Reported in this behavioural section are experiments involving continuous recognition tasks with stimuli not before employed in published continuous recency memory tasks, namely famous and non-famous first and last (full) names. The stimuli chosen for this behavioural series were expected to have highly different levels of pre-experimental strength. This means that participants will experience relatively greater levels of memory strength upon seeing famous names for the first time in the experiment (since they will have been experienced in many pre-experimental settings), in comparison with non-famous names which will be associated with low memory strength (since these combinations of first & last name pairs are unlikely to have been experienced in any pre-experimental context).

An advantage of using famous and non-famous names in this behavioural series is that they can ultimately be used to give a direct assessment of how pre-experimental levels of memory strength can predict lag judgements (this will be discussed in depth in Experiment 8, pages 234-246).

The first purely behavioural experiment (Experiment 4) was conducted to determine whether famous names do attract shorter JORs than non-famous names. Next in the behavioural series, manipulations thought to influence primarily familiarity or recollection were employed. Finally, an experiment was designed to assess whether pre-experimental levels of familiarity and recollection were related to JORs. Since famous names are expected to have a high level of pre-experimental memory strength, it was possible to use this feature in order to explore the nature of recency judgements further. In the final behavioural experiment, the level of memory strength for each famous name was measured before and after the continuous recognition and recency task. These measures of memory strength were then used to assess whether recollection and/or familiarity related to the JORs given by participants during the recency task.

EXPERIMENT 4

Introduction

A long list of famous and non-famous names was rated in a prior experiment so that the most famous names (e.g. Bill Clinton, Julia Roberts) were included along with non-famous names (e.g. Jonny Butterfield, Lurline Newton) in a later continuous memory task. Famous names were expected to have a high level of memory strength and would perhaps be better recognised and attract shorter judgements of recency in comparison with non-famous names.

Method

Participants

Twenty-four participants aged between 18 and 22 years (mean age 19.1 years) took part in the experiment. Six participants were excluded on the basis of poor behavioural performance (hit rate below 50% for non-famous names). All participants had normal or corrected to normal vision. Of those included, 2 were male and all were undergraduates at Cardiff University, each taking part in return for course credit. The participants reported speaking English as their native language. All participants gave informed consent prior to the experiment. The experiment was approved by the ethics committee of the School of Psychology, Cardiff University.

Stimuli

Stimuli were 292 first and last name pairs, half of which were famous (rated in a prior experiment – see Appendix 3, p318). Non-famous names were taken from the 1990 U.S. census. Famous names were taken from various celebrity database websites. The stimulus set was checked to ensure that close variants and highly similar names were excluded. Male names had an average of 11.4 letters and 3.6 syllables and female names an average of 12.0 letters and 4.1 syllables (matched across famous and non-famous names). There was one block per experiment which included 556 trials. Within the experiment block there were 264 names, of which an equal number (44) were repeated after 5, 10, 15, 20, 25 and 30 intervening items. An equal number (22) of famous and non-famous names were repeated at each lag, half of which were male. A further 28 names, half of which were famous - and half were female - were included in the experiment to act as filler items. Six fillers were placed at the beginning of each list and the rest were placed towards the end of each experiment list, with the order of filler presentation in the list randomized according to condition. These items were not included in the experiment analysis. A total of 6 lists were created, so that across lists each name was presented at each lag (with 3 participants completing each list). Test lists were constructed by randomly assigning names as one of 6 lag item types. Items were then organised pseudo-randomly for each block. Stimuli were presented on a computer monitor. All stimuli were presented in uppercase size 40 Times New Roman font in white, set against a black background.

Procedure

Participants sat at a desk to perform this task. The participants read through an instruction sheet and the instructions were then relayed verbally. Each experiment block began with a 'Ready' signal, lasting 6000ms. Each trial began with a fixation mark (*) which lasted 500ms, followed by a blank screen (100ms). Names were then presented for 500ms, followed by a blank screen during which participants decided whether the name was *old* or *new* via key press (*old/new* was on the '0' or 'Del' button on the number section of the keyboard, counterbalanced across participants). Once this judgement had been made, a blank period of 1000ms passed before participants were presented with the words 'How Far Back?'. If the participant had indicated the name was *new*, they were instructed to press the same key again at this point to carry on to the next trial. If they had indicated that the name was *old*, they were instructed to judge whether the name had initially been presented 5, 10, 15, 20, 25 or 30 intervening names previously. The six judgment of recency (JOR) options were made via six key buttons, with the buttons used for responses balanced across participants (so that buttons '1', '2', '3', '4', '5', '6' on the number section of the keyboard represented either 5, 10, 15, 20, 25, 30 – or – 30, 25, 20, 15, 10, 5 respectively). The JOR was followed by a 500ms blank screen before the next trial. Participants were able to remind themselves of which keys to press throughout the experiment by looking at the keyboard on which the buttons were labelled. Participants were instructed to balance speed and accuracy equally. Participants were informed that there were an equal number of items at each lag. The experiment took 40-50 minutes to complete.

Results

Behavioural Results Strategy

Greenhouse-Geisser (1959) corrections were used in the following analyses when it was necessary to correct for violations of sphericity. No reaction times were recorded, since this is not of critical interest for answering the main research questions. This mirrors the approach taken in relevant previous research (e.g. Hintzman, 2003).

Recognition Memory

Discrimination is shown in Figure 25. The mean probability of a false alarm was .07 for famous names (SD .09) and was .07 for non-famous names (SD .07). There were no reliable differences among these paired categories when using t-tests. Mean discrimination rates (hits minus false alarms) for famous and non-famous names were .85 (SD .10) and .62 (SD .15) respectively. *Old/new* discrimination of famous and non-famous names (p[hit] – p[false alarm]) was reliably greater than chance ($t(17) > 3.40; p < .01$ in each case), with discrimination being greater for famous names ($t(17) = 7.27; p < 0.001$).

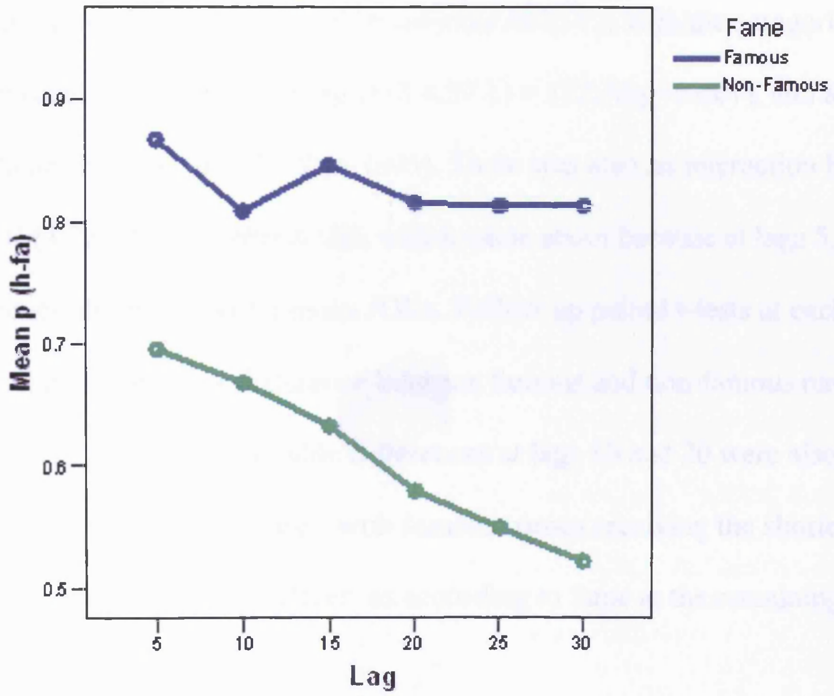

Figure 25. Mean Discrimination (n=18).

A 2x6 within subjects ANOVA on discrimination rates with factors of lag (5, 10, 15, 20, 25 and 30) and fame (famous and non-famous) revealed a main effect of fame ($F(1.0,17.0) = 43.37; p<0.001$), and a main effect of lag ($F(3.4,57.7) = 13.47; p<0.001$). There was also a statistically reliable interaction between lag and fame ($F(3.0,51.4) = 4.49; p<0.01$) which came about because discrimination is superior at all lags for famous names and decreases markedly with increasing lag for non-famous names only. Follow up paired t-tests revealed statistically reliable discrimination differences at each lag between famous and non-famous names ($t(17) >3.73; p<0.01$, in each case).

JOR

An illustration of the mean JORs for famous and non-famous names at each lag is provided in Figure 26 (p206). A within subjects ANOVA with the categories of fame and lag revealed a main effect of lag ($F(3.4,57.1) = 172.76; p<0.001$), and a main effect of fame ($F(1.0,17.0) = 5.19; p< 0.05$). There was also an interaction between lag and fame ($F(3.7,62.8) = 3.09; p<0.05$), which came about because at lags 5, 10 and 20, famous names attracted shorter mean JORs. Follow up paired t-tests at each lag confirmed this; there was a difference between famous and non-famous names at lag 5 ($t(17) = -1.91; p<0.05$), and reliable differences at lags 10 and 20 were also found ($t(17) >-2.66; p<0.05$ in each case), with famous names receiving the shorter mean JOR. There were no reliable differences according to fame at the remaining 3 lags.

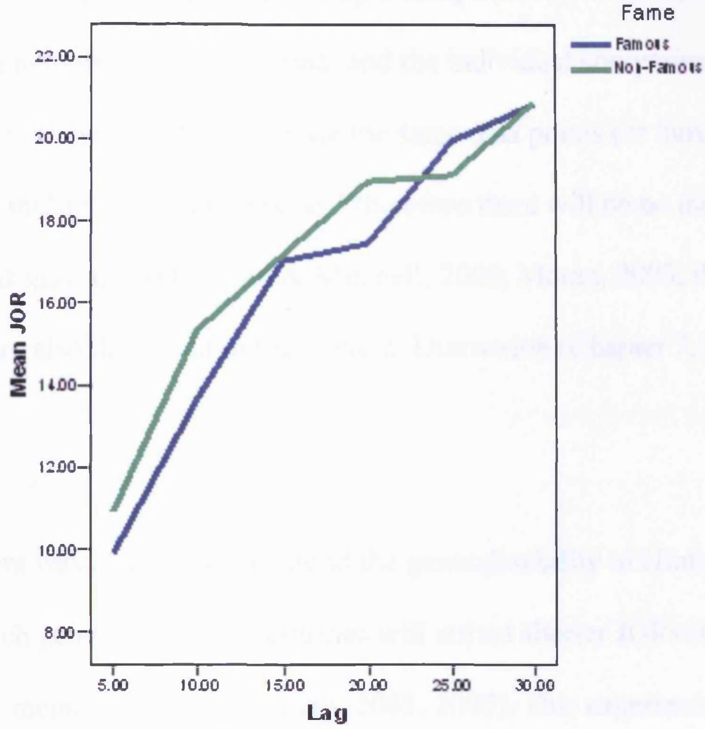

Figure 26. Mean Judgement of Recency (n=18).

Familywise Error Rate

An issue that has not been mentioned so far in the results is the one of familywise error rate. Due to the fact that multiple comparisons have been carried out above on the same dataset, this may appear to have caused an increase in the number of Type I errors (false positives). In order to control for this, it is often argued that a post-hoc test, such as a Bonferroni correction, should be carried out to adjust the significance levels of multiple comparisons so that there is no overall increase in Type I errors across the family of comparisons. In these experiments, however, it is *not* necessary to control for an increase in familywise error rate, or indeed any experiment carried out in the current research where t-tests are used to compare JORs at the same lags for significant differences (e.g. 5 vs.5, 15 vs.15, etc). This is because an increase in Type I errors only occurs when multiple comparisons are made from the same *family* of data, or data where the independent variable and dependent variable are common (i.e. where the same data point is used in multiple comparisons). In the current work, because a within-subjects design is used, and the individual comparisons are across condition for the same lag, at no time are the same data points (or families of data) being used for multiple comparisons, and therefore there will be no increase in Type I error rates (Nakagawa, 2004, Cabin & Mitchell, 2000, Moran, 2003, Perneger, 1998). These issues are also discussed in the General Discussion (Chapter 7, p286).

Discussion

This experiment was conducted to extend the generalizability of Hintzman's finding that items which generate strong memories will attract shorter JORs than items which generate weak memories (e.g. Hintzman, 2003; 2005). This experiment was essentially a replication of Hintzman's recency experiment with the exception that famous and non-famous names formed the strong and weak categories. It was expected that famous names would generate the equivalent of Hintzman's 'strong' memory condition (e.g. similar to long study duration, concrete and low frequency items), and that non-famous names would be equivalent to 'weak' memory items (e.g. comparable to short study duration, abstract and high frequency items). The notion that famous names will lead to stronger memories is consistent with MEG research showing that famous names and faces lead to greater activation in the superior temporal gyrus (amongst other areas of the brain) in comparison with non-famous names and faces even before any memory processing can be carried out (Ryan et al., 2008).

The findings of this experiment were somewhat in line with these expectations. First, the level of discrimination for famous names was much higher than the level of recognition for non-famous names at every lag, consistent with previous research (e.g. Stenberg, Hellman, Johansson and Rosen, 2008; Traversky & Kahneman, 1973). Differences in discrimination were greater than that demonstrated in the Hintzman work (2003; 2005), although recognition performance largely followed the same pattern, with recognition decreasing with increasing repetition interval, mainly for the weak category. The false alarms for non-famous names were in line with previous research using first non-famous female names, where in that study the non-famous names had false alarms of .8 compared to .4 for nouns (Hintzman, 2004). This finding, combined with those presented in this experiment, suggest that non-famous names are a relatively more difficult category than nouns or pictures in a memory task.

The main purpose of carrying out this experiment was to replicate Hintzman findings (2001; 2003) that items of high memory strength are associated with comparatively shorter lag judgements than low memory strength items. The *old/new* discrimination levels indicate that famous names are a stimulus category of relatively high memory strength, and that the non-famous name stimulus category is associated with relatively low memory strength. In terms of lag judgements, famous names attracted shorter judgements of recency than non-famous names. This experiment also provides further support for Hintzman's (2005) view that weaker memories promote relatively longer lag judgements, consistent with the view that distance information (in the form of an assessment of memory strength) can be used for JORs at least under some circumstances.

However, only the JORs at lags 5, 10 and 20 were reliably different and this is where the current findings diverge from Hintzman's (2005) where differences in JOR were found at every lag. Instead the data reported here is more in line with Hintzman's earlier (2003) experiment, where judgements of recency did not differ with some manipulations at the longest lags. Further research is necessary to assess whether a lack of difference in JORs at lag 15 is a robust finding, since this was not expected. If found to be a consistent finding however, it could be some form of bias responding based on the lag being more towards the centre in the range of possible lags. It is also challenging that the lags at which there is the largest difference in *old/new* discrimination (25 and 30) are those at which there is no difference in mean JOR. One potential explanation is the following. If one assumes a common criterion for *old/new* recognition memory for famous and non-famous names, then the higher level of discrimination for famous names reflects the higher proportion that fall to the right of the criterion. If strength falls off with lag however, then it may be the case that at the longer lags the above criterion responses for famous as well as non-famous names are based on strength signals that are on average more similar than is the case at shorter lags. If this is correct, and if the same strength signal is employed in service of recency judgements, then this might explain the smaller divergences between recency judgements for famous and for non-famous names at the longer lags.

One point that may be worth mentioning here is how it can be reconciled that famous names are conceptualised as 'high strength' in line with other stimuli such as low frequency words (Hintzman, 2001), whereas non-famous names are 'low strength' in line with words of high frequency (Hintzman, 2001). It is proposed in the current work that common words are low strength because they are everyday and are *nondescript*, whereas uncommon words are classified as high strength because they stand out as being more unusual. However while non-famous names are uncommon (in their current first and last name pairing), they are also considered to be low strength because compared to famous names, non-famous names are also nondescript. Although famous names (e.g. Hugh Hefner, Susan Sarandon) are high frequency, due to our pre-existing knowledge of them, they are distinctive compared to the less common (in these pair combinations), but lower strength non-famous names (e.g. Nathan Smith, Mary Lewis). Whether an item can be classed as low strength or high strength will depend on the type of stimuli used in the task, and not simply the uncommonness of the stimuli per se. For example, if pictures of famous faces were to be introduced into the recency task used in this experiment, it is highly possible that famous names would become 'middle strength', alongside the pictures (high strength) and the non-famous names (low strength). The classification of the stimuli in terms of strength is relative within task and they are not directly comparable across different tasks.

Item salience has long been implicated in the memorability of items, since salient items (for example, any item that has more significance to an individual for whatever reason, e.g. a name that is similar to their own name, or the stimulus evokes personal feelings or memories, etc) are more likely to capture greater attention and more processing (Hunt, 2006) that will be likely to enhance memory strength. Recent findings that controlled for the distinctiveness of emotional pictures led to their being as equally memorable as neutral pictures, negating their prior advantage (Talmi, Luk, McGarry & Moscovitch, 2006). Brandt, Gardiner and Macrae also found that name distinctiveness (as rated by participants) led to superior memory, even when the number of distinctive and typical names was equivalent (2006). Recent evidence also suggests that the distinctiveness effect in low vs. high frequency items is carried by familiarity, since the putative ERP correlate of familiarity was greater for uncommon rather than common names – with the former category being more memorable (e.g. Stenberg et al., 2008). These studies suggest that distinctive or salient items are of high memory strength.

The key point is that these results suggest that the use of famous and non-famous names could be fruitful for identifying the potential contributions of recollection and familiarity to JORs as described in the introduction of this chapter. The next research question of interest following from this experiment is whether familiarity is responsible for the shorter JORs in the famous name condition. It is possible that since famous names have a higher pre-experimental level of familiarity, this causes them to attract shorter JORs than non-famous names on some occasions. If this is correct, then the divergences between the JORs should be attenuated if the pre-experiment familiarity of the non-famous names is manipulated.

EXPERIMENT 5

Introduction

In Experiment 5, participants were presented with two study phases before taking part in an identical continuous memory task as has been used in Experiment 4. During the study phases, rote repetition (a shallow encoding task) was used for the non-famous names only. Famous names were not presented before the continuous memory task. This experiment was designed in order to increase the pre-experimental familiarity levels of the non-famous names.

Previous research has shown that repeated presentation of stimuli in a shallow encoding task leads to changes in the levels of familiarity but has less of an effect on recollection (Dobbins, Kroll, & Yonelinas, 2004). Therefore this manipulation was expected to elevate recognition memory accuracy for the non-famous names, due to increased levels of familiarity. In terms of JORs, this manipulation should lead to a reduction in the size of the difference between JORs for famous and for non-famous names in comparison to the differences observed in Experiment 4. This will be the case if pre-experimental familiarity is the strength-based process supporting JORs and the process responsible for the fact that famous names in Experiment 4 attracted shorter JORs than non-famous names at some lags.

Method

The method for Experiment 5 was identical to that for Experiment 4 with the exception of the following:

Participants

Twenty-five participants aged between 18 and 21 years (mean age 19.2 years) took part in the experiment. Three participants were excluded because they did not understand instructions and a further three participants were excluded because of poor behavioural performance (hit rate less than 50% of non-famous names). Two were excluded as extreme outliers using SPSS box plot (more than 3 box lengths from 75th and 25th percentile). Of those included, 3 were male.

Procedure

The participants took part in 3 phases, the final phase being the continuous recognition memory task detailed in Experiment 4. In the first phase, participants were presented with the non-famous names in a random order. Each non-famous name was viewed for two seconds on the computer monitor with names presented sequentially. For each name presented, participants were asked to type the initials of the name during a 1.5 second interval. Once they had finished this phase, participants were given a two minute break. Phase 2 was identical to phase 1, with the exception that the non-famous names were presented in a different random order. Before phase 3, participants were given a second break of 2 minutes. Before beginning the final phase, participants were reminded to only press the '*old*' key if seeing an item for the second time in phase 3 only. The entire experiment took 60-70 minutes to complete.

Results

Recognition Memory

Recognition memory performance is shown in Figure 27 (p215). The mean probability of a false alarm was .03 for famous names (SD .02) and was .10 for non-famous names (SD .08). The level of false alarms was higher for the non-famous condition ($t(17) = -4.19; p<0.01$). Mean discrimination rates (p[hit] – p[false alarm]) for famous and non-famous names were .89 (SD .05) and .62 (SD .10) respectively and were reliably greater than chance ($t(17) >25.72; p<.001$ in each case). A paired t-test revealed a reliable difference between these categories ($t(17) = 11.64; p<.001$) with discrimination being greater for famous names. A 2x6 within participants ANOVA revealed a main effect of fame ($F(1.0,17.0) = 134.99; p<0.001$) as expected. There was also a main effect of lag ($F(3.78,64.33) = 10.619; p<0.001$) which came about because the level of recognition decreased as a function of increasing lag (to a greater extent in the non-famous name condition). Finally, there was a statistically reliable interaction between lag and fame ($F(4.2,70.93) = 5.76; p<0.001$), which came about because discrimination decreases markedly with increasing lag for non-famous names only. Follow up paired t-tests revealed statistically reliable differences at each lag between famous and non-famous names ($t(17) >6.33; p<0.001$, in each case).

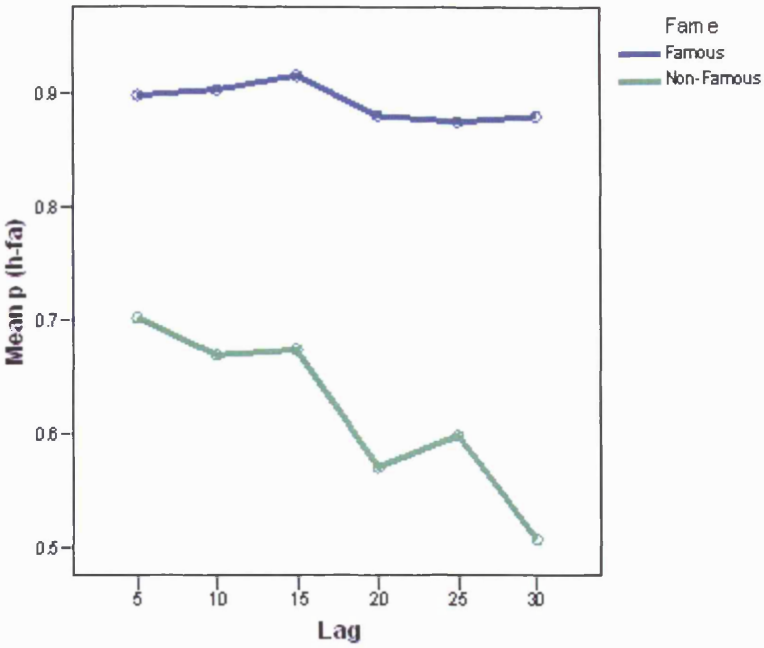

Figure 27. Mean Discrimination (n=18).

JOR

An illustration of the mean JORs for items presented at each lag is provided in Figure 28 (p216). A 2x6 within subjects ANOVA with the categories of fame and lag revealed a main effect of lag ($F(3.0,50.5) = 133.48; p<0.001$) which came about because the JORs increased with lag, and a main effect of fame ($F(1.0,17.0) = 5.71; p< 0.05$), which came about because famous names tended to receive shorter lag judgements. There was also an interaction between lag and fame ($F(4.0,67.3) = 3.65; p<0.05$) which came about because only at lags 5, 10 and 20 did famous names attract shorter mean JORs. Follow up paired t-tests confirmed this as there were differences between famous and non-famous names at lag 5 ($t(17) = -2.08; p<0.05$), and at lags 10 and 20 (t(17) >-3.17;p<0.01 in each case), with famous names receiving the shorter mean JOR.

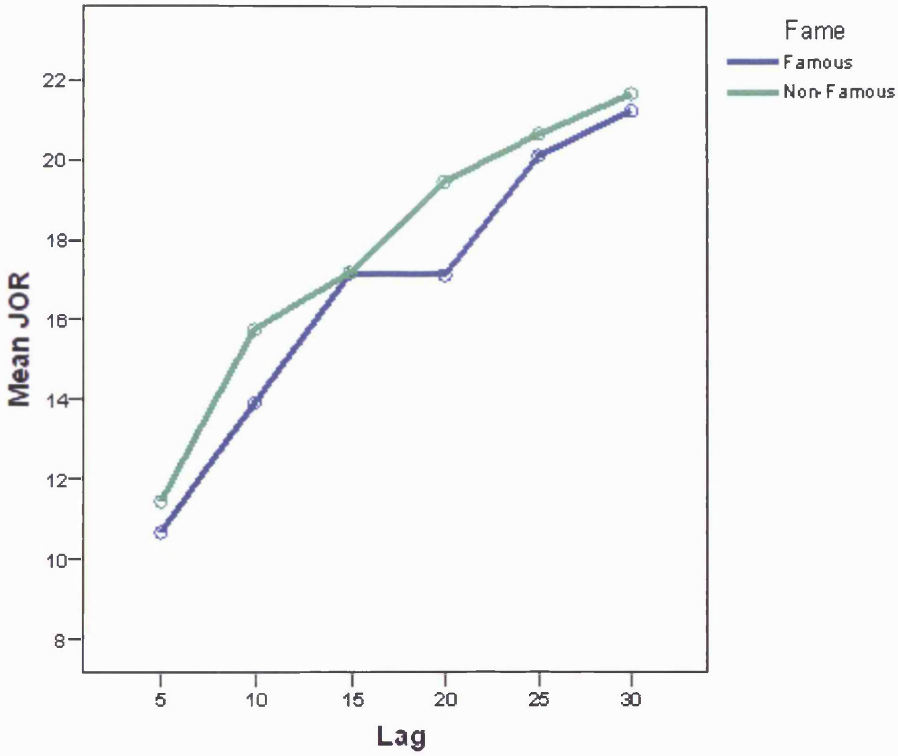

Figure 28. Mean Judgement of Recency (n=18).

Discussion

Experiment 5 was conducted in an attempt to uncover the reasons for the shorter lag judgements in Experiment 4, where famous names were found to attract shorter lag judgements than non-famous names. This experiment was fundamentally a replication of Experiment 4 using famous and non-famous names in a continuous memory task, with the exception that there was an initial study phase with non-famous names only and a shallow encoding task.

As was described in Chapter 1 (p57), familiarity is an acontextual strength-based signal that may lead to judgements of recognition (e.g. Yonelinas, 2002). A strength-based assessment of familiarity, if utilised for recency judgements, would fall under the bracket of distance information according to the Friedman (1993) framework of memory for time. It was reasoned that non-famous names would have an increase in their level of pre-test familiarity because of the encoding manipulation in this experiment. It was argued that familiarity rather than recollection would be increased, because rote repetition in combination with shallow encoding tasks has been shown to influence familiarity to a greater degree than recollection (Dobbins et al., 2004; Rugg, et al., 1998). If familiarity is the basis for memory strength (categorised as a potential source of distance information), then it could be expected that differences between JORs across fame conditions would be reduced in this experiment in comparison to the findings in the previous experiment.

Recognition memory accuracy in Experiment 5 was highly similar to that of Experiment 4, with recognition of famous names being much higher than the level of recognition for non-famous names at every lag. Differences in recognition levels were again greater than that demonstrated in the Hintzman work (2003; 2005), though recognition performance largely followed the same pattern, decreasing with increasing repetition interval largely for the weak category only. In contrast with the predictions, discrimination was not improved for the non-famous names compared to the previous experiment. Thus if pre-experimental levels of familiarity were increased by the manipulation for this category, it was not reflected in discrimination. The findings in this experiment showed that famous names attract shorter lag judgements than non-famous names at a range of lags. The outcomes reported here showed that again lags 5, 10 and 20 were reliably different, in line with Hintzman's (2003) experiment, where judgements of recency did not differ at the longest lags.

The outcomes of this experiment indicate that the strength manipulation did not have any effect on either the level of discrimination, or more importantly, on the JORs. Still there were reliable differences between the JORs for famous and non-famous names, with famous names attracting shorter recency judgements across a range of lags. This is the same pattern of judgements found in the previous study. The findings in respect to the recognition and JOR data suggest that either the level of familiarity was not raised to a great enough extent to influence subsequent judgements in the recency task, or that familiarity is not employed as a form of distance information when making JORs of this nature.

The finding that lags 25 and 30 were not reliably different in the two experiments reported here is consistent with the finding of Hintzman (2005) that mean JORs for different stimulus classes vary minimally at the longest lags. It could be that a strength form of distance information is not sufficient for JORs at longer lags, accounting for the lack of JOR differentiation here. Alternatively, it could be the case that no difference between lag judgements at the two longest lags was caused by lack of statistical power – where discrimination levels meant fewer trial numbers were included in these contrasts. That there was a lack of a difference at lag 15 in both behavioural experiments reported here is surprising. This appears to be due to an increase in the JOR given to famous names at this lag which is not in line with the overall trend for famous names. It is possible that this reflects a bias response for participants in terms of JOR. Since this is a 'middle' lag, it is possible that participants default to either a 15 or 25 response to lag 15 items.

The next research question of interest following from this experiment is whether recollection is responsible for the shorter JORs in the famous name condition in Experiments 4 and 5. It is possible that since famous names have a higher pre-experimental level of contextual information associated with them, this causes them to attract shorter JORs than non-famous names on some occasions. In this way the memory process of recollection would be used in a strength-based manner for recency judgements. This possibility was tested in Experiment 6, as detailed below.

EXPERIMENT 6

Introduction

Though an increase in the familiarity of the non-famous items was expected in Experiment 5, the participants' JORs followed the same patterns as in Experiment 4. It is possible, therefore, that an increase in pre-experimental contextual information may be the key factor leading to shorter JORs for famous names, rather than prior levels of familiarity. This account is in line with some previous research, where contextual information rather than rote repetition influences the accuracy of recency judgements (Chalmers & Humphreys, 1998). Experiment 6 was conducted to explore the possibility that increasing the available pre-experimental contextual information for an item leads to a shorter JOR for that item, in line with a distance account of recency judgements (Friedman, 1993, 2001).

Method

This experiment was identical to Experiments 4 and 5, with the following exceptions:

Participants

Twenty-four participants aged between 18 and 24 years (mean age 20.1 years) took part in the experiment. Two participants did not understand the task and four participants performed too poorly (hit rate below 50% for non-famous names); therefore these participants were excluded. Of those included, 2 were male and each participant took part in return for £5.

Procedure

The participants took part in 3 experiment phases, with the final phase being the continuous memory task described in Experiment 4. In the first phase, participants were presented with the non-famous names in a random order. Each non-famous name was viewed for two seconds on the computer monitor with names presented sequentially. For each name presented, participants were asked to type press the 'z' key if the name sounded like it might belong to a circus performer; or to press the '?' key if the name sounded like it might belong to a librarian (keys counterbalanced across participants). Participants had 1.5 seconds between names to complete this study task. Once they had finished this phase, participants were given a two minute break. Phase 2 was identical to phase 1, with the exception that the non-famous names were presented in a different random order. Before phase 3, participants were given another break of 2 minutes. Before beginning the final phase, participants were reminded to press the '*old*' key only if seeing an item for the second time in phase 3. The entire experiment took 60-70 minutes to complete.

Results

Recognition Memory

Discrimination performance is shown in Figure 29 (p222). The mean probability of a false alarm was .04 for famous names (SD .04) and was .11 for non-famous names (SD .07). There were reliable differences across fame in the level of false alarms ($t(17) = -4.23; p<0.01$). Mean discrimination rates for famous and non-famous names were .82 (SD .15) and .61 (SD .10) respectively. *Old/new* discrimination for famous and non-famous names (p[hit] – p[false alarm]) was reliably greater than chance ($t(17) > 13.09; p<.001$ at each lag).

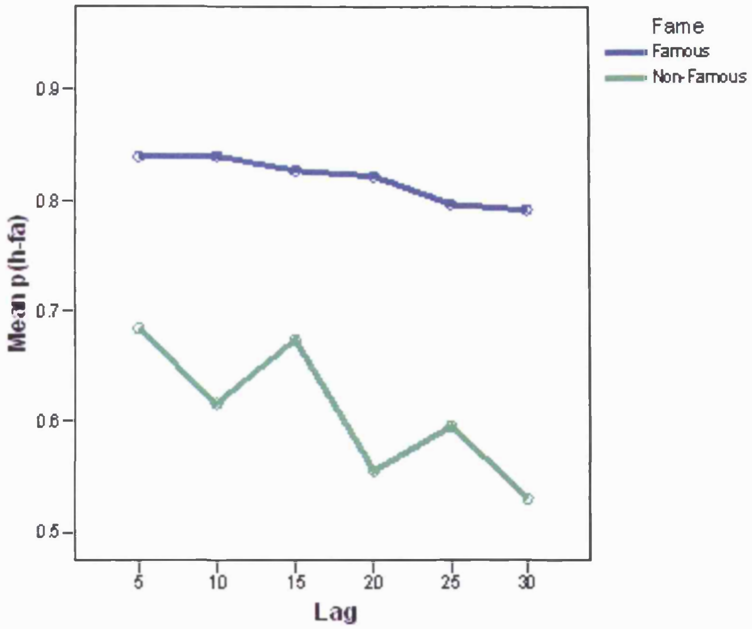

Figure 29. Mean Discrimination (n=18).

A 2x6 within subjects ANOVA revealed a main effect of fame ($F(1.0,17.0) = 99.92; p<0.001$) and there was also a main effect of lag ($F(3.8,65.3) = 10.31; p<0.001$), which came about because the overall level of recognition decreased as a function of increasing lag. There was also a statistically reliable interaction between lag and fame ($F(3.9,65.5) = 3.95; p<0.01$) which came about because recognition memory accuracy decreased with increasing lag at a greater rate for non-famous than for famous names.

JOR

An illustration of the JORs is provided in Figure 30 (p223). A 2x6 within subjects ANOVA with the categories of fame and lag revealed a main effect of lag ($F(2.7,45.2) = 117.51; p<0.001$), which came about because JOR increased as a function of increasing lag. There was no main effect of fame in this experiment. There was an interaction between lag and fame ($F(3.5,59.7) = 5.75; p<0.001$), which came about because famous names attracted shorter lag judgements at 2 lags only. Follow up paired t-tests revealed reliable differences across fame at lag 10 ($t(17) = -2.92; p<0.05$) and at lag 20 ($t(17) = -2.19; p<0.05$) with famous names receiving the shorter mean JOR in both cases.

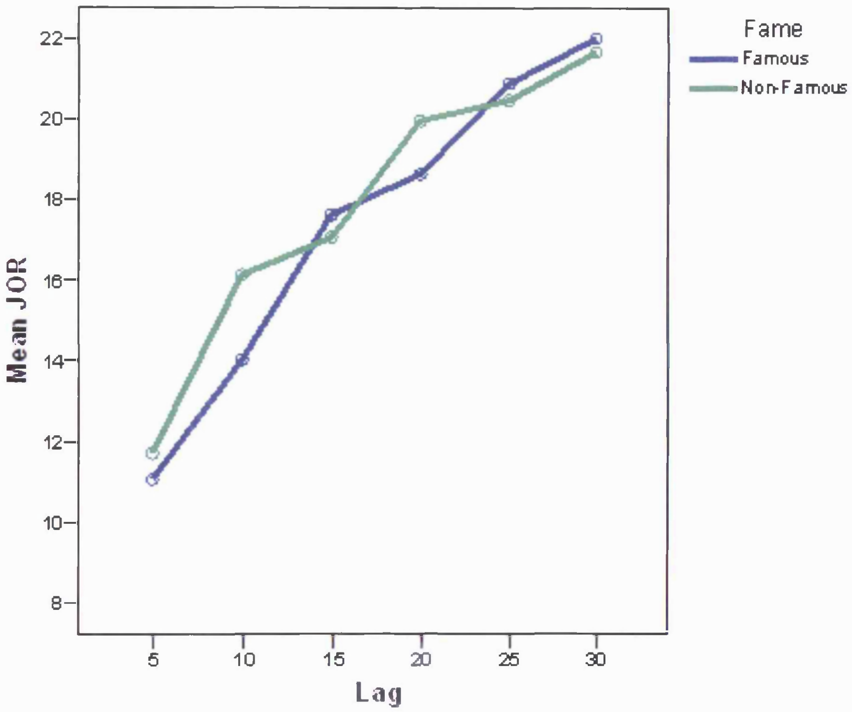

Figure 30. Mean Judgements of Recency (n=18).

Discussion

Experiment 6 was conducted in an attempt to uncover the reasons for the shorter lag judgements in the previous two experiments, where famous names were found to attract shorter lag judgements than non-famous names. This experiment was very similar to Experiment 4 with famous and non-famous names presented in a continuous memory task, with the exception that there was an initial study phase with non-famous names only. The study phase was designed to encourage deep encoding of the non-famous names. Asking whether a name sounds more like a circus performer or a librarian was intended to encourage conceptual processing to a greater degree than the manipulation that was employed in Experiment 5. It was anticipated that this deep encoding manipulation would enhance the level of contextual information available for these names at retrieval, in line with other deep encoding manipulations (e.g. Rugg et al., 1998).

As was described in Chapter 1 (p57), recollection is thought to be a memory process that indexes recovery of contextual information (Yonelinas, 2002). In this way, the volume (or strength) of that contextual retrieval might be used for JORs. If evidence was found to support this notion, then recollection would also fall under the bracket of distance information according to the Friedman (1993) categorization. It was reasoned that non-famous names would be more likely to elicit recollection at retrieval in this experiment, because of this 'deep' encoding manipulation, than they would in either Experiments 4 or 5. The prediction that follows from this is similar to that for Experiment 5. If the degree to which recollection is available forms the basis of JORs in a strength-based manner, then it would be expected that differences between JORs across fame conditions would be smaller in this experiment than in Experiment 4.

The recognition performance in this experiment was highly similar to that of Experiment 5, with recognition of famous names being much higher than the level of recognition for non-famous names at every lag. JORs across fame differed at only two lags. As for Experiment 5, therefore, these findings add little information about the processes supporting JORs, because while the pattern of reliable effects is not identical, it is broadly similar, again suggesting that either the experiment manipulation was not sufficiently strong, or that the processes influenced by the manipulation had little effect on the JORs.

Other research involving continuous recognition tasks have also failed to increase the availability of recollection through deep encoding (Jones & Atchley, 2007). In that research, participants were presented with a long list of items and an *old/new* recognition judgement was to be made in response to each word presented. The lags were 1, 5 and 20 intervening items in that experiment, and repeated items were either identical (e.g. Mother ► Mother) or were lure words (e.g. Blackbird ► Jailbird). Across experiments, participants continued to make more errors (i.e. accepting lure words as being *old*) at shorter lags despite attempts to enhance the use of recollection (which should decrease error rates). Manipulations included providing more time for encoding of the words and providing participants with feedback. Familiarity was thought to cause the pattern of error rates in this instance, since the error rates follow forgetting rates for familiarity (Jones & Atchley, 2007). Thus in the current experiment, the attempt to increase the availability or use of recollection appears to have failed.

Since in this experiment the pattern of JORs was very similar, it was possible that either the experiment manipulation was not sufficiently strong, or that the processes influenced by the manipulation had little effect on the JORs. The former possibility is thought to be reasonable in that the effects of the manipulations may be obscured because the contrast is between famous and non-famous names, rather than between the same class of stimuli that differ only according to whether they were encountered in a prior study phase. In this way it is possible that famous names are so strong due to years (in some cases) of prior exposure that non-famous names cannot be brought in line with this strength under these circumstances. Experiment 7 was designed to investigate this possibility.

EXPERIMENT 7

Introduction

To shed light on the findings in the previous behavioural experiments, the following experiment was devised. Though an increase in the familiarity of the non-famous items was expected in Experiment 5, the participants' JORs followed the same patterns as Experiment 4. It is possible that the manipulations in the two previous experiments failed to have any effect on memory strength. Experiment 7 was conducted to explore this possibility by comparing recency judgements of previously studied (prior to being presented in the continuous recency memory task) non-famous names, to non-famous names which had not been studied.

Method

This experiment was identical to Experiment 5, with the following exceptions:

Participants

Twenty-one participants aged between 18 and 24 years (mean age 20.1 years) took part in the experiment. One participant was excluded because they failed to understand the task, another two were excluded as outliers in the statistical analysis in the same way as Experiment 6. Of those included, 1 was male, each taking part in return for £5.

Stimuli

132 male non-famous names and 132 female non-famous names were used in this experiment (rated in a previous experiment – see Appendix 3, p318). An equal number (11) of female and male names were allocated to one of the 6 lags. 50% of the names were allocated as being 'Prior Study' items, 50% were allocated as being 'No Prior Study' items – an equal number at each lag.

Procedure

The participants took part in 3 experimental phases, with the final phase being the continuous memory task described in Experiment 4 (except that only non-famous names were included, 50% of which were studied prior to the recency task). In the first phase, participants were presented with half of the non-famous names in a random order (an equal number of male and female and an equal number to be presented subsequently at each lag). Each of these 'prior study' non-famous names was viewed for two seconds on the computer monitor with names presented sequentially. For each name presented, participants were asked to type the initials of the name during the blank interval. They had 1.5 seconds between names to complete this study task. Once finished this phase, participants were given a two minute break. Phase 2 was identical to phase 1, with the exception that the 'prior study' non-famous names were presented in a different random order. Before phase 3, participants were given another break of 2 minutes. Before beginning the final phase, participants were reminded to only press the *old* key if seeing an item for the second time in phase 3 only. The entire experiment took 60-70 minutes to complete.

Results

Recognition Memory

Recognition performance is shown in Figure 31. The mean probability of a false alarm was .06 for names with no prior study (SD .04) and was .18 names that had been studied in advance of the recency task (SD .10). There were also reliable differences across condition in the level of false alarms ($t(17) = -6.62; p<0.001$). Mean hit rates (minus false alarms) for studied and non-studied names were .65 (SD .17) and .63 (SD .16) respectively. *Old/new* discrimination of studied and non-studied names (p[hit] – p[false alarm]) was reliably greater than chance ($t(17) >12.90; p<.001$ at each lag).

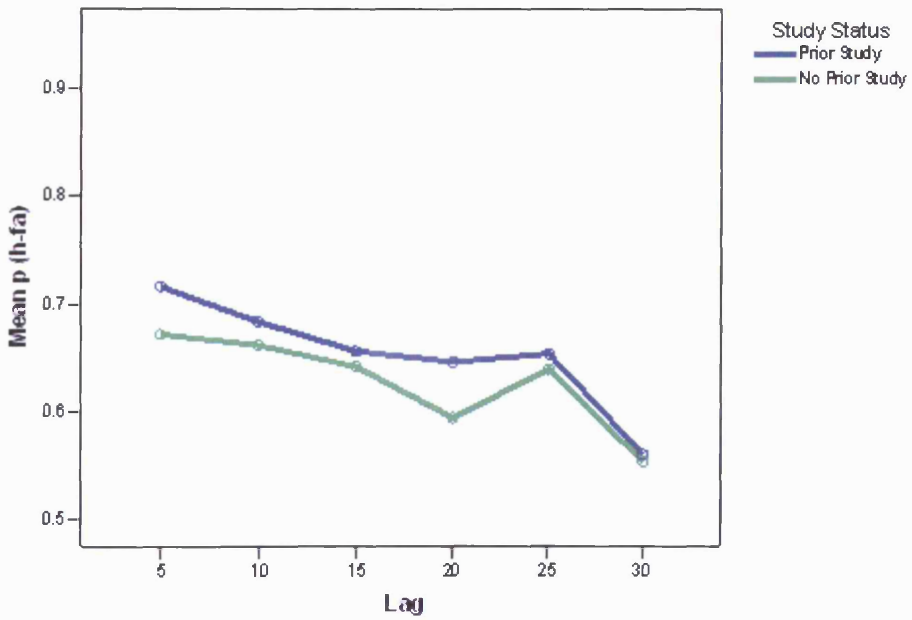

Figure 31. Mean Discrimination (n=18).

A 2x6 within subjects ANOVA revealed no main effect of study condition. There was a main effect of lag ($F(3.8,64.6) = 8.75; p<0.001$), which came about because the level of recognition largely decreased as a function of increasing lag in both conditions.

JOR

An illustration of the JORs is provided in Figure 32. A 2x6 within subjects ANOVA with the categories of study condition and lag revealed a main effect of lag ($F(3.6,61.1) = 142.23; p<0.001$), which came about because JOR increased as a function of increasing lag. There was no main effect of study condition in this experiment.

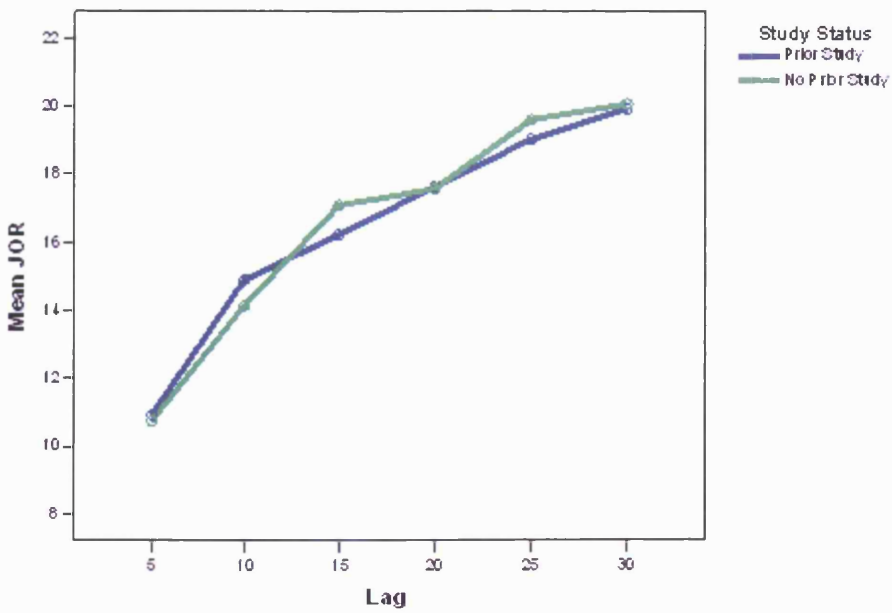

Figure 32. Mean Judgements of Recency (n=18).

Discussion

Experiment 7 was conducted in order to try to uncover the reasons for the lack of pattern change in the lag judgements found the previous two experiments. This experiment was adapted from the task used in Experiment 5, with the exception that only non-famous names were used in the continuous recency memory task. In the study phase, it was expected that half of the non-famous names from the recency task would be shallowly encoded. It was reasoned that studied non-famous names would become 'strong' in terms of familiarity. If studied non-famous names became 'strong' in this experiment, and if this form of strength is the basis of JORs, then it would be expected that differences between JORs across study conditions would be found in line with a distance account of recency (Friedman, 1993; 2001).

The recognition memory performance in this experiment demonstrated that as lag increased, discrimination diminished for both types of non-famous name. This finding is in line with the previous reported experiments, with the trend lines highly similar to those for the non-famous names in previous experiments. The markedly higher rate of false alarms for the studied category of non-famous names indicated that familiarity levels had been raised by the study manipulation (Wolk et al., 2006). In terms of JOR however, names studied in advance of the continuous memory task did not attract shorter lag judgements than non-famous names which had not been studied. When follow up t-tests were conducted (in light of the findings in the previous two experiments which justified this analysis), JORs did not differ at any lag.

There are at least two possible reasons for this pattern of findings. It is possible that memory strength (in the form of familiarity) is used for making recognition and recency judgements, but that the manipulation in this experiment was not sufficient to demonstrate this influence here. Evidence to suggest that this is a reasonable consideration can be established by looking at the false alarm data. Participants did make more false alarms for prior study items, compared to no prior study items. This suggests that familiarity was increased at least to some extent (Yonelinas, 2002), leaving open the possibility that this increase was just not sufficient to influence the levels of discrimination or the lag judgements. It is also possible however, (and entirely consistent with the findings in Experiment 5) that familiarity is not the basis for JORs in this task, or for these kinds of stimuli. In order to investigate these issues further, Experiment 8 was devised.

The next step in this series of experiments was to assess in a different way whether memory strength in terms of *recollection* is related to judgements of recency. After the results of Experiment 4 were obtained, the aim in Experiments 5 and 6 was to employ manipulations of recollection and familiarity that might bring the judgements of recency for the non-famous names in line with those of the famous names, and if successful, this could have shed light on the processes supporting JORs. A related approach is to focus on the strength levels of the famous names.

As was outlined in the introduction of this chapter, one benefit of using famous and non-famous names is that the level of strength varies across participants according to the name. For example, one is likely to recognise both Julia Roberts and Michael Owen – both examples from the high strength famous name category of stimuli. However, it is still possible to have a variation in the level of memory strength (in terms of familiarity or recollection) within the high strength category. These properties of names can be employed to provide insights into how memory strength influences JORs in continuous recency memory tasks in line with a distance account of recency memory (for a review, Friedman 1993; 2001).

EXPERIMENT 8

Introduction

An experiment conducted by Brown et al. (1985) provided evidence to suggest that memory strength predicts recency judgements. In this study participants were presented with a series of public events and were asked to demonstrate their level of knowledge about each event. A second set of participants were then asked to provide a rating of how long ago these events had occurred. The results of this study suggested that the level of knowledge was more related to recency judgements than was the actual date of the event (Brown et al., 1985).

The aim of Experiment 8 was to investigate the reasons for Experiment 4, where famous names attracted shorter lag judgements than non-famous names in a continuous recency memory task. Rather than attempting to artificially manipulate the strength levels of the non-famous names (as had been done across Experiments 5-7), the aim here was to assess the pre-experimental levels of memory strength for the famous names. Though the famous names used in this series of behavioural experiments had been previously rated as being highly recognisable in comparison with non-famous names, the level of knowledge participants have for each name may vary. For example, one might recognise the name 'Frank Sinatra' and know that this man is highly famous, but in actual fact, one might know much more about the name 'Julia Roberts'. This could be the basis of a continuum of memory strength. A famous name could be highly familiar, could elicit the recovery of many semantic facts, and could elicit the recovery of more contextual episodic information during recollection.

These separately or in combination could be the basis of judgements of recency, or at least be contributing factors.

Using famous and non-famous names, it was therefore possible to assess the level of strength for famous names prior to the continuous recency memory task. Participants were asked to provide an indication of their memory strength for each famous name in terms of facts on the day before the continuous recency memory task, along with a famous name fame rating (immediately after the continuous recency memory task). It was expected that memory strength assessed in these ways would be related to the recency judgements of the famous names.

Method

The method for Experiment 8 was identical to that for Experiment 4, with the exception of the following:

Participants

Twenty-three participants aged between 19 and 30 years (mean age 21.2 years) took part in the experiment. Three participants were excluded because they did not perform well enough (hit rate below 50% for non-famous names), and a further two were excluded because they failed to complete the study task. Of those included, 9 were male. Participants were paid £15 for taking part in this experiment.

Stimuli

In the first phase of the experiment, there was what can be regarded as a deep encoding task with famous names. These were presented in a random order for each participant on an Excel spreadsheet. In the top row of the spreadsheet were the famous names (one in each column). Beneath the top row were ten rows of blank cells. Beneath these rows on the spreadsheet, there was a duplication of that described, except that the stimuli were place names (e.g. France, Rwanda, etc).

Procedure

The participants took part in 3 phases, the second phase being the continuous recognition and recency task detailed in Experiment 4. In the first phase, participants were presented with the famous names in a random order. Participants were asked to type bullet point facts which they could recall about each person name on the list. Participants were asked to type a maximum of 10 facts (one in each cell beneath the name) and were asked to spend no more than 60 seconds on each name. Participants were asked to fill out the cells corresponding to the place name only in the event that they did not recognise the person name (this was done to prevent participants skipping names to finish the task more quickly). Once finished this phase, participants were asked to return the following day, and not attempt to recover any further information about the famous names on the list before their return.

Phase 2 was identical to Experiment 4 and was completed 24 hours after the start of phase 1. Following phase 2, participants were asked to complete phase 3. Here participants were presented with the list of famous names in random order on an Excel spreadsheet and were asked to give a rating for each name on a scale of 1-6, the scale denoting how strongly they recognised the name. The scale went from 1 (highly recognise) to 6 (I do not recognise). Participants were asked to base these ratings on their personal semantic knowledge. The entire session took 50-60 minutes to complete on day 2 and 110-130 minutes on day 1.

Results

Recognition Memory

Discrimination is shown in Figure 33. The mean probability of a false alarm was .04 for famous names (SD .04) and was .07 for non-famous names (SD .06). There were reliable differences across fame in the level of false alarms ($t(17) = -2.25; p<0.05$), with this being marginally greater in the non-famous condition. Mean discrimination (hits minus false alarms) for famous and non-famous names was .86 (SD .11) and .61 (SD .13) respectively. *Old/new* discrimination for famous and non-famous names (p[hit] – p[false alarm]) was reliably greater than chance ($t(17) > 10.10; p<.001$ at each lag).

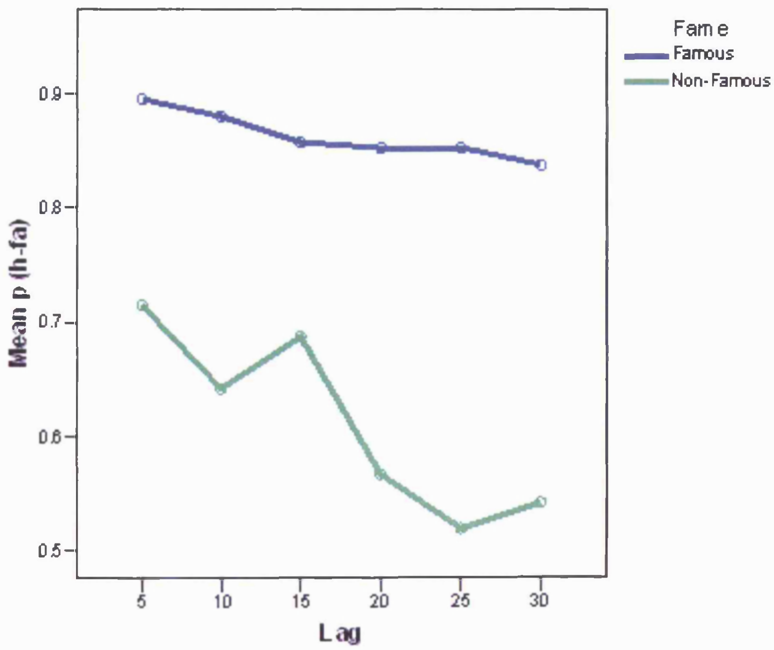

Figure 33. Mean Discrimination (n=18).

A 2x6 within subjects ANOVA revealed a main effect of fame ($F(1.0,17.0) = 64.09; p<0.001$), which came about because famous names were recognised to a greater degree. There was also a main effect of lag ($F(4.0,67.8) = 10.33; p<0.001$), which came about because the level of recognition largely decreased as a function of increasing lag in both conditions. There was also a statistically reliable interaction between lag and fame ($F(3.4,58.1) = 5.86; p<0.01$) which came about because recognition decreased with increasing lag to a greater extent in the non-famous condition. Follow up paired t-tests revealed statistically reliable differences at each lag between famous and non-famous names ($t(17) > 5.22; p<0.001$, in each case).

JOR

An illustration of the JORs is provided in Figure 34 (p239). A 2x6 within subjects ANOVA with the categories of fame and lag revealed a main effect of fame ($F(1.0,17.0) = 5.37; p<0.05$), which came about because famous names attracted relatively shorter lag judgements than the non-famous names. There was also a main effect of lag ($F(3.0,51.6) = 192.15; p<0.001$), which came about because JOR increased with increasing lag. There was also an interaction between lag and fame ($F(3.6,60.6) = 3.33; p<0.05$). Follow up paired t-tests revealed reliable differences across fame condition at lag 5 ($t(17) = -2.49; p<0.05$); and at lag 10 ($t(17) = -3.84; p<0.001$) and at lag 20 ($t(17) = -1.87; p<0.05$) with famous names receiving the shorter mean JOR in all cases.

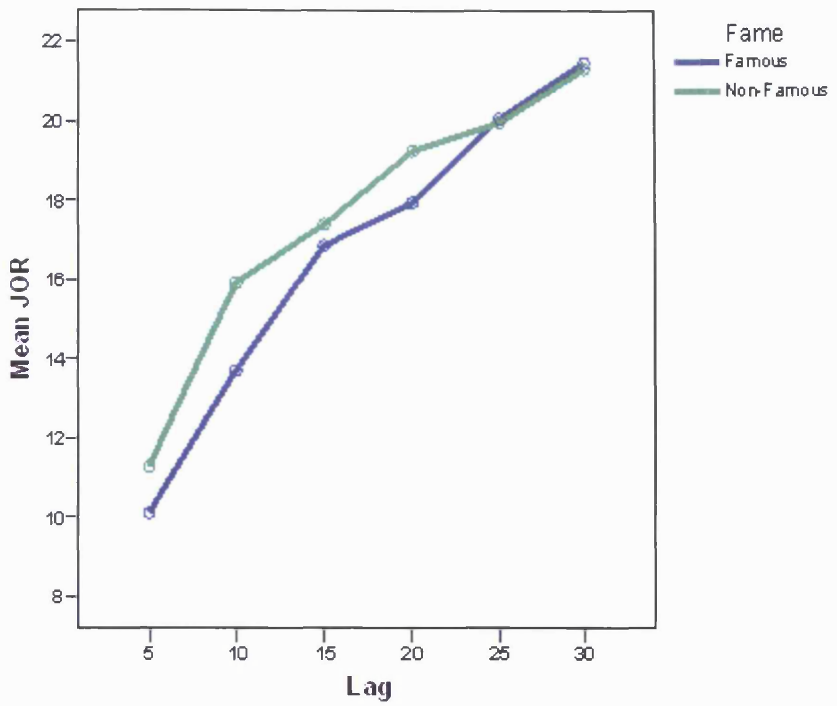

Figure 34. Mean Judgements of Recency (n=18).

Fact Recall and Fame Rating

The mean number of facts recalled across participants was 4.03 (range 1-10; SD = 2.40) and the mean fame rating given was 2.42 (range 1-6; SD = 1.44). To assess whether the level of fact recall and the fame ratings given by participants were meaningful, a correlation analysis was conducted to assess whether these dependent variables were related. There was a negative correlation between the number of facts recalled for a name and the fame rating given for that name ($r = -.39$, $n=18$, $p<0.001$). This shows that as the rating given for a famous name decreased, the number of facts recalled for that famous name increased. This suggests that participants were consistent when asked to demonstrate their level of knowledge for each famous name (since a rating of 1 meant the name was recognised to the greatest degree, and a high level of fact recall indicated high levels of name recognition).

Since there was evidence to suggest that fact recall and fame rating were treated meaningfully by the participants, it was important for the experimental question to identify whether either of these variables predicted JORs. This was tested via multiple regression, where actual lag and fact recall were simultaneously entered as independent variables. JOR was the dependent variable. The overall regression was significant (ANOVA result: $F(2,2133) = 428.76, p<0.001$. Adjusted R square = .286). The effect of actual lag and fact recall on JOR is shown in the results below:

Predictor Variable	**Unstandardised Beta**	***p***
Actual Lag	.444	p<0.001
Fact Recall	-.192	p<0.001

(Fame rating was not a significant predictor.)

This data shows that with each unit increase in actual lag, the JOR rating increased on average by .444, and with each unit increase in fact recall, the JOR *decreased* by .192. Both of these results were significant at $p<.001$ and were as predicted. While it is clear that more variance in the DV was predicted by actual lag than fact recall, this would be expected, and critically this method ensured that the effect of actual lag on JOR was controlled for when examining the effect of fact recall on JOR.

As a follow up to this result, the same regression was carried at each individual lag. These analyses revealed a significant result was obtained at lags 10 and 30 (F(1,361)

>3.94,p<0.05 in each case). Furthermore, there was a trend for a reliable result at lag 15 (F(1,352) = 2.80;p=0.96).

Discussion

Experiment 8 was conducted in an attempt to uncover the reasons for the patterns of lag judgements in the Experiments 4-6, where famous names were found to attract shorter lag judgements than non-famous names across a range of lags. This experiment was effectively a replication of Experiment 4, with the exception that there was an initial study phase with famous names 24 hours before the continuous recency task, and that there was a fame rating task after the continuous recency task. In the study phase, the level of pre-experimental information was measured for each name, to give some indication of the memory strength level for each famous name.

In line with the earlier experiments, it was reasoned that famous names would be 'strong' in terms of memory and that this would lead to them attracting shorter mean lag judgments than the 'weak' non-famous names, in line with distance theory of memory for recency (Friedman, 1993; 2001). It was also predicted that fame ratings provided by participants for each name (after the recency task) would provide a subjective measure of memory strength for each famous name, and that this too would predict JORs in the famous name condition.

Old/new discrimination in this experiment was highly similar to that in Experiments 4, 5 and 6, with discrimination of famous names being much higher than the level of discrimination for non-famous names at every lag. Differences in discrimination levels were again greater than that demonstrated in the Hintzman work (2003; 2005), though performance largely followed the same pattern, with discrimination decreasing with increasing repetition interval – though once again less steeply for the 'high strength' condition compared to the 'low strength' condition.

In this experiment, famous names attracted shorter lag judgements than non-famous names. When follow up t-tests were conducted, JORs across fame differed at the same three lags as in Experiments 4 and 5, and were similar to the findings in Experiment 6. This study provided further support for Hintzman's (2005) view that strength underlies recency memory at least in part, in continuous memory tasks of this kind. When memory strength is high, events experienced for the second time appear more recent than when memory strength is low.

A novel finding in this experiment is that the level of distance information available (in the form of memory strength) predicted JORs. This is consistent with the behavioural findings of Brown et al. (1985), who assessed levels of knowledge for public events and recency memory and found them to be related. The previous research showed that actual recency was less related to recency judgements than was level of factual knowledge about the public events (Brown et al., 1985). This pattern is inconsistent with the current findings, where actual lag was a better predictor than pre-experimental strength levels for the famous names. It is likely that this discrepancy is due to differences in the type of recency task employed. In Experiment 8, a within-subjects memory task was used to explore recency, where the time between the first and second presentation of the items was relatively brief. This is unlike Brown et al.'s (1985) between-subjects task, where the second presentation was between one day and months later. The current experiment appears to be the first demonstration that pre-experimental memory strength is a predictor of memory for recency in a subsequent continuous memory task where only distance information is likely to be available to participants.

What is the basis for memory strength? Assessing the levels of familiarity, recollection and or semantic information could all constitute distance information and may have predicted JORs in this experiment. It has been suggested earlier in this thesis that familiarity could be utilised in strength-based recency judgements, and some support for this was predicted by the findings in Experiment 3. Despite this evidence, the study task used in this experiment (where participants were asked to demonstrate their levels of pre-experimental knowledge for famous names) means that episodic familiarity may be unlikely to underlie memory strength levels here because the study task was contextual in nature, and the levels of contextual or semantic information predicted famous name lag judgements. The task used in Experiment 8, along with the finding of Chalmers and Humphreys (1998) that increases in pre-experimental contextual levels for words were associated with later recency accuracy for those words, suggests that contextual recovery is a more likely basis for the divergences in JORs than familiarity under these circumstances. Though familiarity was likely to vary according to lag judgements in the experiments reported in this thesis, the findings of the current experiment would suggest that this was not the basis of recency judgements in the kind of task employed here. The role of familiarity in JORs will be discussed further in the General Discussion (Chapter 7).

Finally, there was no evidence that levels of familiarity for famous names had been raised in this current experiment by the study task, since false alarms for the non-famous names were higher in the continuous memory task than famous names, despite the prior deep encoding task. This could suggest that for famous names, the level of strength experienced is so strong that presenting them just once before the experiment does not noticeably increase their strength levels. Experiments 5 and 7 show that the level of strength, in the form of familiarity, can be somewhat increased for non-famous names however (as indicated by the heightened levels of false alarms for this category), since the strength levels are low for these names pre-experimentally and therefore any increase in familiarity will be relatively larger for this category.

The finding that fact recall was related to the fame rating given to each famous name suggests that the participants approached these tasks with consistency. If these variables had not been related it might have suggested that participants were not motivated to provide meaningful demonstrations of their knowledge of the famous names. Despite this relationship, there was little evidence to suggest that fame rating predicted JORs in this experiment. One possible reason for this outcome is that there was not enough variance in this measure. It could be that the participants found it more difficult to demonstrate their level of memory strength across names in this manner, in comparison with the fact recall task.

A recurring finding across Experiments 4-6 and 8 is that judgements of recency did not vary across conditions at lags 15, 25 and 30, which is inconsistent with some previous research where differences across low and high strength items were found at every repetition interval (Hintzman, 2005). It has been noted that the longer lag judgements tended to converge in Hintzman's (2003) continuous memory experiment and that this could be explained by the fact that participants were less accurate at the longest lags, in line with the reduction in their recognition levels. This is consistent with the idea that discrimination at the two longest lags would be hardest since the distance between these lags would be proportionally smaller in comparison to the other lags (i.e. lag 10 is double lag 5 in terms of 'distance', whereas lag 25 is only 20% more recent than lag 30).

The lack of difference between high and low strength items at lag 15 could stem from the greater recognition level for non-famous names at this lag. It might be the case that when non-famous names are recognised to a greater degree than other non-famous names, the JORs become more accurate for the better recognised lag. Thus, when participants' recognition for non-famous lag 15 items increases (for whatever reason) then their lag judgements also improve. However, doubt about this suggestion comes from the lag 5 data where participants have superior recognition performance, but less accurate JORs in comparison with lag 15 data.

Another potential reason that lag 15 JORs do not differ across fame is that the lag 15 category is treated as a favoured response option by participants. Across experiments, lag 15 is the last point at which participants' mean lag judgement is an over-estimation. Figures 26, 28 and 30 show that at lag 20 (another 'middle' lag) participants begin to give under-estimated lag judgements. This finding, coupled with the fact that in this series of behavioural experiments participants made lag 15 judgements more than any other lag, suggests that a lag 15 response may be a default response option when uncertain. If and how this might be related to the lack of difference across fame at this repetition interval is something which requires future investigation. Conducting experiments with lags of (for example) 15-60 could be one way to shed light on this issue.

In summary the final experiment in the behavioural series has provided evidence in support of the notion that strength-based memory processes support recency judgements in a task that is considered to be devoid of location or relative information. The findings reported in Experiment 8 are in line with the ERP data, suggesting that distance information is a valid category in the Friedman (1993) framework of memory for recency.

CHAPTER 7 – GENERAL DISCUSSION

The reason for conducting the experiments reported in this thesis was to investigate the nature and number of memory processes that might support relatively short recency judgements. As outlined in Chapter 1, there are broadly three classes of information that could be used to form judgements of recency: relative, location and distance information (Friedman, 1993). In making judgements of recency, one could use these information types either individually, or in combination (Janssen et al., 2006). The principal goal in the experiments described here was to investigate memory for recency when relative and location information are either unavailable or are of limited use, and to understand what cognitive processes might underpin the strength subcomponent of distance information. Few studies have explored questions about how many memory processes might support recency judgements in circumstances where distance information is likely to be utilised, and so the experiments reported in this thesis are likely to contribute towards an understanding of these issues.

It is important to understand the mechanics of recency memory because this is an important cognitive ability and it is one that may deteriorate more rapidly than some other kinds of memory abilities as age increases (e.g. Bastin, Van der Linden, Michel & Friedman, 2004; Fradera & Ward, 2006). The experiments in this thesis involved either a combination of behavioural and electrophysiological (ERP) findings, or behavioural findings alone. In keeping with the order of the work described above, in the proceeding sections the ERP findings are described first, followed by the behavioural studies in which famous and non-famous names were employed as stimuli.

ERP Findings

Three ERP experiments have been reported in this thesis. They were designed with the aim of investigating i) how many memory processes contribute to judgements of recency where the strength subcomponent of distance information is available to participants, and ii) the nature of any such processes. Using tasks similar to those used in the Hintzman (2003; 2005) series of behavioural experiments, it was assumed that access to relative and location categories of recency-based information would be highly limited. Since the tasks were continuous, it was unlikely that participants could use relative ordering information for their JORs. With a long list of at least 398 trials and 5-35 intervening items between repetition lags across experiments, it is difficult to envisage how participants might be continually comparing the relative list positions of items. The use of location information is also unlikely in the experiments reported in this thesis, since the continuous recognition and recency tasks were devised to be largely free of contextual landmarks, as was outlined in Chapter 1. The stimuli used contained no recency information directly in that they were words and not times or dates. Thus, it is likely that one can rule out the use of location information.

One reason for acquiring ERPs in these memory tasks was because it provided a means of addressing questions about recency processing that had not been explored previously. This involved recording ERP activity during continuous recency tasks so that it was possible to analyse the neural responses associated with correct recency judgments, as well as two kinds of incorrect responses, comprising under- and over-estimates of lag, respectively. This is a useful contrast, because a strength-based ERP signature should behave differently for these two kinds of incorrect responses. If the size of an ERP memory effect indexes memory strength, and if an assessment of memory strength is used as a basis for recency judgments, then larger ERP memory effects should accompany shorter recency judgments.

A second reason for employing ERPs was because of a body of previous research that has demonstrated that ERPs are sensitive to the processes of recollection and familiarity (e.g. Curran, 2000; Wilding & Rugg, 1996). In so far as these claims are correct, then analysing the ERP data acquired in recency tasks offers a means of assessing how these two classes of memory process might support recency judgments under different circumstances. These possibilities were explored by analysing the specific parts of the electrical record that have been linked to familiarity and recollection. For the former, this comprised analyses at anterior scalp locations in the 300-500ms time-window. For recollection, this comprised analyses at posterior locations in the 500-800ms period.

ERP Experiment 1

The first ERP experiment reported in this thesis provided evidence that ERP *old/new* effects could be obtained in a continuous recognition and recency memory task, in line with previous findings (e.g. Friedman, 1990). The ERP *old/new* effects that were obtained for correct recency judgments varied across epochs in a manner similar to that observed in previous ERP studies where recognition memory and source memory judgments have been required (e.g. Wilding et al., 1995; Wilding & Rugg, 1996). In this first experiment, there was one repetition lag only (15); however participants were not aware of this and could choose to give lag 10, 15 or 20 responses when making their lag judgements. ERPs did not vary reliably according to JOR in this experiment. Figures 35 and 36 (p250) show that there were small differences in the predicted direction between the ERPs associated with shorter and longer lag judgements over the electrode locations and time-windows associated with familiarity and with recollection.

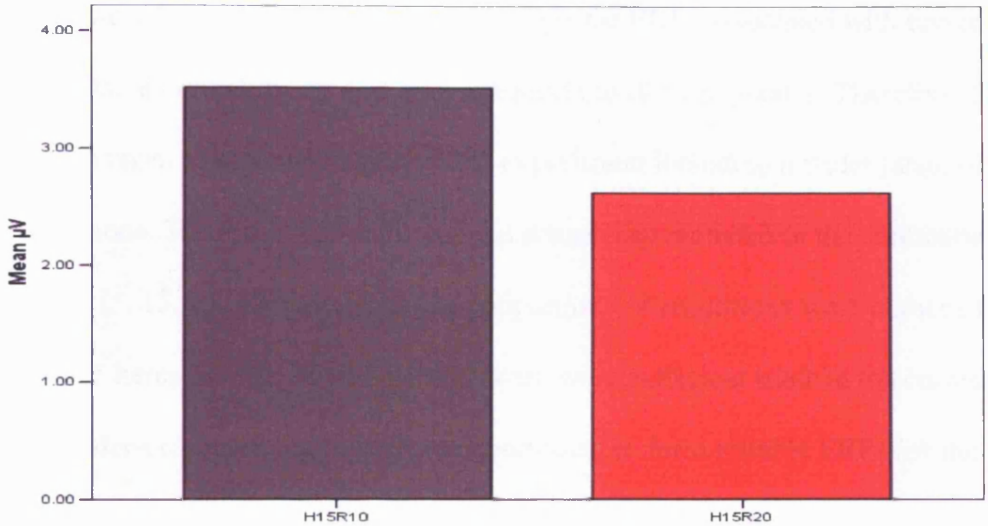

Figure 35. Mean amplitude of the 300-500ms frontal (collapsed across F3,Fz,F4) electrical activity associated with lag 15 hits attracting over-estimated lag judgements (red bars) and lag 15 hits attracting under-estimated lag judgements (grey bars) (n=18).

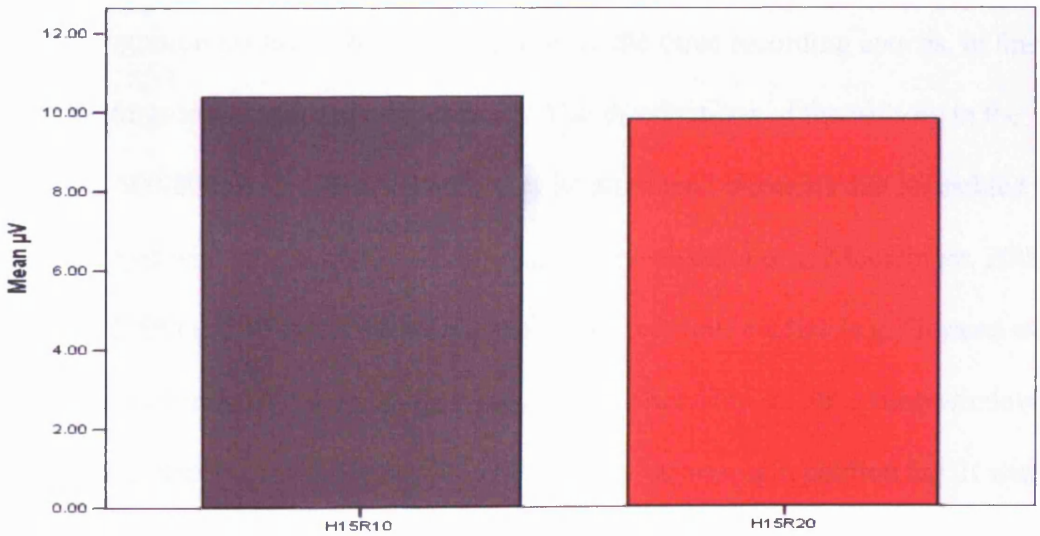

Figure 36. Mean amplitude of the 500-800ms posterior (collapsed across P3,Pz,P4) electrical activity associated with lag 15 hits attracting over-estimated lag judgements (red bars) and lag 15 hits attracting under-estimated lag judgements (grey bars) (n=18).

As was discussed in Chapter 3 among other possibilities, one explanation for the fact that only trends were evident is that, since all stimuli were repeated after only one lag, and since there was only a narrow range of response options, the absence of differences arose because there was limited scope for ERPs associated with correct lag judgments, under-estimates and over-estimates to diverge greatly. Therefore, the decision was taken to conduct another ERP experiment including a wider range of response options. These options reflected the actual lags included in the continuous recency task (5, 15, 25, 35), although the proportions of repetitions were higher for lag 15 and 25 items in order to ensure that there were sufficient trials in the correct, over- and under-estimated lag judgement conditions to form reliable ERPs for items from these two lags.

ERP Experiment 2

The second ERP experiment reported in this thesis provided evidence that ERP *old/new* recognition memory effects changed over the three recording epochs, in line with the findings in the previous experiment. The distributions of the activity in the 300-500ms, 500-800ms and 800-1100ms epochs contained elements that resembled those associated with the processes of familiarity, recollection (e.g. Mecklinger, 2000; Rugg et al., 1998) and with executive processing in previous studies (e.g. Hayama et al., 2008). Importantly, in Experiment 2 there was evidence in all three time-windows that these ERP effects diminished in magnitude with increasing repetition lag. It was not possible to obtain this evidence in Experiment 1, because only one lag (15) was employed. The reason that this finding is important, is because any aspects of the electrical record that are candidates for indices of processes that might be employed in a strength-based fashion in recency judgements should be found to change as lag increases.

Identification of such effects is a necessary but not however, a sufficient condition to support the claim that the effects of interest actually support JORs. It may be the case that the effects signal recency, but do not index processes that can be employed in order to make recency judgments. In order to fulfil this second criterion, the ERP effects of interest should vary according to the recency judgments with which they were associated. In this experiment there was only limited evidence to suggest that this was the case.

The key contrasts in Experiment 2 involved ERPs associated with correct and incorrect JORs for lag 15 and lag 25 items. Few reliable differences were observed for lag 15 items, except that over-estimated lag judgements were associated with less positivity over posterior locations in the 500-800ms epoch compared to those attracting a correct lag judgement. This planned comparison provides some evidence that the strength subcomponent of Friedman's (1993) distance information is utilised for making JORs in the time-window and location associated with recollection (e.g. Wilding, 2000).

For lag 25 items, there was some evidence that correct judgements were associated with greater positivity than over-estimated lag judgements in the early (300-500ms) time-window at frontal sites. However, there was no further statistical evidence in support of this in the directed follow up analyses at sites F3, Fz and F4. Figure 37 (p253) shows that there are only minimal differences at these locations. In the middle

(500-800ms) epoch, there was some evidence to suggest that under-estimated lag 25 items elicited more positive-going activity over posterior electrode locations than over-estimated items. In so far as greater positivity indexes greater memory strength, and greater strength attracts shorter recency judgments, then this finding is consistent with the view that this aspect of the electrical record indexes a strength-based memory process that can be used for JORs in line with Friedman's (1993) distance information. The time course and distribution of the effect also encourages the claim that the process providing distance information here is recollection: effects with similar time courses and topographies have been linked to this process in numerous previous studies (e.g. Rugg et al., 1996; Wilding et al., 1995). Again however, stronger support for this claim would have been to provide evidence of this in the outcomes of subsequent focal analyses (see Figure 38, p254).

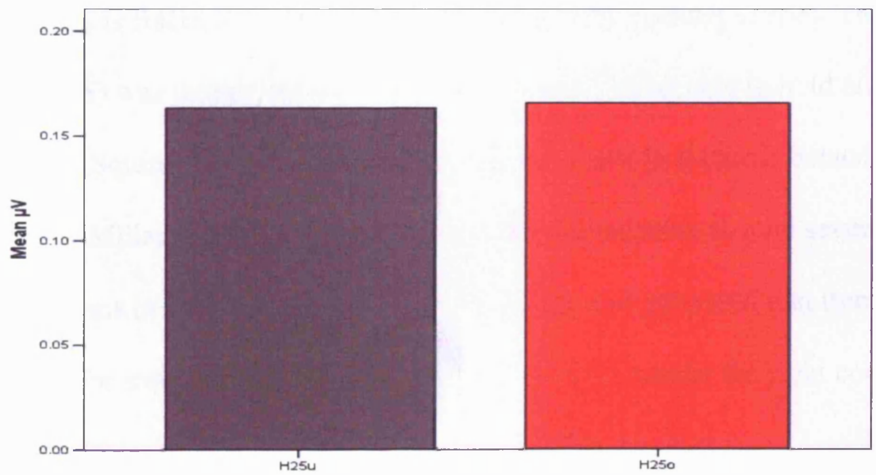

Figure 37. Mean amplitude of the 300-500ms frontal (collapsed across F3,Fz,F4) electrical activity associated with lag 25 hits attracting over-estimated lag judgements (red bars) and lag 25 hits attracting under-estimated lag judgements (grey bars) (n=17).

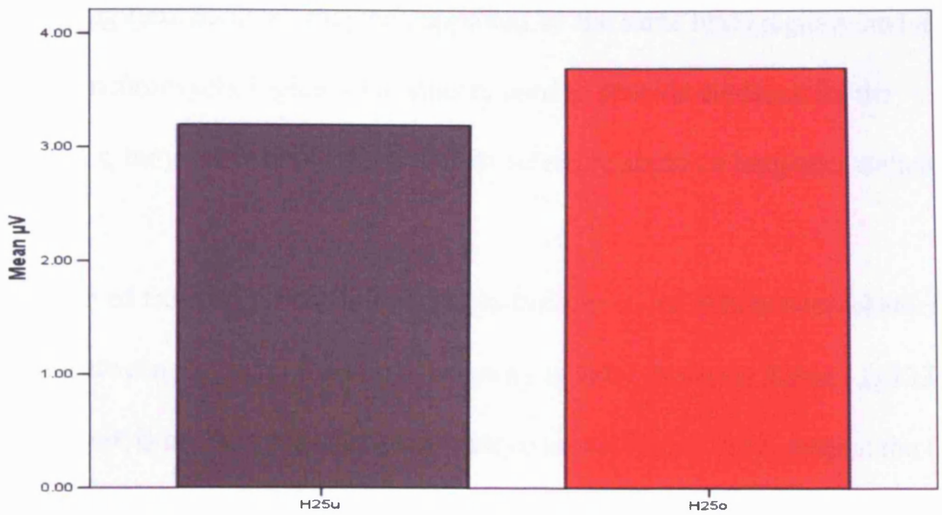

Figure 38. Mean amplitude of the 500-800ms posterior (collapsed across P3,Pz,P4) electrical activity associated with lag 25 hits attracting over-estimated lag judgements (red bars) and lag 25 hits attracting under-estimated lag judgements (grey bars) (n=17).

One interesting point worthy of note here is how the findings in Experiment 2 relate to a long-term vs. short-term memory distinction. Atkinson and Shriffin proposed that human memory is fractionated into short- and long-term memory (1968). The short-term store (STS) was thought to be of limited capacity, being able to hold around 6-8 items (Cave & Squire, 1992). This was first demonstrated in a classic behavioural experiment by Miller (1956) who showed that people can store around seven consecutive items in their immediate memory. It was also proposed that items held in the STS could be transferred to the long-term store (LTS) under the right conditions and that the LTS has potentially limitless capacity. The fact that some amnesic patients present with impaired long-term memories, but with normal short-term memory capacities (Baddeley & Warrington, 1970), lends support to this division. Some, however, do not accept the multiple systems account. For example, Ranganath and Blumenfeld (2005) reviewed the evidence for the short- and long-term memory distinction, and have argued on the basis of neuropsychological and brain imaging data, that these are part of the same memory system. The researchers point out that short- and long-term memory may be supported by the same brain regions, and also note that the neuropsychological case studies used to provide evidence for the separate stores, may not actually demonstrate selective short- or long-term deficits.

The data derived from Experiment 2 cannot contribute to the debate over whether the distinction between short and long-term memory is valid, however Table 3 (p133) shows that there is no drop off with performance across lags 5 to 15, despite the fact that the longer lag presumably depends on long-term memory whilst arguably the short lag might also receive a contribution from short-term memory (e.g. Cave & Squire, 1992). If items were to be transferred into a long-term memory store, participants would require time to rehearse the items in the continuous recency memory task. The structure of the task implemented in the experiments throughout this thesis is such that participants would have little if any time to rehearse the presented items, therefore a drop in recognition of items would be expected after lag 5 according to this dual process view. In terms of the neural data, there is no reason to expect that a change in the cognitive systems supporting recency memory would occur across the very short-term lag (5) and later lags (15-35) if familiarity and recollection support JORs, since both the mid-frontal ERP effect and left parietal *old/new* effects are present for at least 24 hours after an item in memory has been presented (Curran & Friedman, 2003; 2004).

In terms of recency, the patterns in the data obtained in Experiment 2 were encouraging, and for this reason, a third experiment was designed, in which an additional attempt to maximally separate ERPs associated with correct and incorrect lag judgements was incorporated. The change in Experiment 3 was motivated by the concern that some of the null results in the second experiment came about because there was not an even distribution of items at each of the four lags. In Experiment 2, there were markedly fewer items for the two extreme (high and low) lags, but participants were not informed of this disparity. As a result, participants may have been responding on occasions according to what they believed was likely (in terms of an even spread of items repeated across the 4 lags), rather than simply on the basis of relevant mnemonic information that they had to hand (for a discussion, Postma, 1999). The final ERP experiment was devised to address these concerns.

ERP Experiment 3

ERP Experiment 3 involved a shorter experiment than the previous two, along with just three repetition lags (5, 15 and 25). There were equal numbers of items repeated at each of the lags. In this experiment, the pattern of response accuracy meant that robust ERPs could not be formed for both under- and over-estimates for a single lag. Instead, correct and over-estimated lag judgements for lag 5 items were compared, along with correct and under-estimated lag judgements for lag 25 items. In terms of the *old/new* effects, there was strong evidence that the ERP *old/new* effects diminished with increasing actual lag in all three time-windows. This finding was consistent with that in Experiment 2, although not with all previously reported results.

Rugg & Nagy (1989) analysed *old/new* effects in a continuous recognition memory task where words were repeated after either 6 or 19 intervening words. There were no reliable differences between the magnitudes of the *old/new* effects for words re-presented at either lag, despite superior *old/new* discrimination at the shorter lag. It may be the case that the use of data from only 12 participants in that study, alongside the acquisition of data from only 5 electrodes (3 midline and two inferior temporal locations) reduced the opportunity to observe changes in effect sizes with lag. An interpretation of the null result in this way also gains some support from work showing that familiarity does decline over these kinds of lag separations (Yonelinas & Levy, 2002).

These methodological considerations cannot be applied to the data reported by Curran & Friedman (2004), who did not observe differences between the magnitudes of *old/new* effects for items repeated after either 34 mins, 39 mins, or 24 hrs. A similar null result has also been reported by Wolk et al. (2006), who contrasted *old/new* effects for words where the gap between presentation and re-presentation was either 39 mins or 24 hrs. In this case, *old/new* discrimination was lower for words re-presented one day later. Wolk et al. confounded lag with encoding task, however as an equal number of words re-presented at short or long lags were presented either once or three times at study (2006). All of the data presented was collapsed across number of study presentations, thereby making it difficult to assess how this element of the design influenced the behavioural and ERP data that was obtained.

In summary, of these previous studies, the one which is most comparable to the studies in this thesis (because of the contrast across similar lag intervals) is Rugg & Nagy (1989). It may be the case that the absence of changes in *old/new* effects with lag in their study came about because of a combination of reduced power and limited coverage of the scalp. Rugg & Nagy however, required only an *old/new* judgment of participants, whereas in the studies conducted for this thesis, recency judgments were also required. It is not possible to rule out this task-demand difference as a contributor to the disparate findings. The key point for the thesis however, is that changes in the magnitudes of effects with lag are a necessary pre-cursor to analyses that determine whether these electrophysiological modulations also change with the accuracy of lag judgments.

In this regard, the central and most critical finding in this experiment, and in this series of ERP studies, was that incorrect (longer) JORs to lag 5 items were associated with relatively reduced levels of positive-going ERP activity compared to correct lag 5 JORs, whereas incorrect (shorter) JORs to lag 25 items were associated with relatively more positive-going ERPs than correct JORs to lag 25 items. This was the case in both the early time-window (largest over the front of the head), and in the middle epoch (see Figures 39-41, p259-261). In addition, in the late time-window, under-estimated judgements to lag 25 items were associated with more positivity relative to correct lag 25 JORs. This was inconsistent with the findings in Experiment 2, where over-estimated lag judgements were associated with the greatest level of positivity (Figure 13, p157).

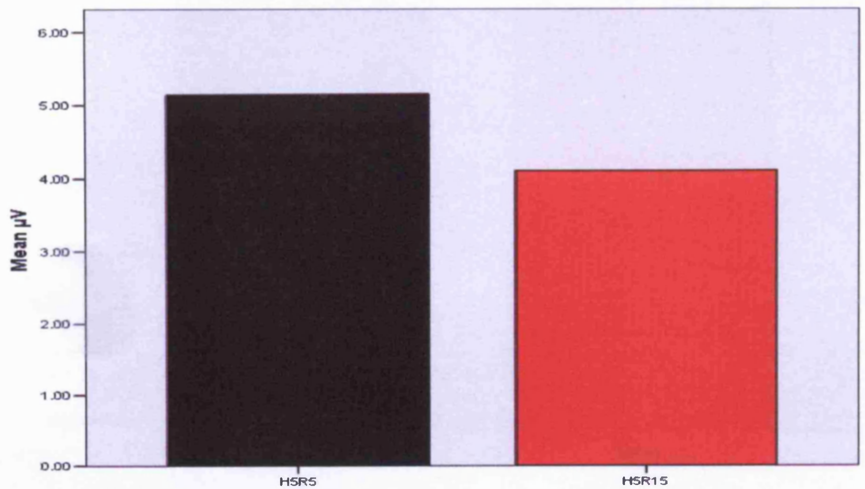

Figure 39. Mean amplitude of the 300-500ms frontal (collapsed across F3,Fz,F4) electrical activity associated with lag 5 hits attracting over-estimated lag judgements (red bars) and lag 5 hits attracting correct JORs (black bars) (n=23).

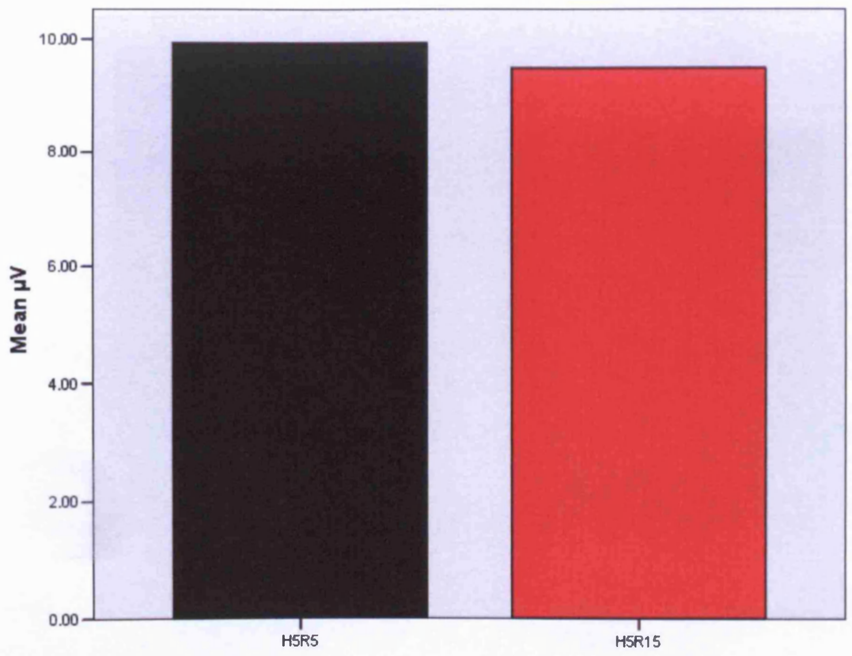

Figure 40. Mean amplitude of the 500-800ms posterior (collapsed across P3,Pz,P4) electrical activity associated with lag 5 hits attracting over-estimated lag judgements (red bars) and lag 5 hits attracting correct JORs (black bars) (n=23).

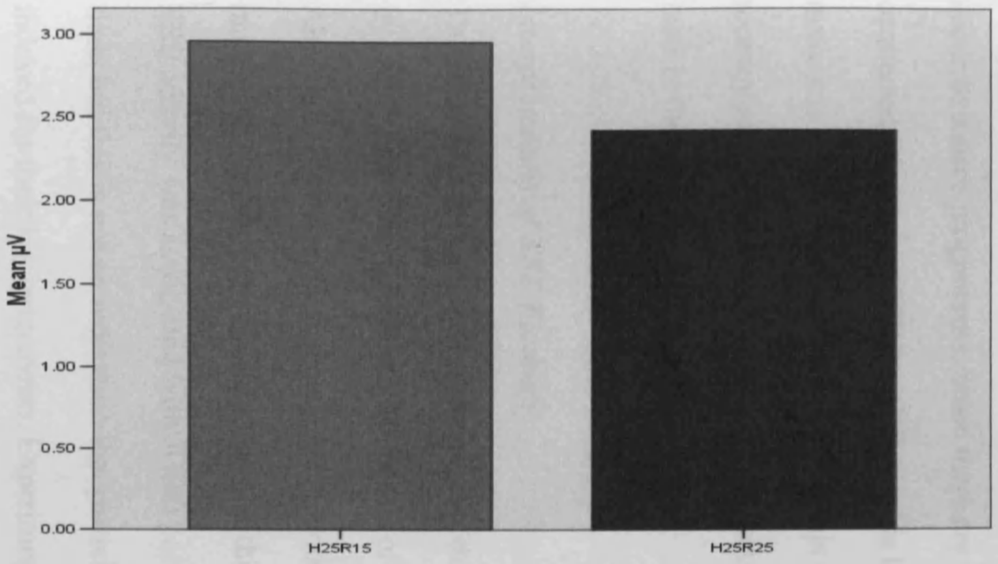

Figure 41. Mean amplitude of the 300-500ms frontal (collapsed across F3,Fz,F4) electrical activity associated with lag 25 hits attracting under-estimated lag judgements (grey bars) and lag 25 hits attracting correct JORs (black bars) (n=23).

The inconsistencies in late frontal activity across this and the earlier studies mirror other inconsistencies in the published literature (see Chapter 2). Previous recognition memory experiments have reported that this effect has behaved in contradictory ways, for example Trott et al. (1999) reported that this effect accompanied *old* judgements associated with source inaccuracy, whereas Wilding & Rugg (1997) reported that the late right frontal activity was greater for correctly identified *old* items associated with accurate source judgements. Since there are multiple examples of conflicting results connected to reports of ERP activity in this late time-window, it was unfeasible to make any strong predictions about how this effect might behave in the continuous recency memory tasks described within this thesis. These issues will be addressed later in this chapter (see pages 267-269).

Interpretations of ERP Findings

The ERP findings provide good evidence that distance information is likely to be used by participants when making judgements of recency in a continuous memory task. Although Experiment 2 provided some evidence that *old/new* effects diminished in magnitude with increasing repetition lag, this was not sufficient to demonstrate that ERP activity was associated with JORs: positive going activity may diminish over time, but this is not an indication that participants used the processes that activity indexed for their lag judgements. Experiment 3 provided that crucial evidence. ERP activity was less positive going for over-estimates than correct lag judgements (lag 5), and larger for under-estimates than for correct lag judgments (lag 25). This final ERP experiment provides support for the claim that distance information was available to participants and that it also formed a basis for their recency judgments. This appears to be a novel and important memory finding about memory for recency.

One other possibility is that some of the ERP differences that have been described reflect the fact that incorrect lag judgements (be they under- or over-estimates) may be decisions associated with lower confidence than correct JORs. If this is the case, then how might this be manifest in the electrical record? Presumably, any such index of decision confidence would be either larger or smaller for correct than for incorrect JORs. Critically however, it is difficult to conceive of a confidence effect that will vary according to whether an under- or an over-estimate (relative to a correct judgment) is made in a graded fashion. Thus the findings at anterior sites in the 300-500ms epoch in Experiment 3, and at posterior sites in the same experiment from 500-800ms, are difficult to interpret in terms of confidence. The same can also be said of the findings in Experiment 2 where there was some evidence to suggest activity in these time-windows was also of a graded nature across JORs.

Another way that effects related to confidence may be manifest in the electrical record is with respect to any potential indices of monitoring/evaluation processes. Presumably these processes will be engaged to a greater degree for incorrect than for correct JORs. The right-frontal ERP old/new effect (see Chapter 2, pages 85-91) has been linked to monitoring/evaluation, but across the experiments in this thesis the effect has not uniformly been larger for incorrect than for correct JORs. This effect is of course very unlikely to be an exhaustive index of monitoring/evaluation processes, but the ERP data provide no direct basis for claims that there are differences in confidence associated with correct and incorrect JORs. The key point that remains however, is that effects that show a graded response across under-estimates, correct responses and over-estimates are difficult to reduce to an explanation that is framed solely in terms of response confidence.

This series of ERP experiments has also contributed to an understanding of how familiarity and recollection might support JORs. As outlined in Chapter 5, in the early epoch, the magnitude of frontally distributed ERP *old/new* effects predicted JORs. In previous recognition memory studies, greater relative positivity for items judged correctly to be *old* - compared to correct judgements to *new* items, has been associated with familiarity (see Chapter 2). The findings of Azimian-Faridani et al. (2006) and Woodruff and colleagues (2006) support the view that ERPs at anterior scalp sites in the 300-500ms time-window index familiarity in a graded manner. The data reported here are consistent with this view since there was some evidence that the mid-frontal *old/new* effect varied according to JORs in a graded manner. This is in line with the view that familiarity is one memory process that can be utilised as a form of distance information. In addition, more positive ERP activity in the middle time-window predicted shorter lag judgments. Positive-going ERP *old/new* effects, often with a left-parietal maximum, have been associated with the process of recollection (see Chapter 2). The data overall suggest therefore, that recollection can also support JORs. The pattern of statistically reliable effects in the directed analyses makes one a little more cautious in this claim than for the associated claims about the process of familiarity. Across the three experiments however, there is some basis for claiming that recollection is also employed in a strength-based manner when JORs are required.

The claim that the mid-frontal *old/new* effect in the early time-window indexes familiarity has not gone unchallenged however, as was reviewed in Chapter 2. Some suggest that the effect indexes conceptual priming (Paller et al., 2007; Voss & Paller, 2006; 2007; Yovel & Paller, 2004). By this account, the fact that the mid-frontal ERP *old/new* effect varies according to response confidence comes about because the same processes that contribute to variations in the confidence with which responses are made are also those that introduce variations in the degree of conceptual priming. It could be the case that these arguments can be reconciled if conceptual priming supports familiarity (Paller et al., 2007; Rugg & Curran, 2007; Yonelinas, 2002).

It is not necessary to adopt this position however, merely noting that there is a degree of correspondence between the factors that induce changes in the two processes is sufficient. From this perspective therefore, the data points in the recency judgment task reported here only add to the list of manipulations for which the factors influencing familiarity and conceptual priming overlap. As was stated in Chapter 2, the weight of evidence to date supports a familiarity account of the mid-frontal ERP *old/new* effect (Rugg & Curran, 2007). The current data therefore is consistent with the view that familiarity supports recency judgments, and it does so in a quantitative manner, in line with a strength-based theory of memory for recency. In this way, reliance on familiarity for recency judgements would fall under the category of distance information in Friedman's (1993) framework (see Figure 2, p56).

It is worth considering here the correspondence between the way in which the mid-frontal ERP old/new effect predicts JORs and the properties of cells identified in single-unit recording studies in the primate (Xiang & Brown, 1998, 2004). Cells that respond differently according to whether an item is being presented for the first or second time have been identified in the temporal lobe and in the pre-frontal cortex

(PFC). Cells in the PFC respond within 250-350ms of a target stimulus, which provides support for the claim that neural activity in this region underlies the mid-frontal old/new effect (Rugg & Curran, 2007). Sub-populations of these cells in the PFC also signal relative recency in that their response to repeated items declines as the interval between first and second presentation increases. Thus these cells can be regarded as a strength-based signal that might be employed to make judgments about when events occurred.

Xiang & Brown (1998, 2004; and see Bogacz, Brown & Giraud-Carrier, 2001) also identified what they termed novelty sensitive neurons, and well as familiarity sensitive neurons. The former respond only to the first presentation of a novel stimulus, and the second respond more strongly to novel than to familiar stimuli, but do so equally for first and second presentations of those stimulus types. Thus only the first class of neurons described here might support JORs, and only the first class are candidates for a neural substrate underlying the mid-frontal ERP old/new effect.

It appears that the only other ERP study of memory and distance information was conducted by Curran and Friedman (2003; 2004). As was outlined earlier in this thesis, although *old/new* effects typically associated with familiarity and recollection were elicited in this study, neither effect was found to differ reliably or meaningfully across the various repetition intervals. In this thesis, the second ERP experiment provided evidence of a difference in the size of the *old/new* effects across repetition interval in the time-windows and locations typically associated with familiarity and recollection, and some support for the notion that these effects vary with JORs. In addition, Experiment 3 also provided evidence that anterior ERP *old/new* effects vary according to JOR in a strength-based manner. If these ERP effects are assumed to reflect familiarity memory processes, then shorter lag judgements are predicted by greater levels of familiarity.

Curran and Friedman (2004) suggested that location memory processing may be analogous to recollection, and that distance processing may be equivalent to familiarity. The final ERP experiment reported in this thesis shows that this distinction is unlikely to be entirely accurate, since both putative ERP indices of recollection and familiarity varied with time, and since there was evidence that these processes also varied according to recency judgements, in a task where only distance information was likely to be available to participants.

A subsidiary aim in conducting the ERP experiments reported in this thesis involved assessing whether late frontal ERP effects varied according to judgements of recency, and whether they did so in a way that contributed to an understanding of the functional significance of late frontal memory-related ERP effects, and by extension the roles that the PFC plays in different kinds of recency judgments. Curran and Friedman (2003) reported that late right frontal ERP *old/new* effects in the 800-1800ms epoch varied depending on whether participants had been asked to make a recency judgement across days or minutes. These were larger when participants had to make day 1 versus day 2 judgements, compared to list 1 versus list 2 (both day 2) judgements. Curran and Friedman interpreted this evidence as suggesting that participants were more likely to use memory reconstruction, supporting the use of location information (2003), since these ERP effects have been associated with processing linked to reconstruction (e.g. Wilding & Rugg, 1996).

The experiments in this thesis have provided additional information in regard to memory for recency and late frontal ERP activity. In Experiment 2, *old/new* effects decreased with decreasing JOR in the late epoch (800-1100ms), with this diminution being largest over the front of the head. This stands in contrast with the results of Experiments 1 and 3, where late frontal *old/new* effects were larger for shorter than for longer JORs. In Experiment 3, there was also evidence that these frontal effects were right lateralised. The effects reported in Experiment 2 were not larger over the right hemisphere, and may not have correspondences with the late right frontal *old/new* effects described in Chapter 2, but why distinct processes might be engaged across the three experiments described on this thesis is not straightforward to explain.

In general the frontally distributed activity revealed in the current ERP experiments provides additional support for the idea that the frontal lobes are involved in recency memory processing, most likely in an executive manner, but does not contribute to questions about the identity of these executive operations (e.g. Curran & Friedman, 2003; Eyler-Zorrilla et al., 1996). It should also be noted that the 800-1100ms time-window is one in which frontally distributed ERP *old/new* effects can be contaminated by the anterior projection of activity generated in more posterior brain regions – for example that responsible for the parietal ERP *old/new* effect. For this reason, a later time-window (e.g. 1100-1400ms) is one that is often employed in studies where the intention is to explore the functional significance of late frontal ERP *old/new* effects. The use of a 1280ms post-stimulus recording epoch in these experiments precluded examination of activity in this later time period.

Another possibility is that some of the effects seen in the late recording epochs are a reflection of anticipation/preparation for the upcoming trial. From this perspective, a key question is how this possibility would predict differences between the ERPs that are time-locked to stimulus onset on a given trial and separated according to lag as well as to the accuracy of test judgments. One way in which this could occur would be if the times taken to make task judgments varied systematically with the conditions under which frontal *old/new* effects changed in magnitude.

In concrete terms, one might anticipate larger indices of a process related to preparation for a subsequent trial when the time taken to reach a decision was shortest. Unfortunately, the designs of the three ERP experiments in this thesis do not permit an accurate assessment of this account. This is because an *old/new* judgment preceded the lag decision in all three test phases, and RTs were recorded for the first decision only. An adequate assessment of consistent correspondences between reaction times and the conditions under which frontal ERP *old/new* effects change would require information about the time at which the last trial judgment (in this case the lag judgment) was made, and how that varied with lag as well as response accuracy. This could be assessed in a design in which the *old/new* and lag judgments were made at the same time. That said, in studies where ERPs have been acquired in tasks where source judgments have been made at the same time as *old/new* judgments, frontal *old/new* effects have not varied in a way that would support an anticipatory account of the frontally distributed activity. For example, Senkfor and van Petten (1998) required participants to make a three-way new/old male/old female task judgment. Late frontal *old/new* effects were statistically equivalent for correct and incorrect voice judgments, despite markedly shorter RTs for correct responses.

It should be emphasised that, while the ERP data presented support a strength-based account of JORs in continuous recency memory tasks, they do so on the basis of a contrast that is somewhat different to that employed in prior behavioural studies. In previous research, the focus has typically been on differences in mean JORs associated with two different classes of stimuli that are assumed to vary in memory strength. For example, across a range of lags, JORs for pictures are shorter than those for words (see Chapter 1, as well as Hintzman, 2005). These data points support a strength-based contribution to JORs in that memories for pictures are on average stronger than those for words. Importantly, the ERP data reported here support this conclusion, as well as conclusions about the number of processes that contribute, on the basis of a different experiment manipulation. This stems from the ability to contrast, for items from the same stimulus class, changes in the neural activity differentiating correctly identified *old* items that attracted either correct or incorrect JORs.

ERP Summary

In summary, the ERP studies have given rise to novel and interesting findings relating to memory for recency. In particular, the findings support the claim that two distinct processes – recollection and familiarity – have the properties to support JORs in a strength-based fashion and evidence that these processes varied in these experiments according to JOR, with stronger evidence supporting the use of familiarity. In the remaining experiments in the thesis, a different approach to assessing the processes supporting memory for recency was taken. In these studies, similar tasks were used, but the stimuli comprised famous and non-famous names. These stimuli were employed because, for famous names, the availability of different kinds of information associated with them offered additional means of assessing what processes contribute to JORs, as outlined in Chapter 2. In addition, the experiments were designed with manipulations that have been shown to influence either familiarity or recollection to greater or lesser degrees, in order to determine how these two processes, either singly or in combination, support JORs. These kinds of inferences cannot be made on the basis of the ERP data described above, because the possibility remains that while two distinct ERP effects predicted JORs, the ERP data signals only the availability of the processes indexed by these effects, rather than their use in support of recency judgments.

Behavioural Findings

In the series of behavioural experiments, the aim was to explore recency memory further. Once again the continuous recency task adapted from Hintzman (2003) was used, along with a behavioural manipulation that involved presenting categories of stimuli that were expected to have different levels of pre-experimental strength. These comprised famous and non-famous names. These were selected because famous names should be associated with recovery of more forms of information than non-famous names such as semantic information, feelings of familiarity and other contextual information, thereby comprising an overall difference in memory strength compared to non-famous names. In addition, famous names were selected because they provided the opportunity to acquire JORs alongside an assessment, on an item-by-item basis, of the quality and/or quantity of information that was available about the individual denoted by each name.

First Behavioural Experiment

Experiment 4 was conducted in order to establish whether the patterns of behavioural data found in the Hintzman (2003) experiment would also be found with famous and non-famous names. Evidence suggests that for classes of stimuli that might reasonably be associated with different levels of memory strength, the mean JOR across most repetition lags is shorter for items judged to be higher strength (Hintzman 2003; 2005). Therefore, if famous names were high strength, they would be expected to attract shorter mean lag judgments across repetition intervals, in line with a distance account of recency memory (Friedman, 1993; 2001). Such a finding would justify the further use of famous and non-famous names in other tasks used to explore memory for recency as described above, and would also support and expand upon Hintzman's results (2003).

The results of Experiment 4 did indeed appear to support these predictions, with the famous names being judged as significantly more recent by participants across a range of lags. These differences are proposed to be due to the differing levels of strength between famous and non-famous stimuli, as supported by the fact that the *old/new* judgements made by participants were significantly more accurate for famous names. These findings are entirely consistent with the notion that an assessment of memory strength influences JORs, consistent with a distance account of recency memory under these circumstances. However in order to further confirm that the resulting differences in lag judgements were due to the famous and non-famous names forming high and low strength categories, future research could ask participants to rate the familiarity of the stimuli on a Likert-type scale after the experiment, to ascertain whether the familiarity ratings corresponded to the lag judgements. Since there was evidence in Experiment 4 that famous names were likely to be of greater overall memory strength than non-famous names, and since there was some evidence that an assessment of memory strength influenced the type of JOR an item attracted, there was sufficient reason to continue to utilise these categories of items in order to ask further questions about recency memory.

Second Behavioural Experiment

Experiment 5 was conducted in order to determine whether familiarity forms one basis for the strength differences that support JORs, which would complement the findings in the earlier ERP experiments. Participants were presented with the non-famous names twice before the continuous memory task, in order to raise their levels of pre-experimental familiarity (e.g. Dobbins et al., 2003; Rugg et al., 1998). It was expected that if familiarity does contribute to the formation of recency judgements, then exposing the participants to these names before the task should increase their pre-experiment familiarity and as a result reduce any differences in mean JORs between the famous and non-famous names (if familiarity can be used as a source of distance information). In contrast to this prediction, increasing the level or strength of familiarity did not have an effect on JORs. This was the case despite the fact that the increased false alarm rate for the initial recognition memory judgment for the non-famous names suggested that the pre-exposure manipulation did have some impact on behaviour. This suggested that familiarity was either not a basis for JORs, or that the level of familiarity of the non-famous names was not increased sufficiently to alter the pattern of JORs for this category relative to the pattern for famous names.

One possible reason for this null result is that exposing non-famous (and rather nondescript) names prior to the recency experiment might cause participants to attend less to these items later on – since more typical items may be less interesting and thus more poorly encoded than atypical items (Stenberg, Hellman & Johansson, 2007). If this line of reasoning is followed, it would suggest that non-famous names became relatively less strong after pre-experiment exposure in this experiment, in comparison to Experiment 4 where there was no pre-exposure phase. This account of the data is unlikely however; since there was no drop in the level of discrimination in the continuous memory task across the two experiments, which would be expected if the participants were paying less attention to the non-famous items.

It is also possible that participants were able to identify the strength gained for non-famous items in the pre-experiment study phase, and that they discounted this increase for their later recency judgements. Chalmers & Humphreys (1998) suggested that this was the case in their study where exposing their participants to items before the recency task did not lead to shorter JORs. In terms of the data reported in this thesis, given that the rate of false alarms was higher in Experiment 5 than in Experiment 4, it is unlikely that participants had been able to perform this cognitively complex task, since familiarity is likely to be one basis of such a strength increase and is a cause for heightened false alarm rates (Wolk et al., 2006). Instead the findings in respect to the recognition and JOR data suggest that either the level of familiarity was not raised to a great enough extent to influence future judgements in the recency task, or that familiarity is not employed as a form of distance information when making JORs of this nature. In response to this latter possibility arising from Experiment 5, it was decided to explore whether an increase in the availability of contextual information does influence later JORs in this type of continuous recency memory task.

Third Behavioural Experiment

Experiment 6 was almost identical to Experiment 5, with the exception that in the study phases prior to the continuous recency task, pre-experimental levels of recollection for the non-famous names were manipulated. An attempt was made to increase the levels of contextual information available to participants for the non-famous stimuli by asking them to think about each name in a conceptual way (rather than in a perceptual way, as in Experiment 5). It was reasoned that a deep encoding task was more likely to influence recollection than was a shallow encoding task such as that employed in Experiment 5 (e.g. Rugg et al., 1998). The results of Experiment 6 were highly similar to Experiment 5, both in terms of recognition memory accuracy and mean JORs. This was an unexpected result, since deep and contextually-rich prior study of items in other research was positively associated with recency judgements (Chalmers & Humphreys, 1998). One possible reason for this discrepancy is that in the earlier research, much more extensive and perhaps more meaningful pre-experiment tasks were used than that implemented here. Further, more general explanations such as that participants were not motivated to engage in deep encoding and that they preferred to rely on less effortful familiarity for their recency judgements, could equally have provided the basis for these results.

Another explanation for these null results is that the changes in strength induced by the pre-experiment manipulations (either in terms of recollection and/or familiarity) were small relative to the levels of pre-experiment familiarity associated with the famous names. In order to further explore the reasons behind the results that were obtained in Experiments 5 and 6, therefore, the decision was taken to include only non-famous names in Experiment 7. If non-famous names studied in advance of the continuous recency task using the manipulation employed in Experiment 5 attracted equivalent lag judgements in comparison with the other (non-studied) non-famous names, it would suggest that the strength manipulation was not sufficient to influence JORs. On the contrary, if studied non-famous names did attract relatively shorter JORs, it would be evidence to suggest that, in earlier experiments, the strength manipulation for non-famous names was ineffective relative to the levels of pre-experiment familiarity associated with the famous names. Importantly, this finding would suggest that familiarity does contribute to JOR formation in line with a distance account of memory for recency.

Fourth Behavioural Experiment

The results of Experiment 7 revealed that pre-experimental exposure to non-famous names did not influence the recency judgements they went on to attract, despite increasing the level of false alarms (indicating that familiarity levels had been raised). Judgements of recency associated with studied non-famous names were not found to differ from non-famous names that had not been previously studied. What could be the reason for this null effect? One likely suggestion is that the pre-experiment strength manipulation to increase the level of familiarity in 50% of the non-famous names did not lead to a sufficient incremental increase to influence later discrimination or recency judgements.

Though it is likely that the increasing level of false alarms shows that familiarity was raised by the pre-experiment manipulation (Wolk et al., 2006), it is probable that only what some would call 'general familiarity' was increased (Stenberg et al., 2007). General familiarity is not accompanied by an increase hit rates, and it is likely that this allowed pre-studied non-famous names to lead to memory confusion in the later recency task. This might be because is because the strength of familiarity that is increased is not specific to the episode, and may thereby make items less salient. Generalised strength is thought to make items 'more ordinary' (Stenberg et al., 2007). If this is the case, less attention may have been paid to the non-famous names after study, influencing the accuracy of discrimination levels. This would signal a failure to enhance familiarity in a way that might enhance the distinctiveness of the pre-experiment studied items.

Since the results of Experiment 7 failed to demonstrate that pre-experimental strength manipulations have an impact on subsequent JORs associated with the non-famous names, it was decided that an important related approach could be taken whereby the strength of the famous names could be measured directly. An investigation would be conducted in order to assess whether the level of pre-experimental strength of famous names influenced subsequent JORs. This was thought to be an important and novel way of exploring how judgements of recency might be influenced by the availability of distance information.

Fifth Behavioural Experiment

In Experiment 8, the question of how recovery of task-relevant information associated with recollection might relate to JORs was explored, exploiting directly item-by-item differences in the amount of knowledge participants had about different famous names. The primary aim was to assess the levels of pre-experimental strength for each of the famous names, and then to explore whether these were related to subsequent JORs for this category in a way that would support a distance account of recency memory.

Once again, famous and non-famous names were included in the continuous recency memory task. The method used for measuring the strength levels of the famous names was analogous to a deep encoding manipulation, in that participants were asked to recover multiple forms of information about the individual denoted by each famous name. Despite the nature of the deep encoding task, the patterns of recognition and recency judgements were strikingly similar to the sixth experiment in this thesis. This pattern of findings provides support for the notion that attempts to 'artificially' manipulate distance information levels is extremely difficult. The attempts reported here are not the only endeavours to have failed (Friedman & Kemp, 1998).

Most important in regard to the aims delineated at the start of this section of behavioural studies, Experiment 8 revealed evidence in support of the idea that recollection, or retrieval of contextual information, is associated with JORs in a manner consistent with a distance account of recency memory (Friedman, 1993; 2001). The number of facts participants recalled for famous names was related to the subsequent lag judgements for those names. Crucially for a distance theory of recency memory judgements, the more facts recalled for a name (high strength) – the shorter the lag judgement that name attracted.

It is difficult to reconcile these findings with a location or relative ordering account of recency judgements. Though these types of information are likely to be available in other tasks, such as those described in Chapter 1, their use is limited to a great degree in a continuous recency memory task. Instead, participants must largely make use of distance information in order to make JORs. Since the task was very long, participants are unlikely to be able to use relative ordering information. In addition, the fact they had poor recognition memory for many of the intervening items also rules out relative ordering information (since you must remember the items before being able to compare recency relatively).

Location information is also unlikely to have contributed to JORs to the same extent as distance information in this task type, since there were no apparent temporal landmarks or any temporal information inherent within the stimuli (see Hintzman, 2001). For example, if you recovered a memory of your birthday, this provides you with location information – since you can relate this contextual retrieval to time conventions. It is difficult to see how participants could derive any location information in this task. The recency judgements in the continuous recency memory task were also often inaccurate, suggesting that distance information was being used, if not exclusively, then to a greater extent than location information, which is thought to be superior for recency accuracy (Janssen et al., 2006).

Interpretation of Behavioural Findings

In the behavioural studies there was evidence that an assessment of strength does contribute to JORs in that famous names were associated with shorter JORs across a range of lags. The results of Experiments 4 to 7 suggest that pre-experiment manipulations do not influence JORs, though they had some influence over recognition performance. This is in line with Hintzman's data that showed recognition and JORs are not based on entirely the same memory processes, since lag influenced JORs more than recognition (2003). In Experiment 8, the overall difference between JORs for famous and non-famous names did not vary much from the way it did in the earlier behavioural experiments. This is consistent with the view that immediate pre-test manipulations do not influence later recency performance to a marked degree.

The results of Experiments 4-6 and 8 are in line with an activation hypothesis of memory for recency, whereby strength of a memory trace declines over time and this information can be used to place events in time (Hintzman, 2005). The results do not provide support for an accuracy hypothesis of recency, which posits that stronger memories will be more accurately judged in terms of time than comparatively weaker memories (Hintzman, 2005). Famous names (strong) attract relatively shorter lag judgements than non-famous names (weak) at lags 5, 10 and 20; however Figures 28, 30 and 34 illustrate that the strong category does not attract more accurate JORs than the weak stimuli for all lags. Thus, the behavioural experiments in this thesis provide support for the activation hypothesis of memory for recency.

The final experiment involved the equivalent of a deep study task for famous names. Levels of processing experiments (Craik & Lockhart, 1972) have revealed that deep encoding leads to elevated recognition based on recollection and (to a somewhat lesser extent) familiarity, whereas shallow encoding leads to elevated recognition based primarily on familiarity only (see Toth 1996; for a review, Yonelinas, 2002). In addition, Greve, van Rossum and Donaldson (2007) have argued that semantic processing leads to superior levels of familiarity-based recognition. The final experiment in this thesis did not correspond to these previous findings, in that discrimination levels remained largely similar to those obtained in Experiment 4. This inconsistency is likely to result from task differences; including the fact that semantic processing occurred the day before the test in the current research.

The final behavioural experiment in Chapter 6 showed that semantic or contextual information might be employed in a strength-based manner to support JORs, consistent with a distance theory of memory for recency. The findings in Experiment 8 are consistent with previous research where increasing the level of contextual information available during a prior study task leads to more accurate temporal source judgements (Chalmers & Humphreys, 1998). In their between subjects task, participants were presented with a list of low frequency words and were told either to learn the words, or were told to learn the words along with their presented definition. After a week, participants returned for a second study phase with half of the words from phase one being presented: 50% of the words were repeated once and 50% were repeated three times. During second study, the definition group were asked to rate how well they knew the meaning and the no definition group were asked to rate their level of recognition (sure recognise, unsure, or sure don't recognise). The final study phase occurred the following day with participants being presented with the second half of the words from study session 1, in the same manner as study session 2 (Chalmers & Humphreys, 1998).

Chalmers & Humphreys reported that, at test, participants were asked to make either a recency ('today'/'yesterday') or a frequency judgement ('one time'/'three times').

Only for the participants in the definition group was there an increase in recency accuracy for 'today' responses for items studied three times in comparison with items studied once. The no definition group had lower levels of recency accuracy for items studied three times 'today'. This study suggests that in a task where contextual information is likely to be utilised, an increase in the level of contextual information available to participants about the word prior to test increases the accuracy of temporal judgements (Chalmers & Humphreys, 1998; for similar results with melodies see also McAuley, Stevens, & Humphreys, 2004). An increase in the level of familiarity would be expected for the no definition group (see Dobbins et al., 2003) because they had been exposed to the items several times and high strength in the form of familiarity should make items appear more recent. Since the level of familiarity being increased in this task did not lead to greater 'today' responses, familiarity does not appear to lead to recency accuracy in this kind of task. Chalmers and Humphreys (1998) suggested that 'generalised strength' is discounted by participants when making their recency judgements.

High levels of contextual information recovered for an item during the pre-experiment session led to shorter lag judgements in Experiment 8, compared to when only low levels of information were recovered for an item. It may be that this data provides evidence for the role of semantic memory in certain kinds of recency judgments. According to Tulving (1983), episodic memory is always formed and accessed in reference to the self. Semantic memory, on the other hand, includes fact or conceptually based information that will be changed little by retrieval of its contents. Semantic memory is accessed in reference to the world (Tulving, 1986; 2002) and is assumed to build up over a long period of time - not typically linked to any one particular episode in memory. Though there has been some debate over the validity of the notion that there are multiple explicit memory categories (e.g. Hintzman, 1984; Roediger, 1984), the combination of developmental, pharmacological and neuropsychological evidence suggests that the distinction between episodic and semantic memory is well-founded (e.g. Baddeley et al., 2001; Mitchell, 1989; Roy-Byrne et al., 1987; Vargha-Khadem, Gadian, & Mishkin, 2001; Warrington & Weiskrantz, 1974; Wood, Taylor, Penny & Stump, 1980). Thus one possibility is that the outputs from semantic memory can be considered as a form of memory strength signal that, in addition to familiarity and recollection, can support JORs (Figure 42).

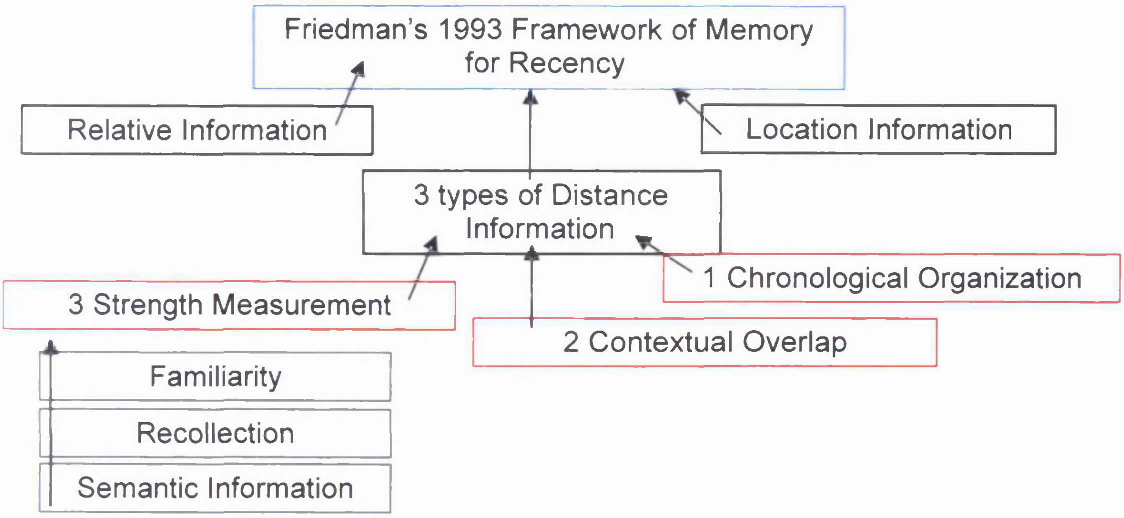

Figure 42. Interpretation of Friedman's framework, illustrating the different forms of memory which could underlie the strength subcomponent of distance information.

As an example of semantic strength differences, one might know that Paris is the capital city of France and that Santo Domingo is the capital city of the Dominican Republic. Semantic memory for the former however, is likely to be stronger for those living in the UK (since this information is more likely to have been extensively repeated). If this account is correct, the final experiment in this thesis reveals that in addition to recollection and familiarity signals, semantic memory strength can also contribute to recency judgements.

One other possibility is that semantic memories are supported by recollection and familiarity memory processes. Mayes et al. (2004) have suggested that a form of semantic recollection may exist which depends upon equivalent memory processes to 'traditional' recollection. In a similar fashion, ERP evidence has revealed that executive memory processes are engaged during both episodic and semantic tasks (Hayama et al., 2008). Thus, although previous studies have largely linked familiarity and recollection processes to episodic memory, they may be tied to semantic memory also.

In fact, Tulving suggested that familiarity (noetic awareness) is supported by semantic memory (1985). In consideration of amnesic patients with impaired episodic memory, despite retention of semantic memory capacity, Tulving suggested that noetic awareness could be relied upon for knowledge about previous episodes. This he called 'Knowing' – a concept later tied with familiarity. Thus, semantic memory is linked to familiarity memory processes in that familiarity can be elicited when retrieving factual memory rather than only in cases of episodic retrieval (Gardiner & Richardson-Klavehn, 2000).

Neuropsychological research has provided some support for these notions. Vargha-Khadem et al. (1997) showed that patients with damage to the hippocampus during childhood had impaired ability to recall, but that their semantic memory and recognition performance abilities were preserved. Where contextual retrieval was required, these patients failed to perform (Vargha-Khadem et al., 1997). The patients in the Vargha-Khadem et al. (1997) study had an intact perirhinal cortex, providing some support for the theory that semantic memory and familiarity are closely linked and may even rely on the same processes.

A relevant ERP study by Nessler, Mecklinger & Penney (2005) also provided evidence for the link between familiarity and semantic memory, showing that frontal ERP effects emerged 300-450ms post-stimulus that were highly similar after both first and second presentations of famous faces. The first presentation effect they regarded as an index of semantic familiarity – activity that was not associated with non-famous faces. The second presentation *old/new* activity present for both types of repeated faces was regarded as an index of recognition-based familiarity (Nessler et al., 2005). The similarity of these observed effects suggests that they could be related, sharing at least some of the same memory processes (Nessler et al., 2005).

More recent neuro-imaging evidence has also provided support for this potential link between semantic memory and familiarity, in that the mid-frontal *old/new* effect was larger for unitized word pairs that were semantically related than for unrelated pairs (Greve et al., 2007). If this line of reasoning is followed, the data in this thesis are consistent with the idea that semantic memory supports JORs under some circumstances. Experiment 8 illustrated that the greater the level of semantic information (and therefore presumably the greater the level of familiarity in this instance) elicited for a famous name, the more recently the name will appear to have been experienced. This supports the notion that the strength subcomponent of distance information (Figure 42, p283) can be relied upon in judgements of recency.

Familywise Error Rate and the Bonferroni Correction

As stated in the discussion in Experiment 4, a criticism that could be made of the methods used in this thesis is related to the problem of the multiple comparison error rate (or familywise error rate). Familywise error rate is the likelihood of finding false positives, or Type I Errors in the results, and this is said to increase if multiple comparisons are made from the same "family" of data (where the dependent variable and at least one of the independent variables is the same). However, it has previously been argued in Experiment 4, that the nature of the comparisons used in the current work are not from the same family of data, due to the lack of multiple use of the same data points across different lag comparisons, and therefore are not subject to increases in Type I error rate. Furthermore, the Bonferroni method itself has been strongly criticised in recent years for being too conservative and causing significantly increased Type II error rates (Nakagawa, 2004, Cabin & Mitchell, 2000, Moran, 2003, Perneger, 1998). Indeed in a typical analysis with a large number of family comparisons, the number of Type II errors that occur due to the application of a Bonferroni correction, is likely to be greater than the number of Type I errors prevented by the procedure. Therefore, while it is concluded that post-hoc corrections for increased Type I error rates can be useful in certain circumstances, due to the methods used in the current work, and the criticisms described, they are not considered suitable for use here.

Future Research Directions

Although the ERP experiments described above provided novel findings in regard to memory for recency, some limitations are worth mentioning here, in addition to those already outlined previously in the discussion and individual experiment discussions. The consequence of averaging single trial ERPs associated with the same response category for each participant prior to analysis is that it is not possible to make inferences about the relative contributions of familiarity and recollection processes to recency judgments on individual trials.

It was described in Chapter 1 that it is likely more than one category of recency information is available for recency judgements under some circumstances (Janssen et al., 2006). An important line of enquiry for possible ERP and behavioural studies in the future will be concerned with the conditions under which people may prioritise one or other form of information in order to make recency judgments – for example, when the outcomes of two processes provide conflicting information. It is generally assumed that, when multiple sources of mnemonic information are available, people will rely on those sources that are the most reliable means of making memory judgments (Johnson, Hashtroudi, & Lindsay, 1993).

An obvious extension to this work would be to acquire ERPs in tasks where the JOR is a list1/list 2 judgment. It may be the case that under these circumstances the relative contributions of familiarity and recollection differ, and indeed it may be the case that recollection under these conditions is employed in a location-based format, with list-specific information providing the basis for the recency judgments. The ERP index of recollection (the left-parietal ERP *old/new* effect) would be expected to behave differently when indexing the use of information in either a distance- or a location-based manner. If supporting JORs based on distance, the left parietal effect would be graded in nature, unlike when supporting location-based JORs. The fact that the availability of familiarity declines more quickly over time that does the availability of recollection (for a review see Yonelinas, 2002) leads to the prediction that this process should be less influential for JORs as the gap between exposure and re-exposure increases, and the ERP data offer a means of testing this assumption.

Finally, a particularly interesting avenue to pursue could involve manipulations of the emotional content associated with stimuli that require recency judgments. Valence manipulations are known to influence responses on recognition memory tasks (e.g. Greder & Malmberg, 2008; Ochsner, 2000), and social cognitive investigations (Gebauer et al., 2008) have led to the proposal that positively valenced events are judged to have occurred more recently than negatively valenced events. Variants on the continuous recognition memory task employed here appear to be well-suited to investigate related issues in a task where valence can be manipulated across stimulus categories.

Conclusions

The experiments in this thesis were designed to explore the basis of recency judgements in tasks where location information and relative ordering information were of limited use. Few studies have addressed the use of distance information in recency memory processing and no imaging experiments have been designed in order to investigate what memory processes could underlie the strength subcomponent of distance information. The ERP data support the claim that familiarity contributes to judgements of recency in continuous memory tasks devoid of location cues, and where there is limited scope for making use of relative ordering information. The findings also provide some evidence that recollection can be utilised in judgements of this kind. The behavioural studies in this thesis revealed that the availability of semantic information about famous names predicted recency judgments, thereby linking this kind of memory content to JORs as well. The findings reported here thus indicate that multiple forms of information can be employed in a strength-based fashion to make JORs and these therefore fall under the bracket of distance information in Friedman's (1993) framework of memory for recency. They provide a platform for initiating future studies where what is explored are the links between distance information and other kinds of processes that might support JORs in a wider range of circumstances than those that were investigated here.

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APPENDIX 1

Table AP1. The outcomes of the global analyses (F-values and significance levels) of the ERP *old/new* effects for words attracting correct *old/new* and correct lag judgements for the 3 selected time-windows. Experiment 1 (n=17)§.

	300-500ms	500-800ms	800-1100ms
CC	20.19***	42.52***	14.60***
CCxAP	-	10.84***	-
CCxHM	-	-	3.50*
CCxST	14.58***	26.82***	-
CCxAPxST	2.29•	7.16***	2.93*
CCxHMxST	-	-	-
CCxAPxHMxST	-	-	-

§ The factors were Condition (cc), Hemisphere (hm), Anterior-Posterior Dimension (ap) and Site (st). Conditions = H15R15, H25R25, CR.
*p<0.05
**p<0.01
***p<0.001 (epsilon corrected)
•trend

Table AP2. The outcomes of the global paired analyses (F-values and significance levels) of the ERP *old/new* effects for words attracting correct *old/new* and correct lag judgements for the 3 selected time-windows. Experiment 1 (n=17)§.

Epoch	300-500ms		500-800ms		800-1100ms	
Lag	15	25	15	25	15	25
CC	51.92***	24.15***	66.94***	37.28***	13.39**	24.99***
CCxAP	-	4.10•	28.20***	12.17**	-	-
CCxHM	-	3.41•	-	-	-	4.25•
CCxST	42.21***	11.42**	38.31***	21.50***	-	-
CCxAPxST	2.95•	2.98•	9.33***	9.95***	3.83*	5.36**
CCxAPxHMxST	-	2.34•	-	-	-	-

§ The factors were Condition (cc), Hemisphere (hm), Anterior-Posterior Dimension (ap) and Site (st). Conditions = H15R15vsCR; H25R25vsCR.
*p<0.05 ***p<0.001 (epsilon corrected)
**p<0.01 •trend

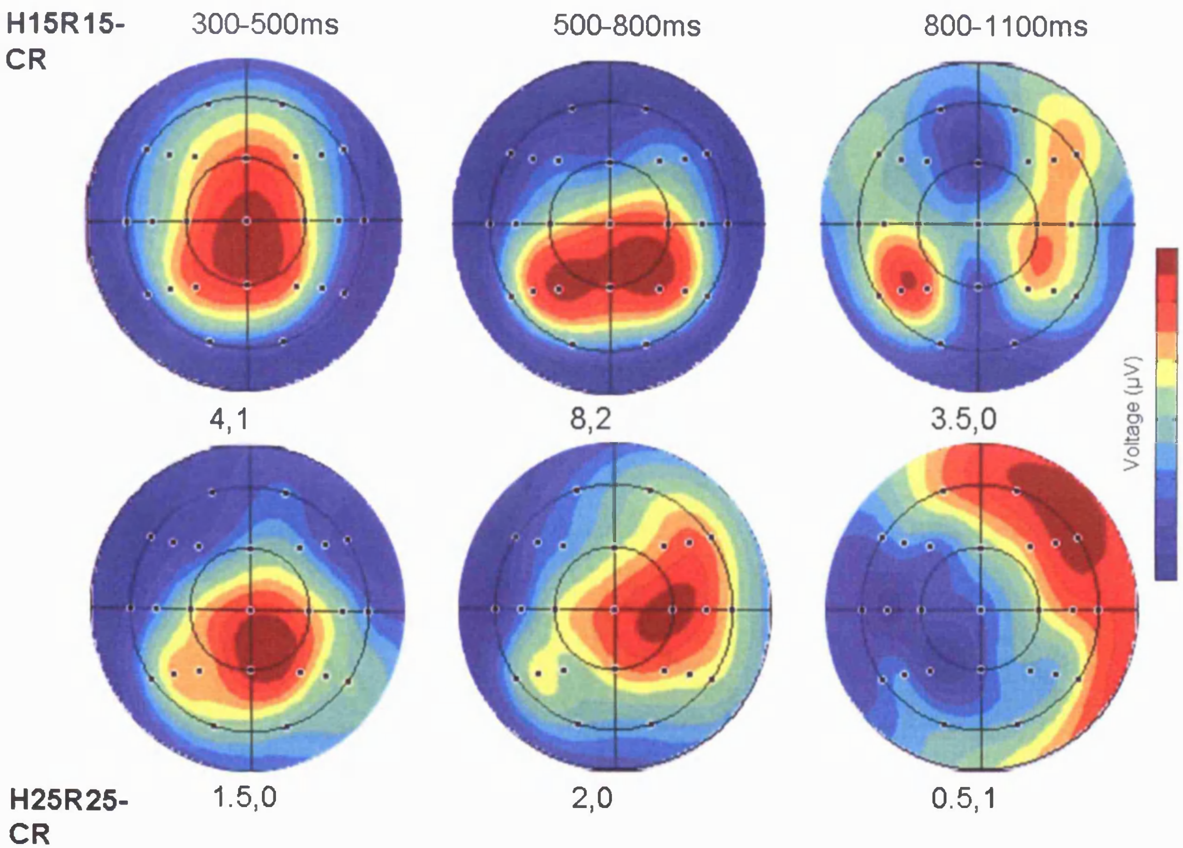

Figure AP1. Topographic maps showing the scalp distributions of the neural activity associated with correct lag judgments for the 300-500ms, 500-800ms and 800-1100ms time-windows. The maps were calculated on differences scores obtained by subtracting mean amplitudes within each time-window for correct rejections from amplitudes associated with correct lag 15 and 25 judgements, respectively (n=23).

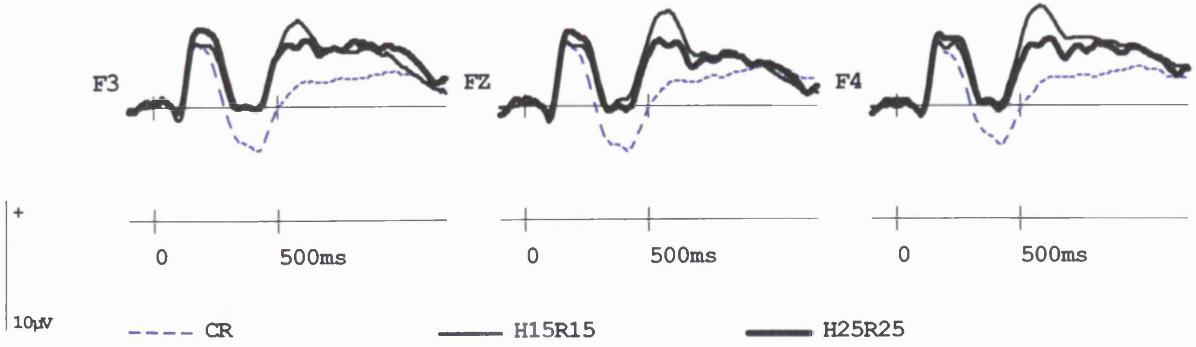

Figure AP2. Grand average ERPs associated with correct JORs for lag 15 words and for lag 25 words at selected anterior electrodes (n=17).

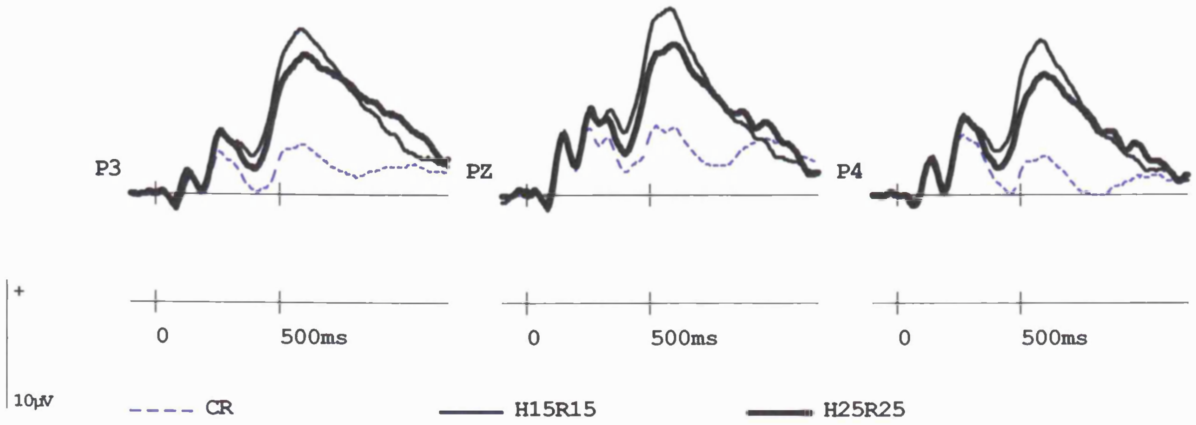

Figure AP3. Grand average ERPs associated with correct JORs for lag 15 words and for lag 25 words at selected posterior electrodes (n=17).

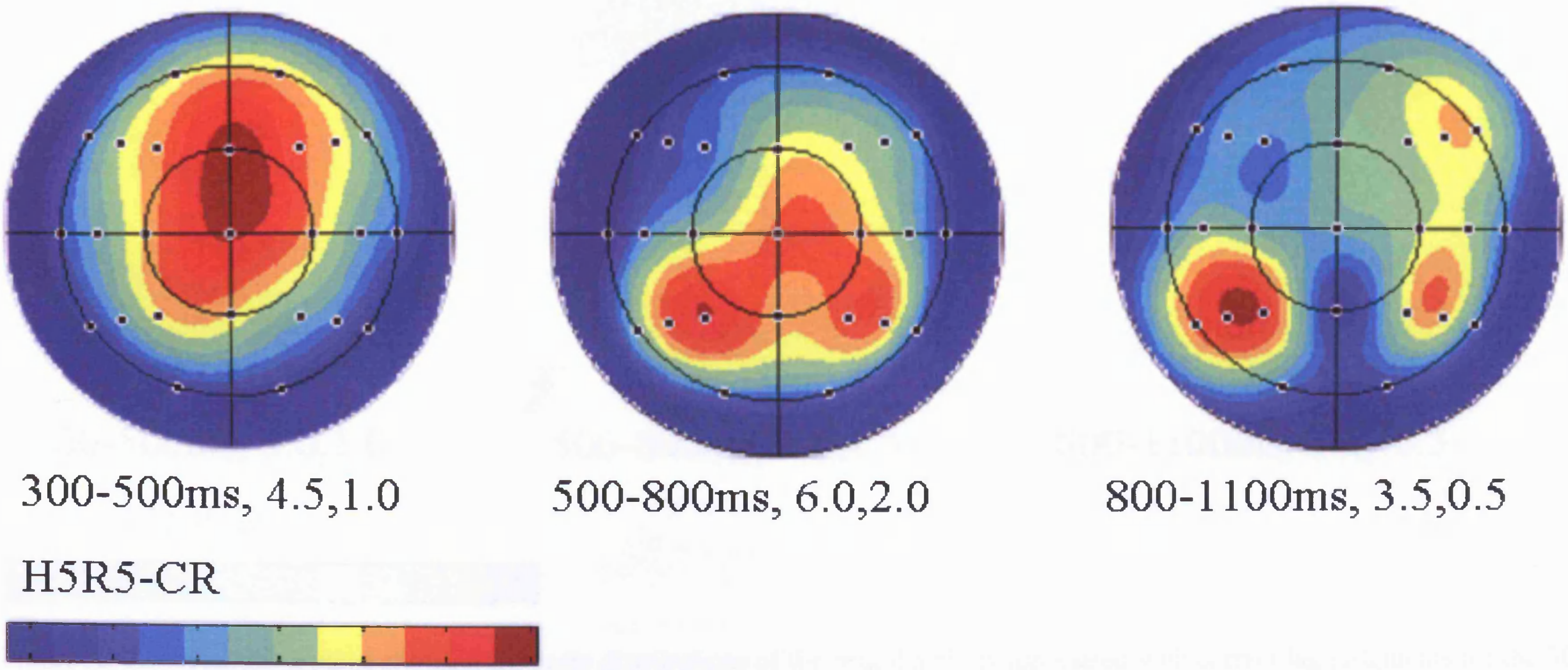

Figure AP1. Topographic maps showing the scalp distributions of the neural activity associated with correct lag judgments for the 300-500ms, 500-800ms and 800-1100ms time-windows. The maps were calculated on differences scores obtained by subtracting mean amplitudes within each time-window for correct rejections from amplitudes associated with correct lag 5 (n=23).

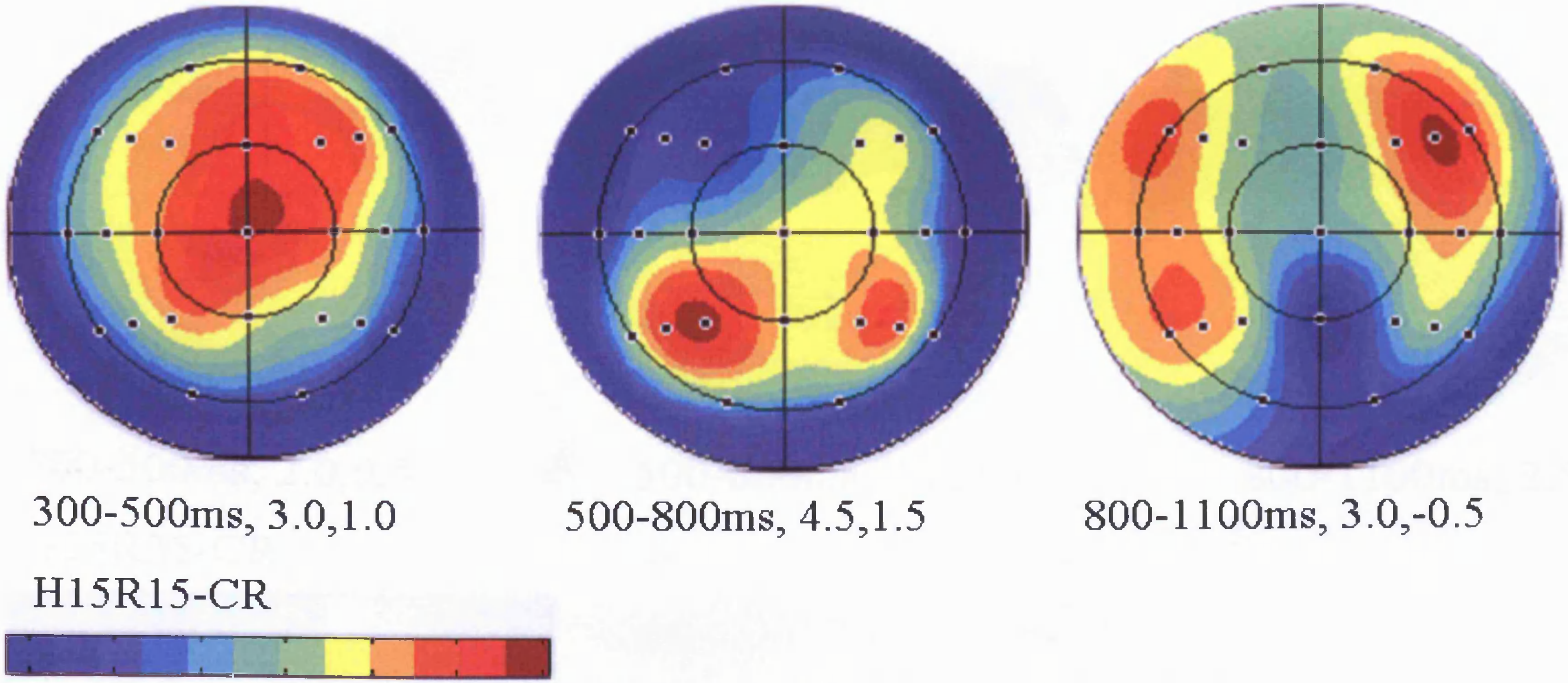

Figure AP2. Topographic maps showing the scalp distributions of the neural activity associated with correct lag judgments for the 300-500ms, 500-800ms and 800-1100ms time-windows. The maps were calculated on differences scores obtained by subtracting mean amplitudes within each time-window for correct rejections from amplitudes associated with correct lag 15 (n=23).

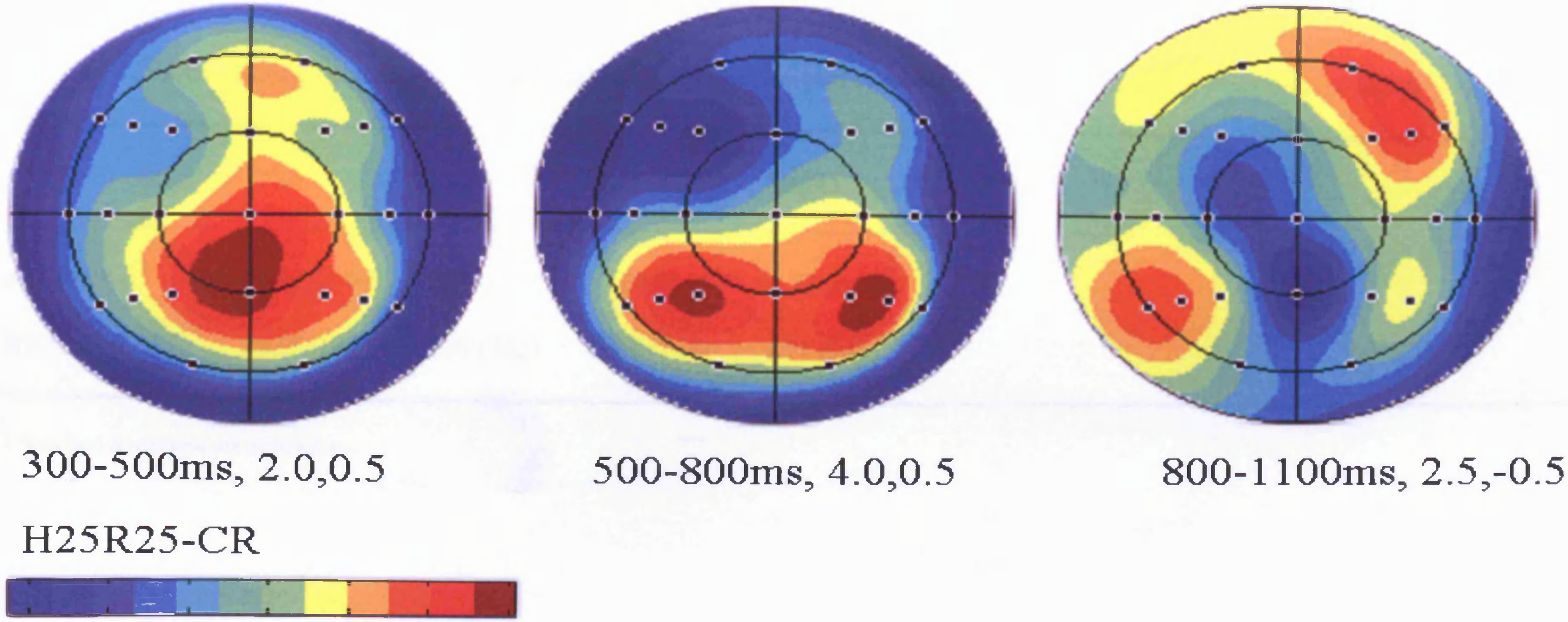

Figure AP3. Topographic maps showing the scalp distributions of the neural activity associated with correct lag judgments for the 300-500ms, 500-800ms and 800-1100ms time-windows. The maps were calculated on differences scores obtained by subtracting mean amplitudes within each time-window for correct rejections from amplitudes associated with correct lag 5 (n=23).

Table AP1. Probabilities of correct *old* and *new* judgments and associated reaction times (RT), separated according to lag (n=23) §

	New	Lag 5	Lag15	Lag25
p(correct)	0.96 (0.04)	0.90 (0.08)	0.89 (0.09)	0.88 (0.10)
RT	835 (144)	975 (242)	907 (184)	871 (145)

§ Standard deviations are in brackets

Table AP2. Probabilities of each lag judgment (lag 5, 15, 25), conditional on a correct *old* judgment and separated according to lag (n=23) §

	Actual Lag		
	Lag5	Lag15	Lag25
Judgment			
Lag5	**0.55 (.11)**	0.11 (.05)	0.05 (.04)
Lag15	0.38 (.09)	**0.63 (.10)**	0.47 (.10)
Lag25	0.07 (.04)	0.26 (.10)	**0.48 (.11)**

§ Correct lag judgments are in bold, standard deviations are in brackets

Table AP3. The outcomes of the analyses (F-values and significance levels) of the ERP *old/new* effects (n = 23) for words attracting correct *old/new* and correct lag judgments for the 300-500 and 500-800ms epochs §

	300-500ms			500-800ms		
	Lag5	Lag15	Lag25	Lag5	Lag15	Lag25
CC	115.21***	61.59***	15.67**	63.73***	47.83***	25.30***
CC x AP	5.31*	3.07•	-	7.35*	5.72*	10.25**
CC x ST	13.63***$_{(0.59)}$	2.53• $_{(0.60)}$	2.72•$_{(0.50)}$	2.69•$_{(0.64)}$	-	-
CC x AP x ST	4.26**$_{(0.73)}$	2.28•$_{(0.65)}$	-	4.81*$_{(0.44)}$	3.95*$_{(0.44)}$	-

§ All other nomenclature as for Table 9

APPENDIX 3

Participants

Six participants aged between 20 and 28 years (mean age 23 years) took part in the experiment. All participants had normal or corrected to normal vision. Of those included, 4 were female and all were undergraduates at Cardiff University, each being paid £2. The participants reported speaking English as their native language. All participants gave informed consent prior to the experiment. The experiment was approved by the ethics committee of the School of Psychology, Cardiff University.

Stimuli

Stimuli were 400 male first and last name pairs and 400 female first and last name pairs, half of which were famous names. Famous names were taken from celebrity database websites (www.who2.com, www.famousfolk.com) and from various magazine websites (www.heatworld.com, www.glamourmagazine.co.uk, www.dailymail.co.uk). Non-famous names were taken from the 1990 U.S. census. Male names had an average of 11.4 letters and 3.6 syllables. Female names had an average of 12.0 letters and 4.1 syllables. Letters and syllables were equated across fame type.

Procedure

Names were randomly organised in an excel spreadsheet and participants were asked to put a value in the box to the left of each name. A value of '0' was to be given if the name was not recognised. A value of '1' was to be given if the value might perhaps be recognised. A value of '2' was to be given if the name was recognised. This rating scale was in line with that of previous research (Schweinberger, Pickering, Burton, & Kaufmann, 2002). The entire task took a maximum of 20 minutes to complete.

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