Event-Related Brain Potential Studies of Gist-Based Source Memory Errors

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Abstract

The experiments presented in this thesis employed a procedure that incorporated two types of memory errors: 'source memory errors' and 'gist-based false recognition', and investigated their underlying mechanisms by recording the ERPs associated with these errors. Subjects studied lists of word pairs formed by pairing one of two, or one of four, associated words with a group of semantically related or unrelated words. At test, subjects differentiated old pairs from 'rearranged pairs', whose initial words had been exchanged, and 'old-new pairs' in which a new second word was paired with an old initial word. The rearranged pairs were either in accordance or not in accordance with the gist of the study pairs. Inaccurate endorsement, or source judgement errors, to these two classes of rearranged pairs were compared. One specific point addressed was whether these memory errors comprise 'recollection' of episodic details, or alternatively, whether these errors solely reflect undifferentiated familiarity. This issue was explored by requesting subjects to report their subjective experiences associated with memory judgments (the Remember/Know procedure) in Experiments One and Three, and by examining the different ERP effects associated with recollection-based recognition memory in Experiments Two, Four, and Five. The first two experiments explored how partial source information derived from gist memories formed at encoding modulates the involvement of recollection processes in source memory errors. Experiments Three and Four explored the necessary conditions for the formation of gist memories that induce recollection-based source judgment errors. The last experiment investigated the relation between brain activity during encoding and subsequent memory judgement accuracy. The results showed that recollection is involved in source judgement errors when the rearranged pairs correspond to the gist of study pairs formed during encoding. Moreover, although correctly classified old pairs and incorrectly classified rearranged pairs appear to engage equivalent processes at the time of retrieval, these two classes of memory judgement appear to depend on qualitatively distinct encoding operations.

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Chapter 1. Recognition Memory

1.1 Introduction

The notion that human memory is not a literal reproduction of experienced events has long been recognised by psychologists. Since the pioneering study of Bartlett (1932), many laboratory studies and real life events have demonstrated that memory is a constructive process, and is subject to different kinds of errors (for review, see Roediger, 1996; Roediger & McDermott, 2000; Schacter, 1995). A rememberer's report for a past event can deviate seriously from the event's actual occurrence due to different factors in the encoding and retrieval of a memory. In the past decades, psychologists have developed a variety of experimental procedures to investigate memory errors with the ultimate aim of increasing our understanding of human memory. Recently, the rise of cognitive neuroscience, which focuses on the relation between brain and cognitive functions, and the development of high resolution neuroimaging techniques such as functional magnetic resonance imaging (fMRI), positron emission tomography (PET) and event-related potentials (ERPs), have provided us a new vision and framework to explore the underlying mechanisms of memory distortion.

The experiments presented in this thesis employed a procedure (introduced in Chapter 5) that incorporated two types of memory errors: 'source memory errors' and 'gist-based false recognition' (both reviewed in Chapter 2), and investigated their underlying mechanisms by recording the ERPs (reviewed in Chapter 3) associated with these errors. One specific point addressed in this thesis was whether these memory errors comprise 'recollection' of episodic details, or alternatively, whether these errors solely reflect undifferentiated familiarity. This issue was explored by requesting subjects to report their subjective experiences associated with memory judgments, and by examining the different ERP effects associated with recollection-based recognition memory (reviewed in Chapter 4). The aim of Experiments 1 and 2 (Chapter 6) was to explore how partial source information derived from gist memories formed at encoding modulates the involvement of recollection processes in source memory errors. Experiments 3 and 4 (Chapter 7) explored the necessary conditions for the formation of gist memories that induce recollection-based source judgment errors. The last experiment (Chapter 8) investigated the relation between brain activity during encoding and the subsequent memory judgment accuracy. The relation between gist memory, recollection-based recognition, and source monitoring will be discussed on the basis of the results of the five experiments (Chapter 9).

The remainder of the current chapter reviews previous studies of recognition memory, principally concerned with dual-process theories of recognition memory, such that it will provide a theoretical context for linking issues of recollection- and familiarity-based memory, and the memory errors investigated in this thesis. This review is organised into three sections. The first section describes the origins of and the debates between single- and dual-process models. The second section reviews different methods that have been used to examine the natures of recollection and familiarity. In the final section, the characteristics of the two processes are summarized.

1.2 Single- vs. Dual-Process Models of Recognition Memory

Recognition memory refers to the ability to identify items that have been previously presented from those that have not been experienced before. Tests of recognition memory can take the form of the 'yes-no' procedure, in which subjects are presented with a cue and decide whether it has been presented before; or the form of the 'forced-choice' procedure, in which subjects are presented with a pair of stimuli and must identify one of them as old. A long debate in explaining recognition memory performance concerns whether recognition decisions are based on one or two mnemonic processes.

1.2.1 Global Matching Models

One class of theories, which are collectively referred to as 'global matching models', postulate that recognition memory is based on a single factor. Although differing in their assumptions about representation and retrieval rules, recognition in these theories is modeled as a signal detection process based on the assessment of the memory strength, or the global familiarity, of the test items (for review of these models, see Clark & Gronlund, 1996; Ratcliff & McKoon, 2000). It is postulated that all items have some pre-experimental familiarity with variation that can be described by a normal distribution. The mean familiarity value of an item will be increased or shifted if the item has been studied. The distributions of studied old items and unstudied new items may overlap, and the distance between the mean familiarity values of studied and unstudied items reflects the sensitivity or strength of memory (see figure 1.1). In recognition tests, subjects set a criterion along the familiarity scale, such that items whose values exceed this level are identified as studied ones. It is also assumed in these theories that a test cue is combined with its context to form a single probe of memory, and this probe is matched against all items in the memory trace simultaneously. These assumptions enabled global matching models to explain two characteristics of recognition memory: (1) recognition decisions are made quickly; (2) recognition judgments are based on characteristics of both the test item and of other items in memory (Clark & Gronlund, 1996).

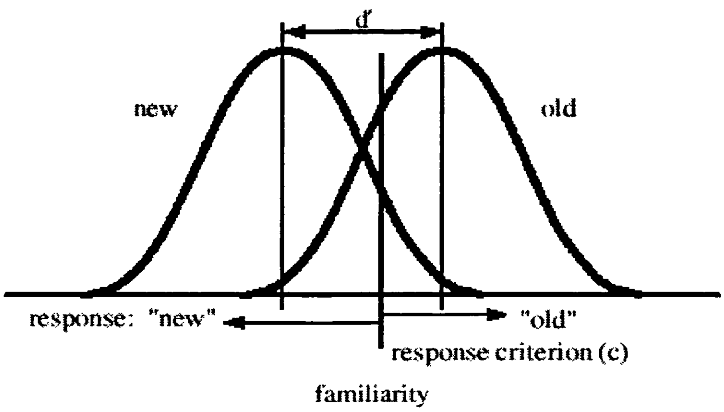

Figure 1.1. An equal-variance signal detection model illustrating familiarity distributions associated with studied and unstudied items. Adapted from Yonelinas (2001a).

Although explaining recognition memory with a single mnemonic process seems parsimonious and straightforward, a number of studies of recognition memory have revealed results that are not easy for single-process models to explain. Particular problematic for global matching models is the 'mirror effect' (Glanzer & Adams, 1985, 1990). The mirror effect refers to the general finding that if one stimulus class (e.g., low frequency words) attracts a higher hit rate than another stimulus class (e.g., high frequency words), the former class also attracts a lower false alarm rate than the latter class. The challenge for global matching models regarding the mirror effect concerns why the average memory strength of more memorable items can be both greater when the items are old, and less when the items are new, than the average strength of less memorable items. Other difficulties for single-process models of recognition come from cognitive studies in which recognition memory was tested with two measures, such as 'Remember' and 'Know' responses (Tulving, 1985; Gardiner, 1988, reviewed in a latter section). Some of these studies showed that such measures are experimentally dissociable. These dissociations are difficult to explain under the assumption of a single mnemonic process.

1.2.2 Dual-Process Models

Another class of theories, which are collectively referred to as dual-process models, postulate that there are two distinct processes underlying recognition memory performance (Atkinson & Juola, 1974; Jacoby, 1991; Mandler, 1980, 1991; for detailed review, see Yonelinas, 2002). These two processes are often referred to as familiarity and recollection. The familiarity process reflects the assessment of the memory strength or familiarity of a test item, and has been conceptualized as an acontextual, fast-acting, and automatic process. In contrast, the recollection process reflects the ability to retrieve contextual information of experienced events, and is under conscious control.

1.2.2.1 The Mandler Model and the Atkinson and Juola Model

The early dual-process models developed from studies addressing the relation between recall and recognition, specifically, whether retrieval processes in recall play a role in recognition memory. In a sorting/recall paradigm, Mandler and colleagues (Mandler, Pearlstone, & Koopman, 1969) demonstrated that organisation variables, which were known to affected recall performance, also affect recognition performance. Subjects in their experiments sorted sets of unrelated words into 2 to 7 categories according to their own criteria at study. After the sorting task, subjects were given recall and/or recognition tests for the sorted items. The results revealed that the number of categories (organisation variable) used at study was highly correlated with immediate recall performance and then declined, and was relatively less correlated with immediate recognition performance but then improved dramatically over time. From these results Mandler et al. proposed that in recognition judgments, the 'occurrence information' of a target event was evaluated in the first instance, and a 'retrieval check' was performed when that information did not exceed a critical value. The notion that there is a 'retrieval check' process after uncertain occurrence information was also embodied in the dual-process model proposed by Atkinson and Juola (1974), who conceptualized familiarity as a continuously distributed entity with subjects setting two criteria (high and low) along this distribution. If the familiarity value of a stimulus is higher than the high criterion or lower than the low criterion, subjects respond to the stimulus as old and new respectively. However, if the familiarity value falls between the two criteria, a search process is performed before responding, which results in slow responses.

The early dual-process models proposed by Mandler et al. (1969) and by Atkinson and Juola (1974) were conditional search models, as they argued that 'retrieval check' process (recollection) was only initiated when occurrence information (familiarity) led to an ambiguous response. However, in a subsequent paper that consolidated early work and provided a theoretical framework for recollection and familiarity, Mandler (1980) suggested that the two processes are independent and function in parallel. Familiarity was conceptualized as the product of 'intra-item integration', involving the organisation of an item's sensory and perceptual features in memory. By contrast, recollection was related to conceptual or categorical elaboration of inter-item relations, such as contextual information, and supported both recognition and recall. It was proposed that the effects of recollection and familiarity on recognition performance were additive and separate, as described by the equation 'Rg=R+F–RF', where R and F denotes the probabilities of identifying a test item as old on the bases of recollection and familiarity respectively, and Rg stands for the probability of identifying a test item as old. Using recall as the primary index of recollection in recognition performance, Mandler (1979, 1980) reviewed previous studies of recall and recognition, which led to the conclusion that different kinds of processing affect recollection and familiarity. For instance, sheer repetition with maintenance type of rehearsal affects recognition but not recall, while elaborate processing among inter item relations affect both recall and recognition. Additionally, Mandler (1980, 1991) proposed a number of functional characteristics of recollection and familiarity. Specially, familiarity was thought to be somewhat faster than recollection; and the familiarity value of an item was argued to decay more rapidly than does its recollection.

1.2.2.2 The Jacoby Model

While Mandler (1980) focused on using recall as the index for the contribution of recollection to recognition, Jacoby and Dallas (1981) addressed the relation between perceptual processing and the familiarity process in recognition memory. Following early dual-process models that assigned familiarity to physical information about items (Atkinson & Westcourt, 1975; Mandler, 1980), Jacoby and Dallas treated perceptual identification performance as an index of familiarity and identified two classes of variables that affect recognition memory and perceptual identification in different ways. The first class, such as the level of processing of items at study, influenced recognition memory but had no effect on subsequent perceptual identification. The second class, such as the number and spacing of repetitions of stimuli at study, had parallel effects on recognition memory and perceptual identification. The association and dissociation between recognition memory and perceptual identification, as well as between recognition memory and recall performance, support the notion that there are at least two processes underlying recognition memory, with one (recollection) related to recall and the other (familiarity) related to perceptual processing.

In contrast to previous models that viewed familiarity as an inherent characteristic of an item, Jacoby and colleagues argued that there was an unconscious inference or attribution that assigned the perceptual fluency of processing an item to the feeling of familiarity (Jacoby, 1991; Jacoby & Dallas, 1981; Jacoby & Kelley, 1992; Jacoby, Kelley, & Dywan, 1989). When people are presented with an item that had been experienced before, processing the item's perceptual or physical properties would be relatively fluent in comparison to processing items without recent prior experience. This relative perceptual fluency provides a heuristic that can be used as a basis for recognition memory. However, this heuristic is subject to error, as processing fluency caused by factors other than memory can be incorrectly attributed to familiarity (e.g., Whittalsea, Jacoby, & Girard, 1990). Alternatively, processing fluency associated with experienced items might be incorrectly attributed to factors other rather familiarity (e.g. Jacoby, Woloshyn, & Kelley, 1989). By contrast, recollection, the retrieval of study context, serves as a more reliable and conservative basis for recognition memory, and can be used to correct inaccurate attributions of perceptual fluency. Jacoby also brought in the distinction between controlled and automatic processing, which had been discussed extensively in attention literature, to dual-process models of recognition memory, and linked these forms of processing with recollection and familiarity respectively (Jacoby & Dallas, 1981). Familiarity is proposed to be an automatic basis for recognition memory judgments that does not demand attentional resources, whereas recollection is thought to be a consciously controlled basis for recognition and is subject to a limited processing capacity.

1.2.2.3 The Yonelinas Model

On the basis of a series of studies investigating receiver operating characteristics (ROCs), Yonelinas and colleagues (Yonelinas, 1994, 1997, 2001a,b; Yonelinas, Dobbins, Szymanski, Dhaliwal, & King, 1996; Yonelinas, Kroll, Dobbins, & Soltani, 1999) proposed a dual-process theory in which conscious recollection and familiarity contribute to recognition memory as a threshold process and a signal-detection process respectively. They characterized recollection as a discrete all-or-none memory state providing 'qualitative' information about experienced events, while familiarity reflects the assessment of continuously distributed 'quantitative' memory strength information. More details of the Yonelinas Model will be given in section 1.3.1.3.

1.3 Recollection and Familiarity

The association and dissociation between recognition memory and recall, as well as between recognition memory and perceptual identification, provided solid ground from which to postulate that recognition memory consists of two components. However, using recall and perceptual identification or other tasks to estimate or investigate the two processes in recognition memory is indirect. In order to evaluate the functional characteristics of these two components, i.e. recollection and familiarity, methods that can separate these two processes in recognition memory are required. These methods, which were first developed in behavioural studies, were later applied to neuropsychological studies and neuroimaging studies to test the results obtained from behavioural studies and to identify brain structures associated with these two processes of recognition memory. The following sections review behavioural and neuropsychological studies of recollection and familiarity. Neuroimaging studies of recollection and familiarity are discussed in Chapter 4 as part of a wider discussion of the ERP literature.

1.3.1 Behavioural Studies of Recollection and Familiarity

One of the main defining features of recollection, the ability to consciously retrieve contextual information of a prior event, has been utilised in developing methods that separate the contributions of recollection and familiarity in recognition memory performance. Three lines of studies are introduced in this section. The first one focuses on the subjective experience of consciously retrieving the context information. The second one employs a set of equations to objectively measure the effect of recollection and familiarity on recognition memory performance. The third describes the functional characteristics of recollection and familiarity from a signal detection viewpoint.

1.3.1.1 The Remember/Know Procedure

The Remember/Know procedure was originally developed by Tulving (1985), aiming at measuring the nature of subjects' conscious awareness in memory tests. Tulving (1972, 1983) postulated two memory systems: episodic and semantic, with the former for autobiographical form of personal memory and the latter for facts and general knowledge. The main distinction between these two types of memory lay in the states of consciousness they were associated with. Episodic memory was proposed to be accompanied by 'autonoetic' awareness, in which subjects could 'mentally time travel' back to the past and re-experience a prior episode. By contrast, semantic memory was thought to be associated with 'noetic' awareness, which reflects an awareness of information in the absence of recollection.

Tulving (1985) proposed that the measure of these two kinds of conscious awareness in memory tests could be obtained by asking subjects to report their mental experience associated with memory judgments. 'Remember' responses are made when subjects recollect any contextual aspect of the prior presentation of the test item, while 'Know' responses are made when subjects feel that the test item is familiar but cannot recollect any specific experience associated with it. Tulving (1985) reported that subjects could readily distinguish between the two states of awareness, and the proportion of Remember responses declined as the amount of information provided by cues increased. Furthermore, it was found in a recognition memory experiment that the decline associated with retention interval (from Day 1 to Day 8) was larger for the proportion of Remember responses than for the overall recognition performance. Later studies adopting the Remember/Know procedure addressed two separate but related issues. The first issue concerns the different variables that affect these two classes of responses (see Gardiner & Java, 1993; Rajaram & Roediger, 1997; and Gardiner & Richardson-Klavehn, 2000; for reviews). The second issue concerns how these two classes of responses correspond to recollection and familiarity processes.

Gardiner and Richardson-Klavehn (2000) categorised four sets of experimental manipulations that can dissociate Remember and Know responses. A set of variables, mostly those that differentially engaged conceptual and elaborative processing, influence Remember responses but have little effect on Know responses. Such variables include levels of processing (Gardiner, 1988), generating vs. reading (Gardiner, 1988), retention interval (Gardiner & Java, 1991), undivided vs. divided attention (Gardiner & Parkin, 1990). Another set of variables, mostly those related to perceptual processing, influence Know responses but do not affect Remember responses. These variables included the manipulations of surface features, such as different presentation modalities across study and test (Gregg & Gardiner, 1994), more vs. less maintenance rehearsal (Gardiner, Gawlik, & Richardson-Klavehn, 1994), identical vs. unrelated test primes of test items (Rajaram, 1993). There are also variables that affect Remember and Know responses in opposite directions, such as massed vs. spaced repetition of items (Parkin & Russo, 1993) and repetition of previously novel melodies (Gardiner, Kaminska, & Dixon, 1996), or variables that have parallel effects on both responses, such as response deadline (Gardiner, Ramponi, & Richardson-Klavehn, 1999).

The dissociations between Remember and Know responses are consistent with the notion that these two classes of responses reflect different cognitive processes involved in, or states of awareness associated with recognition. Nevertheless, some single-process models of recognition memory employing a slight modification of signal detection theory have been proposed to accommodate the dissociations between Remember and Know responses (Donaldson, 1996; Hirshman & Master, 1997; Inoue & Bellezza, 1998). These models are referred to as 'two-criterion signal detection models', which postulate that subjects place two criteria along the memory strength continuum: a 'yes/no' criterion for determining an item as old and a more stringent 'remember/know' criterion for making Remember responses (see figure 1.2).

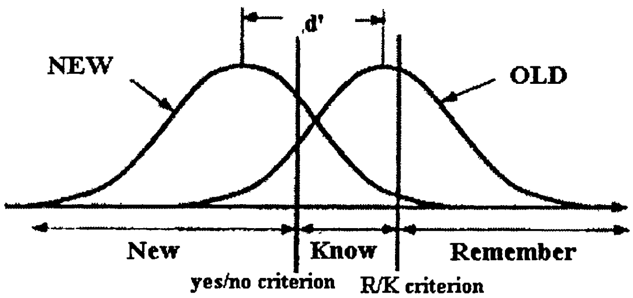

Figure 1.2. A two-criterion signal detection model of Remember and Know responses, illustrating familiarity distributions associated with studied and unstudied items and the placement of the yes/no and Remember/Know (R/K) response criteria. Adapted from Inoue and Bellezza (1998).

Items that lie above the remember/know criterion attract Remember responses, whereas those that lie between yes/no and remember/know criteria attract Know responses. The dissociations between Remember and Know responses can be accounted for by placing and shifting the yes/no and remember/know criteria along the memory strength continuum. For instance, the left and right distributions shown in figure 1.2 can be thought to represent test items presented in the 'difficult' and 'easy' levels of the variable manipulated in a recognition experiment. If subjects adopt conservative yes/no and remember/know criteria, a larger number of Remember and Know responses will be observed for the 'easy' level than for the 'difficult' level. By contrast, if subjects adopted liberal criteria, there will be more Remember responses but fewer Know responses observed in the 'easy' level than in the 'difficult' level.

Donaldson (1996) argued that, based on two-criteria signal detection models, bias-free estimates of memory (d′ or A′) should be equal for overall recognition and for Remember responses, as Remember and Know responses reflect differences in response criterion rather than memory strength. Donaldson also argued that the yes/no criterion and bias-free estimates of memory calculated based on Know responses would be positively correlated, as the difference between the number of Know responses associated with hit and false alarms would be larger when conservative rather than liberal criterion are adopted. Both predictions gained support from a meta-analysis on 28 studies that employed the Remember/Know procedure (Donaldson, 1996). It should be noted that Donaldson did not argue against the notion that there are two conscious states (recollective and non-recollective) associated with recognition memory. Instead, he was arguing that identifying non-recollective memory with the measures of d' or A' associated with Know responses is inappropriate, as such measures are not independent of response criteria.

Different from the finding of Donaldson (1996), however, Gardiner and Gregg (1997) reported that the measure of A' obtained from individual subject data (Gregg, and Gardiner, 1994) was greater when it was calculated on overall hit rate than when it was calculated on Remember rate. Additionally, Gardiner, Richardson-Klavehn, and Ramponi (1998) mentioned that when subjects were allowed to make 'Guess' responses, A′ for Remember responses, A′ for Remember and Know responses, and A′ for Remember, Know and Guess responses were all significantly different. It was argued that it is Guess rather than Remember or Know responses that have been influenced by response bias. The dissociations between Remember and Know responses might not be accounted for by a single mnemonic process as proposed by two-criterion signal detection models.

Dobbins, Khow, Yonelinas, and Kroll (2000) evaluated two-criterion signal detection models by examining the relationships between hit, Remember, and false alarm rates across individual subjects. Dobbins et al. reasoned that two-criterion signal detection models would predict positive correlation between hit and false alarm rates because both would increase when a conservative yes-no criterion becomes liberal. The models would also predict positive correlation between Remember and false alarm rates because both would increase when stringent remember/know and yes/no criteria become more lax. However, the Remember rate was found to be unrelated to the false alarm rate. Moreover, it was found that the Remember rate shares a relationship with the hit rate that was independent of the false alarm rate, suggesting that hit rate can not be viewed as the result of a single underlying strength process.

The second issue concerned how these two categories of memory responses correspond to the underlying memory processes. Although Remember and Know responses are mutually exclusive in the sense that an item can only be given one of the two responses, it is not necessarily the case that the correspondences between Remember/Know responses and recollection/familiarity are also exclusive. How to estimate the contributions of recollection and familiarity to recognition by Remember and Know responses depends on the assumed theoretical relationships between recollection and familiarity.

Three types of fundamental relationships: exclusivity, redundancy and independence (Jones, 1987) could exist between recollection and familiarity. A relationship of exclusivity means that recollection and familiarity can never co-occur (figure 1.3.1), so that an item could be recognised on the basis of recollection or familiarity but not both. Under this assumption, the contributions of recollection and familiarity to recognition can be measured as the proportions of Remember and Know responses (e.g. Gardiner & Parkin, 1990). Another possible relationship is that of redundancy, stating that recollection is always accompanied by familiarity, whereas familiarity can occur in the absence of recollection (figure 1.3.2). Inconsistent results have been obtained in Remember/Know experiments that assumed a relationship of exclusivity between recollection and familiarity. For instance, Gardiner (1988) reported that the processing depth of study items had no effects on Know responses, whereas Rajaram (1993) reported that more Know responses were attracted by shallowly instead of deeply processed items. Jacoby, Yonelinas, and Jennings (1997) suggested that employing an independence assumption for recollection and familiarity could reconcile the inconsistent results. A relationship of independence means that recollection can occur with or without familiarity and vice versa. The contributions of recollection and familiarity to recognition are separate but overlapping (figure 1.3.3). It is argued that the proportion of Know responses underestimates the effect of familiarity, as the contribution of familiarity in Remember responses is ignored.

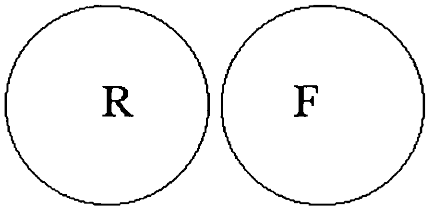

Figure 1.3.1

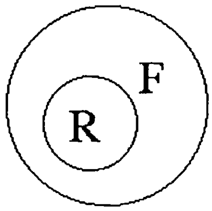

Figure 1.3.2

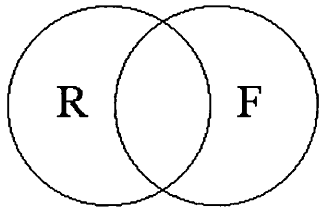

Figure 1.3.3

Figure 1.3. Venn diagrams of theoretical relationships between recollection (R) and familiarity (F). Figure 1.3.1. Exclusivity; Figure 1.3.2. Redundancy; Figure 1.3.3. Independence.

To compensate for this underestimation, the formula 'F=K/(1-R)' has been suggested by the 'Independent Remember/Know Procedure (IRK)' to correct the proportion of Know responses as the index for familiarity (Yonelinas & Jacoby, 1995). Applying such procedure with the data of Gardiner (1988) and Rajaram (1993) showed consistent results that both recollection and familiarity are affected by depth of processing. Jacoby et al. (1997) argued that experiments applying the IRK procedure gave rise to results that are consistent with those from experiments employing a 'process dissociation procedure' (reviewed in the next section), which separates recollection and familiarity with the independence assumption. Applying the independent assumption can also help to interpret some findings that were difficult to interpret with the exclusivity assumption.

Rajaram and Coslett (1992) manipulated the size congruence between line drawings of objects shown at study and test. It was found that objects whose sizes were the same at study and test attracted more Remember responses, and fewer Know responses, than objects whose sizes were different at study and test. Viewing the proportion of Know response as the measure of familiarity in this study would lead to the surprising conclusion that increasing similarity (size congruency) decreased familiarity. Yonelinas and Jacoby (1995) demonstrated that, when the IRK procedure was employed to correct the proportion of Know response to randomly generated shapes, changing the size of the items led to a decrease in both recollection and familiarity.

1.3.1.2 The Process Dissociation Procedure

Jacoby (1991) introduced the process dissociation procedure (PDP) as a means for separating the contribution of recollection and familiarity to recognition within a task. This procedure hinges on the assumption that recollection and familiarity correspond to controlled and automatic uses of memory respectively, and that the effect of recollection can be directed to be in parallel with or in opposition to the effect of familiarity. In a typical recognition experiment employing the PDP, study stimuli are presented as two classes, defined by different presentation modalities, presentation lists, or encoding tasks etc. At test, subjects are presented with the studied items from these two classes together with unstudied new items, and engage in two kinds of tasks: inclusion and exclusion. In the inclusion task, subjects are instructed to differentiate studied items of both classes (e.g., both visually and aurally presented words) from unstudied new items. In the exclusion task, however, only studied items belonging to one specific study class (e.g., aurally presented words) are classified as targets, and should be identified as 'old'. Studied items from the other class (e.g., visually presented words) are classified as nontargets, and should be responded to as 'new' along with unstudied new items. It is assumed that in the inclusion task, the effects of recollection and familiarity work in concert. A studied item can be identified as old because it is familiar or because it elicits recollection of the study class that item belongs to. In contrast, in the exclusion task, the effects of recollection and familiarity are in opposition when dealing with nontargets. The effect of familiarity on nontargets is opposed by recollecting that they belong to the study class that should be rejected. Specifically, nontargets will be responded to as 'old' only when recollection fails.

With the assumption that recollection and familiarity are functionally independent and several other assumptions, the contributions of these two processes (F and R for familiarity and recollection respectively) to recognition memory can be estimated by solving a set of equations that involve the probabilities of 'old' responses in the inclusion and exclusion tasks. In the inclusion task, the probability of a studied item being identified as 'old' can be expressed by the formula: P(Inclusion)=R+F(1–R), as both recollection and familiarity can be the basis for making an 'old' response to a studied item. In contrast, the probability of identifying a nontarget as 'old' in the exclusion task can be expressed by the formula: P(Exclusion)=F(1–R), as a nontarget would be identified as 'old' only when it is familiar without attracting recollection. Based on these two formulas, the probability of recollection can then be estimated with the formula: R=P(Inclusion)–P(Exclusion), which in turn leads to the estimate for familiarity as F=P(Exclusion)/(1–R). Using the PDP to separate controlled and automatic influences of memory, a number of variables have been reported to produce dissociative effects on the estimates of recollection and familiarity (for recent reviews see Jacoby, Yonelinas, & Jennings, 1997; Kelley & Jacoby, 2000). Some variables, such as aging, fast vs. slow response, full vs. divided attention, and short vs. long study list, influence recollection but have no effects on familiarity. For instance, Jennings and Jacoby (1993, 1997) reported the contribution of recollection to recognition was lower for older than young adults, but the contribution of familiarity to recognition was not different across these two age groups. Yonelinas and Jacoby (1994) reported that forcing subjects to make fast responses reduced the estimate of recollection in comparison to asking participants to make slow responses. The same effect on estimates of recollection and familiarity was also reported when subjects were presented with longer or shorter lists of words at study (Yonelinas & Jacoby, 1994). There are also variables that have opposite effects on recollection and familiarity, as estimated by the process dissociation procedure. For instance, Jacoby and colleagues (Jacoby, Toth, & Yonelinas, 1993) reported that generating a word at study, in comparison to reading the word, increased the estimate of recollection and decreased the estimate of familiarity.

The PDP has been criticized in respect of its assumptions about recollection and familiarity. Jacoby (1991) listed three critical assumptions underlying the procedure. First, the criterion used for familiarity-based memory judgments should be constant across inclusion and exclusion tasks. Second, the probability of recollection should be the same in inclusion and exclusion tasks. Finally, recollection and familiarity must be completely independent. That is, values of familiarity and recollection must not be correlated. If any of these assumptions is violated, the estimates of recollection and familiarity obtained from the process dissociation procedure will be invalid. Each of these three assumptions has been challenged. The problem for the first two assumptions, i.e. that the contributions of recollection and familiarity are invariant in inclusion and exclusion tasks, comes from the fact that subjects are given different instructions in these two tasks (Yonelinas, 2002). Previous studies have shown that the kind and amount of memory information retrieved can be affected by different memory tests (e.g., Dodson & Johnson, 1993; Lindsay & Johnson, 1989). Because recollection is required in the exclusion task but not in the inclusion task, it is likely that recollection is utilised or weighted differently in the two tasks, which will bias the estimates of recollection and familiarity. Yonelinas (2002) suggested that this problem might be avoided by mixing inclusion and exclusion trails (e.g., Jacoby, Toth, & Yonelinas, 1993) together, or by modifying the design such that recollection is also required in the inclusion task (Yonelinas & Jacoby, 1994). However, Yonelinas also pointed out that results obtained from inclusion tasks with or without modified instructions did not differ significantly, suggesting that the modification may not be necessary. There were also challenges to the assumption that the automatic and conscious memory influences are independent (e.g., Curran & Hintzman, 1995, 1997; Joordens & Merikle, 1993). However, these debates were more related to cued recall tasks than to recollection and familiarity in recognition, and hence will not be reviewed here.

Another potential problem for the PDP is that its estimate of recollection is restricted to contextual information that can be used to distinguish targets from nontargets, and which is therefore task-dependent. Recollecting aspects of the prior event that does not support the discrimination would not be reflected in the estimate for recollection. Yonelinas and Jacoby (1996) termed the recollection of non-discriminative information 'noncriterial recollection', and argued that such recollection will function as familiarity, with effects independent of intended recollection. However, it has been shown in several studies that estimates of recollection and familiarity can be affected by noncriterial or partial recollection, especially when targets and nontargets originate from similar sources or share non-discriminative contextual information (Dodson & Johnson, 1996; Gruppuso, Lindsay, & Kelley, 1997; Mulligan & Hirshman, 1997). Furthermore, Dodson and Johnson (1996, experiment 2) showed that the recognition rate on exclusion tests decreased as the similarity between targets and nontargets increased. They suggested that this effect resulted from the 'misrecollection' of, or source confusion between, the similar contextual information shared by targets and nontargets, which was not considered appropriately in the process dissociation procedure.

The PDP provides an objective way for separating and estimating the contributions of recollection and familiarity, or conscious and automatic processes in recognition memory. However, when applying this procedure, it is necessary to be cautious about whether its basic assumptions are met or inaccurate conclusions might be drawn.

1.3.1.3 Receiver Operating Characteristics (ROCs)

Recognition memory ROCs are a function that relates the proportion of correct recognition response (i.e., the hit rate), to the proportion of incorrect recognition response (i.e., the false alarm rate), across different response criterion. For instance, after studying a list of words, subjects are required to identify studied old items from unstudied new items with a confidence evaluation of each memory judgment on a scale ranging from 'sure old' to 'sure new'. The number of the confidence levels usually ranges from 6 to 10. The performance observed across these different confidence levels are then plotted on a unit square, the 'ROC space', with the x and y coordinates represent the false alarm and hit rates respectively. Points on the ROC are plotted as a function of confidence. The leftmost point on the ROC space includes only the most confident responses. The second point includes the most confident responses as well as the next most confident responses. The subsequent points include less and less confident responses (see figure 1.4.1). When plotted as z-scores (see figure 1.4.2), the slope of the z-ROCs provides a measure of symmetry of the ROCs. (Yonelinas, 1994). ROCs that are symmetrical along the diagonal will yield transformed z-ROCs with a slope of 1.0. In contrast, skewed or asymmetrical ROCs will generate z-ROCs with slopes away from 1.0.

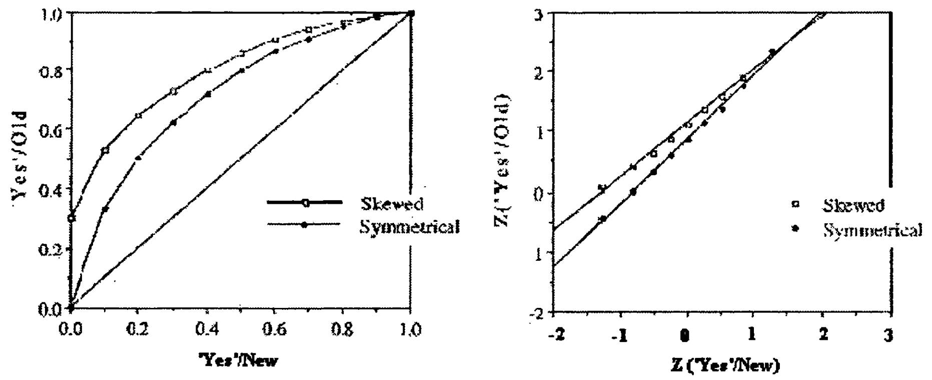

Figure 1.4.1 Figure 1.4.2

Figure 1.4. Symmetrical and skewed receiver operating characteristic curves plotted on probability coordinates (figure 1.4.1) and on z-coordinates (figure 1.4.2). Adapted from Yonelinas and Jacoby (1995).

Based on signal-detection theory (Green & Swets, 1966; Macmillan & Creelman, 1991), single-process models predict that recognition memory will yield curvilinear ROCs and linear z-ROCs because the distributions of familiarity of different items are normal. It is also predicted that if the familiarity distributions of old and new items have equal variance, the resulted ROCs are symmetrical along the diagonal, and z-ROCs will have slopes of 1.0. However, although ROCs observed in recognition memory are usually curvilinear, symmetric ROCs, or z-ROCs with slopes of 1.0, are rarely observed (Yonelinas, 1994). Most studies gave rise to the slopes of z-ROCs of less than 1 (e.g., Ratcliff, Sheu, & Gronlund, 1992), ranging from 0.6 to 0.9 (Yonelinas, 2001b). There are two ways of explaining these findings. The first account follows the signal-detection theory, and proposes that there is a larger variation in the familiarity distribution for old items than that for new items. Because of the greater variance for old items than for new items, the ROCs are pulled toward the top left corner of the ROC space, and hence the slopes of z-ROCs are less than 1.00. The other account is the 'dual-process signal-detection model' developed by Yonelinas and colleagues (Yonelinas, 1994; Yonelinas, Dobbins, Szymanski, Dhaliwal, & King, 1996). They proposed that the asymmetric ROCs, or z-ROCs with slopes less than 1.00, are best described by a dual-process model for recognition memory that incorporates a signal-detection based process of familiarity plus a threshold process of recollection. Because recollection tends to increase the number of high-confident hits without affecting false alarm rates, ROCs will be pushed up along the left y-axis such that the slopes of z-ROCs would be less than 1.0 (Yonelinas, 1994).

Although asymmetric ROCs, or z-ROCs with slopes less than 1.0, can be explained by both the 'unequal-variance signal-detection model' and the 'dual-process signal-detection' model, there are some subtle differences between the ROC data predicted by these two models. Because the dual-process signal detection model assumes that there is a threshold process of recollection, ROCs predicted by this dual-process model will be slightly flatter than those predicted by the unequal-variance signal detection model, especially when the contribution of recollection is large and the contribution of familiarity is small. This difference in ROCs will in turn make the z-ROCs predicted by the dual-process model slightly more 'U-shaped' in comparison to the linear z-ROCs predicted by the unequal-variance signal detection model. In an experiment that employed a level-of-processing manipulation, Yonelinas et al. (1996) demonstrated that the z-ROCs of deeply processed items were U-shaped, whereas the z-ROCs of shallowly processed items were linear. This result is in line with the prediction of dual-process signal-detection model, as the contribution of recollection to recognition is larger for deeply processed items than for shallowly processed items, such that U-shaped linear z-ROCs were observed for these two classes of items respectively. By contrast, the U-shaped z-ROCs for deeply processed items were difficult to be accounted by the unequal-variance signal-detection model.

1.3.2 Neuropsychological Studies of Recollection and Familiarity

Dissociations between performance on direct and indirect memory tasks have been reported in amnesic patients with medial temporal or diencephalic damaged (for review, see Richardson-Klavehn & Bjork, 1988). There are also studies investigating whether amnesic patients perform equally poorly on different direct memory tests, such as recall and recognition. However, the results are not consistent. Some studies reported that amnesic patients' performance on recall tasks was disproportionately disrupted in comparison to their performance in recognition tasks (e.g. Bowers, Verfaellie, Valenstein, & Heilman, 1988; Hirst, Johnson, Kim, Phelps, Risse, & Volve, 1986; Hirst, Johnson, Phelps, & Volpe, 1988). Other studies however found that amnesic patients' performance in recognition and recall tasks were equivalently poor (e.g. Haist, Shimamura, & Squire, 1992; Shimamura & Squire, 1988). One possible explanation for these inconsistent results is that these studies adopted different recognition tests, such that they were measuring different underlying components of recognition memory (Aggleton & Shaw, 1996; Verfaellie & Treadwell, 1993). For instance, Aggleton and Shaw (1996) suggested that certain patterns of pathology, such as focal damage to hippocampus and diencephalic regions, would spare recognition on the basis of familiarity but disrupt recollection-based recognition. Thus, these patients might have near normal performance on recognition tests supported by familiarity but perform poorly on recognition tests that require conscious recollection. This explanation can be tested by estimating the contributions of recollection and familiarity in amnesic patients' recognition memory performance.

In a study adopting the remember/know procedure, Knowlton and Squire (1995) presented amnesic patients and control subjects a list of words to study. Their memories for these words were tested with a 10-minute delay (for amnesics and one control group) or with a 1-week delay (for another control group). The results showed that the recognition memory of amnesic patients was impaired in both Remember and Know responses when compared with the 10-minute delay control group, and was similar to the performance of the 1-week delay control group. However, the amounts of impairment as indexed by Remember and Know responses were not equivalent. In comparison to the 10-minute delay control group, the corrected proportions of Remember and Know responses (i.e., the proportion of Remember and Know responses for unstudied new items were subtracted from those for studied old items) of the amnesic patients dropped by 36% and 11% respectively. This finding suggested that there was a large deficit in recollection and a modest deficit in familiarity for amnesic patients.

A different result was reported by Schacter and colleagues (Schacter, Verfaellie, & Pradere, 1996) in another remember/know study which was designed to investigate the false recognition induced by the Deese-Roediger/McDermott (DRM) procedure (Deese, 1959; Roediger & McDermott, 1995; reviewed in chapter 2). Amnesic patients and control subjects studied lists of semantically related words. Subjects engaged in a free recall or arithmetic task after studying each study list, and engaged in a recognition test after studying all the study lists. They were required to identify studied words from unstudied new words and semantically related lures. Schacter et al. reported that in comparison to the control groups, amnesic patients exhibited impairment in Remember responses to studied words, which decreased by 58% and 65% for recall and arithmetic conditions respectively, but no impairment in Know responses. In a following study Schacter and colleagues (Schacter, Verfaellie, Anes, 1997) investigated the DRM memory errors for conceptually and perceptually related items. Their data showed that again, amnesics exhibited impairment in recollection as the corrected proportions of Remember responses decreased by 40% and 31% for conceptual and perceptual conditions respectively. In contrast, the results of familiarity was not consistent, as the corrected proportion of Know responses increased slightly by 3% in the conceptual condition but decreased by 7% in the perceptual condition.

Across the above three experiments that employed the remember/know procedure with amnesic patients, there is convergence that amnesic patients have a profound impairment in recollection-based recognition. However, whether amnesic patients also have an impairment in familiarity-based recognition is uncertain. It should be noted that the two experiments conducted by Schacter and colleagues were originally designed to investigate false memory, such that the stimuli used in these two studies were very different from those used in the study of Knowlton and Squire (1995). It is possible that the characteristics of the stimuli might be responsible for the inconsistent results obtained in these two experiments. Inconsistent results were also obtained from a study that employed the process dissociation procedure to estimate the contributions of recollection and familiarity in amnesic patients. Verfaellie and Treadwell (1993) had amnesic patients and control subjects solve anagrams or read words in phase 1, and listen to words in phase 2. In the following inclusion condition, words presented in both phase 1 and phase 2 had to be responded as old. In the exclusion condition, words presented in phase 2 were targets while those presented in phase 1 were nontargets, and had to be responded to in the same way as unstudied new words. Applying the proportion of old responses in inclusion and exclusion conditions to the equations of the process dissociation procedure, Verfaellie and Treadwell found that amnesic patients' impairment in recollection was large for old items shown in the anagram condition but smaller for those read at study. More complex was the estimate for familiarity, as it was slightly larger for amnesics than for control subjects when the items were read at study, and showed reversed patterns when an item was presented as an anagram at study. It should be noted that this complex finding of familiarity may have been an artefact resulting the different false alarm rates observed for controls and amnesics, which Verfaellie and Treadwell did not take into account when they apply the PDP (Roediger & McDermott, 1994).

Yonelinas, Kroll, Dobbins, and Lazzara (1998) suggested that the conflicting results from the above studies resulted from the lack of appropriate consideration of subjects' response bias. Both amnesic patients and control subjects exhibited variable false alarm rates for unstudied new items across the different experimental conditions. They argued that correcting the response bias by subtracting the false alarm rate for new items from the hit rate for old items, as suggested by the threshold model, was inappropriate. Instead, Yonelinas et al. proposed that an appropriate method is to view familiarity as a signal-detection process, and estimate its contribution by measuring d', or the average difference between the mean familiarity values of old and new items, as suggested in their dual-process signal detection model (Yonelinas, 1994; Yonelinas & Jacoby, 1996). Yonelinas et al. (1998) re-analysed the above Remember/Know and process-dissociation studies by correcting the response bias with the dual-process signal detection model. They found that all these studies obtained a similar result, and showed that amnesia led to a pronounced reduction in recollection and a smaller but consistent reduction in familiarity. Yonelinas et al. (1998) also conducted an experiment to examine the recognition memory ROCs in amnesic patients and control subjects. The rationale was that if amnesic patients have a pronounced impairment in recollection but only a minor reduction in familiarity, their ROCs should be more symmetrical along the diagonal than the ROCs of control subjects, as the threshold process of recollection will contribute little to the amnesics' recognition performance. The results supported their prediction, indicating that the amnesics rely primarily on familiarity to make memory judgments.

1.4 Summary

Evidence in favor of dual-process theories comes from studies showing that recognition memory performance can be divided into two components, which are dissociable in respect to various experimental manipulations. In some cases, dissociations were observed when performance in recognition test was compared with performance on other tasks, such as recall (e.g., Mandler, 1980) or perceptual identification (e.g., Jacoby & Dallas, 1981). In other cases, recognition memory was tested with two measures, such as Remember and Know responses, which were found to be modulated by different experimental variables. Such dissociations are not easy to explain under the assumption of a single mnemonic process. Some sophisticated single-process models, with additional assumptions such as how response criteria are employed, have been proposed to simulate some patterns of dissociations observed in recognition performance. Nevertheless, not any single-process model can explain all the various dissociations observed in recognition memory. One particular challenge for such single-process models is to explain how different states of awareness can be produced from a single memory trace (Gardiner & Richardson-Klavehn, 2000). Supporting evidence for dual-process models also comes from neuropsychological studies, which showed that different aspects of recognition memory performance are impaired to different degrees by certain brain injury (e.g., Yonelinas et al., 1998). Additionally, as will be reviewed in Chapter 4, the two processes underlying recognition memory have been reported to be associated with at least partially non-overlapping neural correlates. All these finding provide converging evidence for dual-process models of recognition memory. There is some agreement regarding the characteristics of the two processes, recollection and familiarity, among the different dual-process models. For instance, it is generally agreed that familiarity is faster, and less demanding of attentional resources than recollection. It is also generally thought familiarity can be described as a continuously distributed signal-detection process based on trace strength, whereas recollection can be characterized as a discrete all-or-none memory state providing 'qualitative' information about experienced events (Yonelinas, 2002). However, there is also disagreement regarding the characteristics of recollection and familiarity, mainly concerning the relational assumption of these two processes.

Note that recollection is generally assumed to be an all-or-none process. However, it has been proposed that the specificity of contextual information can vary along a continuum from vaguely to vividly remembered (Johnson, Hashtroudi, & Lindsay, 1993). Partial information about of an episode can be recollected and utilised in memory judgments (Dodson, Holland, & Shimamura, 1998). It is also assumed that familiarity may lead to incorrect memory judgments, whereas recollection can oppose, or correct, the errors caused by the misattribution of familiarity. However, it has been demonstrated that 'false' recollection can occur and influence memory judgements, especially when similar episodic information is 'shared' by different events. The characteristics of partial recollection and false recollection were addressed in the experiments contained within this thesis, and are reviewed in the next chapter.

Chapter 2. Memory Distortion

2.1 Introduction

Memory distortions occur when what is remembered about an episode does not correspond to what was originally experienced (Roediger, 1996; Schacter, 1995). A variety of experimental procedures have been developed to manipulate memory distortions (for review see Roediger, 1996), and several different phenomena fall under this rubric. Their functional characteristics vary greatly and are likely generated by a range of different mechanisms. This chapter reviews recent studies of two classes of memory distortions, 'source memory errors' and 'false recognition', which have demonstrated robust illusory memories in the laboratory. Reviews of these two kinds of memory distortions include behavioural experiments of healthy young and old subjects, as well as neuropsychological studies of brain-damaged patients. Neuroimaging studies of these memory distortions are reviewed in chapter 4.

2.2 Source Memory Errors

Source memory refers to information that specifies the context or condition under which a memory is acquired. There are many different ways to define source memory, as contrasted to the 'item' memory that refers to the content of a memory record. In most experimental studies, there is a many-to-few mapping between item memory and source memory (Glisky, Rubin, & Davidson, 2001). The 'Source Monitoring Framework' (SMF) developed by Johnson and colleagues (Johnson, Hashtroudi, & Lindsay, 1993; Mitchell & Johnson, 2000) provides an integrative framework to investigate the cognitive processes involved in identifying sources of memories. Originally this framework was proposed to explain processes involved in 'reality monitoring' (Johnson & Raye, 1981), i.e., how people differentiate internally derived memories, such as imaging words, from externally derived memories, such as listening to words spoken by someone. The framework was then expanded to the source monitoring framework (Johnson, Hashtroudi,

& Lindsay, 1993) that includes reality monitoring, internal source monitoring (e.g., differentiating what one thought from what one said), and external source monitoring (e.g., differentiating statements made by person A from those made by person B).

2.2.1 The Source Monitoring Framework

The central claim of the SMF is that source information is not bound to the memory record as an abstract tag or label that can be retrieved directly. Rather, it requires an attribution and decision process to assign a memory record to a particular source by evaluating its characteristics. The SMF assumes that memory records consist of different characteristics, or features, that are results of perceptual and reflective processes involved in the formation of the memory. These memory characteristics include records of perceptual information, contextual information, semantic detail, affective information, and cognitive operations (Johnson, Hashtroudi, & Lindsay, 1993). The amounts of these different characteristics vary with the sources of the memory records, as memories acquired from different sources have different patterns of the distributions of these characteristics. The SMF proposes that the distributions of these characteristics are evaluated and utilised in source monitoring processes. For instance, an activated memory record is likely to be judged as a perceived event if the record has rich vivid perceptual details, or judged as an imagined event if the record has few vivid perceptual details but many cognitive operations. These kinds of source monitoring decisions, which are based on the characteristics of activated memories, are usually made rapidly and relatively nondeliberative as a heuristic. In addition to the rapid heuristic process, the SMF proposes that source judgments can also be made on the basis of a systematic and analytical process, which tend to be slow, deliberate, and involve retrieval of supporting memories. This class of systematic source monitoring processes is related to beliefs about memory, as well as dependent on the retrieval of additional information from memory to check the consistency within a memory record or between different memory records. For instance, a vivid memory for talking to a friend on a certain date can be rejected as veridical because it conflicts with other memories.

Another fundamental idea of the SMF is that both heuristic and systematic memory evaluations involve decision processes, which include setting criteria, assigning different weights to different dimensions of memory characteristics, assigning confidence to different levels of the weighted information, and assigning overt responses according to the weighted source information. These components of decision processes in source monitoring can be influenced by motivational and social factors, such as bias, task demand, current goals and agendas (Dodson & Johnson, 1993; Hekkanen & McEvoy, 2002; Hoffman, Granhag, See, & Loftus, 2002; Johnson, Raye, Foley, & Foley, 1981).

2.2.2 Behavioural Studies of Source Memory

Several lines of research have been conducted to investigate source memory, such as the dissociation between source memory and item memory, the different characteristics associated with memories from different origins, and the influence of setting criteria on identifying the source of a memory record. Many of these studies addressed these issues by exploring how source memory errors occur when memories from different origins share similar characteristics, or when inappropriate decision processes are engaged in ascribing memories to different sources.

2.2.2.1 The Dissociation between Source Memory and Item Memory

Evidence for the dissociation between source memory and item memory comes from studies employing a range of approaches. Some studies address the different time courses of source memory and item memory. Johnson, Kounios, and Reeder (1994) explored this issue using the 'signal-response procedure' (Reed, 1973, 1976). In the study phase, subjects were shown object labels with pictures of the objects, or labels with blank screen and the instruction to imagine the object. At test, with different intervals after the presentation of test stimuli, subjects saw a sequence of object names and judged each of these words corresponded to a previously perceived picture, a previously imagined picture, or a new item. Johnson et al. (1994) estimated the probabilities of successful old-new detection and successful source identifications for perceived and imagined items with a high-threshold multinomial model (Batchelder & Riefer, 1990), and found that old/new recognition performance accuracy grew to above-chance level earlier than source discrimination. This difference in time-courses for old/new recognition and source identification is consistent with the notion that source memory is dissociable from item memory. A similar conclusion was reached by McElree, Dolan, and Jacoby (1999), who utilised the opposition logic (see chapter 1) to investigate the time courses of source memory and item memory.

Source memory is also dissociable from item memory in respect to their dependencies on the similarity between the study and test contextual information. Dodson and Shimamura (2000) assessed cue dependent effects on item and source memory by presenting test words in four conditions: (1) The 'match' condition, in which the test words were spoken by the same voices that presented the words at study. (2) The 'mismatch' condition, in which the test words were spoken by a different but familiar voice that other study words were presented in at study. (3) The 'novel' condition, in which the test words were spoken by a novel voice that was not presented at study. (4) The 'control' condition, in which the test words were presented visually without voices. Dodson and Shimamura reported that in comparison to the control condition, source identification was facilitated in the match condition, impaired in the mismatch condition, and was not affected in the novel condition. By contrast, the performance of item recognition was not different in the match, mismatch, and control conditions, but was significantly worse in the 'novel' condition than in other conditions. Dodson and Shimamura argued that these results reflect the fact that item memory and source memory are differently affected by contextual cues. They suggested that congruent cues and incongruent cues at test activated related source information that facilitates or interferes with the identification of the accurate sources respectively. This 'source activation account' is interesting because it suggests that properties of other experienced episodes might affect source judgments via some mediator, such as the voices words are presented in, when different events shared common features or components. It was not clearly specified in Dodson and

Shimamura (2000) how these components shared by a number of episodes are bound or exchanged in memory formation and source identification, and how they interact with the similarity between these sources. More research about this issue will be discussed in a latter section that addresses feature binding and discriminating memories for events from confusing sources sharing similar or related features.

2.2.2.2 The Characteristics of Memories from Different Origins

One of the main ideas in the SMF is that memories from different origins have different kinds of characteristics, which reflect the cognitive and perceptual processes involved in the forming the memory records. To compare the characteristics associated with memories from different origins, Johnson and colleagues (Johnson, Foley, Suengas, & Raye, 1988) developed a 'Memory Characteristics Questionnaire' (MCQ) for subjects to evaluate their memories on several dimensions, such as amount of perceptual and contextual details, thoughts and feelings, and supportive memories. Johnson et al. asked subjects to recall a perceived and an imagined autobiographical event that occurred recently or in their childhood, and rate each event on the MCQ. The ratings on the MCQ showed that in comparison to imagined events, perceived events were given higher ratings on perceptual information, contextual information and supporting memories. By contrast, imagined events engaged more self-feelings, more rehearsal, and related implications than perceived events. These results indicate that the memories for internally and externally derived events are different in their characteristics. The utilisation of these characteristics in source identification was revealed in another study of Johnson et al. (1988). Subjects in that study were requested to recall one perceived event and one imagined event, and then to describe how they knew the event they remembered was perceived or imagined. For perceived events, subjects tended to report perceptual and contextual details associated with those events as well as how that event refers to other supporting memories. For imagined events, by contrast, subjects tended to report their reasoning of the event based on prior knowledge as the justification for identifying imagination as the source of the memory. These subjective reports are consistent with the notion that different characteristics of memories from different origins are utilised in identifying the sources of these memories.

Other evidence for the utilisation of memory characteristics in source identification comes from studies demonstrating that inaccurate source judgements occur when a memory record lacks the characteristics typically associated with a particular source. Johnson, Kahan, and Raye (1984) asked subjects to report and exchange with each other the contents of the dreams they dreamed, read, or made up the night before. In a subsequent source discrimination test, Johnson et al. found that in comparison to read and made-up dreams, subjects had more difficulty in identifying their real dreams from those reported by other participants. This result can be interpreted within the SMF by considering that real dreams are deficient in conscious cognitive operations, which are typically involved in forming internally derived memories, such that they are confusing with dreams reported by others. Source memory errors also occur when a memory record is associated with characteristics typically associated with other sources. Johnson, Foley, and Leach (1988) asked subjects to listen to words, and imagine the words with the speaker's voice or with their own voices. In the later source memory test, Johnson et al found that heard words were better discriminated from words imagined in their own voices than those imagined in the speaker's voice. The results are consistent with the idea that source identification is affected by the degree of similarity in sensory characteristics of memories derived from perception and from imagination (Johnson, Hashtroudi, & Lindsay, 1993; Johnson & Raye, 1981).

2.2.2.3 Memory Characteristics and Memory Strength

Recent studies have shown that under some circumstances, source identification can be achieved by assessing the strength of the memory records, rather than by evaluating their qualitative characteristics (Hoffman, 1997). This idea was derived from a source judgment response bias reported by Johnson, Raye, Foley, and Foley (1981). Subjects in their study judged test items as 'perceived at study', 'imagined at study', or new items.

Johnson et al. found that incorrectly recognised new items were more likely to be identified as 'perceived' words than as 'imagined' words. They argued that this 'it-had-to-be-you' effect reflects the reliance on cognitive operations as the critical memory characteristics in source identification. For items that are familiar but do not show evidence of the involvement of cognitive operations, such as inaccurately recognised new items, subjects tend to ascribe them to external sources. This interpretation reflects the fundamental notion of the SMF that different dimensions of memory characteristics are evaluated with different weights in source monitoring processes.

Hoffman (1997) proposed an alternative interpretation for the 'it-had-to-be-you' effect. He argued that familiar items with ambiguous cues to source tend to be ascribed to the source that produces memories with the weakest memory strength. To test this strength hypothesis, Hoffman designed an experiment in which subjects had memories from external and internals sources with strong and weak strength respectively, or vice versa. Subjects in his study were divided into perceived-imagined and imagined-perceived groups. In the perceived-imagined group, subjects saw pictures of objects in the first day, and imagined pictorial images of objects two days later immediately before the source memory test. In the imagined-perceived group, the temporal order of the tasks was reversed. It was assumed that memories acquired in the first day were weaker than those acquired in the third day for both groups. This assumption was supported as the old/new recognition hit rate, which did not consider source accuracy, was higher for perceived items than for imagined items in the imagined-perceived group, and vice versa in the perceived-imagined group. Hoffman found the 'it-had-to-be-you' effect in the perception-imagination condition. However, the source response bias was reversed in the imagination-perception condition. Unstudied new items that were inaccurately recognised were more likely to be identified as imagined than as perceived, which Hoffman termed as 'it-had-to-be-me' effect. Hoffman argued that these results demonstrated that whether the source judgment is biased toward internal or external sources could be modulated by the strength of these two classes of memories, reflecting the utilisation of memory strength in source monitoring processes.

The question whether source identification can be achieved using evaluating undifferentiated memory strength was also addressed by Donaldson and colleagues (Donaldson, MacKenzie, & Underhill, 1996) in a study comparing source monitoring and recollective memory. Donaldson et al. reported that with A' as the measure for discrimination, recollective judgment, as indicated by the proportion of 'Remember' responses, and source memory were highly similar. Given this similarity between the recollective memory and source monitoring, Donaldson et al. argued that it might be useful to consider that both recollective memory and source monitoring are based on evaluating the memory strength of items from different categories. Donaldson et al. also suggested that even when the overall memory strength of items from different sources is identical, source judgments can still be made on the basis of evaluating the memory strength of a specific source. However, Donaldson et al. did not provide empirical evidence to test or to support this notion, nor did they specify the relationship between strength distributions of separate sources and the undifferentiated memory strength distribution.

The relation between undifferentiated memory strength and source-specific memory characteristics is an extension of the debate between dual-process and single-process models for recognition memory into source memory. Both Hoffman (1997) and Donaldson et al. (1996) advocated a single-process model for understanding item recognition memory and source memory. They assume that the distribution of strength of memories from different sources varies, and people have the knowledge to utilise these differences to infer the sources. They do not reject the idea that there are memory characteristics typically associated with different sources. However, they argue that these qualitative differences in memory records should be collapsed (Hoffman, 1997), or propose that these different kinds of information constitute a multidimensional memory representation that can handle both source memory and item memory with a change in a single parameter (Banks, 2000; Donaldson et al, 1996). The SMF proposed a slightly different relation between undifferentiated memory strength and memory characteristics. Johnson et al. (1993) argued that a retrieval cue initially elicits an undifferentiated activation that can only provide information for old/new recognition. This initial activation may become more differentiated over the course of a few milliseconds or seconds such that specific attributes of memory will be yielded from this differentiated activation. Thus, although the SMF does not explicitly specify whether source and item memory rely on a single process or different processes, it assumes that there is a single memory representation containing multiple types of information that could derived for source judgments with different time courses.

Dual-process models suggest that source memory tasks, similar to item recognition memory tasks, involve both recollection and familiarity. The difference between source memory and item memory is that the former primarily relies on recollection, whereas the later one relies on both recollection and familiarity (Yonelinas, 1999). Yonelinas (1999) further suggested that source identification can be modeled as a high-threshold recollection process, in contrast to the viewpoint of single-process models (including the SMF) that source identification is a graded and continuous process (e.g., Banks, 2000; Qin, Raye, Johnson, & Mitchell, 2001). To test the threshold assumption of source identification, Yonelinas (1999) conducted four experiments to compare the ROCs of recognition memory and source memory. His prediction was that if source memory relies heavily on recollection while recognition memory relies on both recollection and familiarity, than the ROCs for source memory should be linear and exhibit a pronounced U shape when transformed to z-ROCS. In contrast, the ROCs of recognition should be curvilinear, reflecting the contribution of familiarity. What Yonelinas (1999) found was mixed. When source identification cannot be achieved by examining the familiarity values of different sources, the ROCs for source memory are linear as expected. However, in conditions where familiarity information is indicative of an item's source, such as in the study of Hoffman (1997), the source ROCs become curvilinear. These results seem to suggest that undifferentiated memory strength (familiarity) and source specific information (recollection) act in different ways in supporting source identification, and might be separate from each other.

There are problems for both single-process models and dual-process models in explaining the relation between undifferentiated memory strength and source-specific memory characteristics. For single-process models, the challenge is how these two types of information are incorporated into a single memory representation, and how source information can be derived when overall memory strength for memories from different sources are not different, such that source identification must rely on source-specific information. On the other hand, there have been studies showing that the source information retrieved might be partial and not complete (Bink, Marsh, & Hicks, 1999; Dodson, Holland, & Shimamura, 1998; Hicks, Marsh, & Ritschel, 2002), such that people can only obtain vague source information. It is necessarily for dual-process models, or theories that propose that source information is an all-or-none threshold process, to interpret how this partial source information is retrieved if source information is modelled as a threshold model.

2.2.2.4 Decision Processes in Source Monitoring

The decision processes in source monitoring involve different components, such as weighting different dimensions of memory characteristics, weighting the results of heuristic and systematic processes, setting criteria for judgments, and so on. A number of studies have shown that source monitoring performance is modulated by factors that affect decision processes. One particular factor that influences source monitoring is whether subjects are encouraged to, or oriented to, examine all possible sources. Dodson and Johnson (1993) found that subjects exhibited better source discrimination performance when test questions presented all possible sources for subjects to consider than when yes-no binary questions specific to on one particular source are asked. They argued that presenting all sources simultaneously rather than presenting them sequentially oriented subjects to consider all dimensions of source information at the same time, and encouraged them to put more weight on dimensions that are diagnostic for the task demand. A similar conclusion was reached by Multhaup (1995), who examined the source memory in older people using the "false fame" paradigm (Jacoby, Kelly, Brown,

& Jasechko, 1989; Jacoby, Woloshyn, & Kelley, 1989). In this paradigm, subjects are first presented with a list of nonfamous names. In a later fame judgment, subjects are shown a list of unstudied famous names, together with old nonfamous names and new nonfamous names. Subjects must to decide whether each test name is famous or not, and are told that if they recognise any name from the study list, it will be nonfamous. As the old nonfamous names seem familiar, if subjects do not attribute the familiarity to their previous encounter at the study, they will inaccurately identify them as famous. Dywan and Jacoby (1990) demonstrated that this false fame error was more profound for older people than for young adults. However, Multhaup (1995) showed that when all choices of sources, i.e. old nonfamous, new nonfamous, and famous, were listed for subjects to choose, older adults reduced their false fame errors to the level of young adults. This result supports the notion that relatively stringent decision criteria may be established and source identification performance might be improved, when the test format encourages subjects to examine all potential sources of memory records.

Another aspect of the source monitoring decision process concerns how different dimensions of memory characteristics are weighed. Marsh and Hicks (1998) suggested that some memory characteristics are diagnostic cues in certain source monitoring tasks, and the performance of source identification can be modulated by focusing subjects toward or away from these diagnostic memory characteristics. Changing the test format might lead subjects to inspect different dimensions of memory characteristics and exhibit different levels of source discrimination performance. They tested this idea by asking subjects questions specific to one particular source, such as whether the test word was generated (e.g., Did you generate the word?) or seen (e.g., Did you see the word?) at study. Marsh and Hicks found that for both generated and seen items, the proportion of accurate responses was lower for source questions focusing on perceptual details than it was for those focusing on cognitive operations. This result is consistent with the notion that weights applied to different memory characteristics can be changed by the format of the tasks. Marsh and Hicks (1998) further suggested that the 'it-had-to-be-you' and 'it-had-to-be-me' effects, which Hoffman (1997) explained with a differential memory strength account, could result from subjects weighting memory characteristics differently across different test conditions. Subjects in the imagined-perceived group might weigh perceptual details (e.g., visual vividness) more heavily than cognitive operations because the acquisition of memories for perceived pictures were just prior to the test. In contrast, subjects in the perceived-imagined group might weight perceptual details and cognitive operations in the opposite way, because they had just imagined the pictures before the test. Items that are familiar but fail to provide evidence for the heavily weighted memory characteristics might be ascribed to sources that are not associated with these diagnostic memory characteristics, by default. This idea was supported by a study conducted by Bink and colleagues (Bink, Marsh, & Hicks, 1999). In the experiment of Bink et al., study items that were learned two days before the test were repeated three times, such that their memory strength was equated with that of study items that were learned immediately before the test. They found that even in the absence of different memory strengths, the 'it-had-to-be-me' and 'it-had-to-be-you' effects on inaccurate attributions of new items were observed, and were modulated by the temporal order of the encoding tasks. These results reflect different weightings of diagnostic source information when people are involved in different source monitoring situations.

Applying inappropriate decision processes in source monitoring may result in memory errors in everyday life. For instance, Marsh and colleagues (Landau & Marsh, 1997; Marsh & Bower, 1993; Marsh, Landau, & Hicks, 1997) conducted a series of studies investigating how unconscious plagiarism is induced when lax criteria are established in discriminating ideas generated by self from those generated by others. Studies that addressed eyewitness errors resulting from inaccurate source monitoring have also demonstrated that these errors can be reduced if stringent criteria are established in source monitoring processes (Lindsay & Johnson, 1989; Zaragoza & Lane, 1994).

2.2.2.5 Partial Source Information and Feature Binding

An event or an episode consists of many elements or features that can be described along different dimensions, and people may remember events or episodes with different degrees of precision. For instance, sometimes one can retrieve many details about an experienced event, such as where, when, and what was discussed in a conversation with a friend. However, on other occasions, one may only remember the place, but not the time, in which the conversation happened. It is proposed in the SMF that the specificity of source information varies from vague to vivid. Vague, imprecise information about the origin of a memory record has been termed as 'partial source information' (Dodson, Holland, & Shimamura, 1998). Partial source information can be categorized into two classes. The first kind, which can be called 'categorical source information', refers to information that is not sufficiently detailed to meet the requirements of a source judgement. For instance, one might remember that a word was spoken by a male voice, but cannot specify whether it was John or Simon who spoke that word. The second kind of partial source information, which can be called 'noncriterial source information', refers to information that is not relevant to the requirements of a given source identification task. For instance, one might remember a word was spoken by a male voice, which is not helpful if the requirement is to identify whether the word was spoken one day or two days ago. Both types of partial source information have been reported to influence memory judgements.

Dodson et al. (1998) divided subjects into 'same-gender' and 'different-gender' groups, and had them listen to words spoken by four different voices at study. In the 'same-gender' group, the four voices consisted of four male voices, while in the 'different-gender' group, the four voices consisted of two male and two female voices. At test, subjects were required to identify the person who spoke the test items. Dodson et al. found that subjects in the 'different-gender' group tended to remember and utilize the gender information when they failed to remember exactly who spoke the test item. For instance, when they failed to identify male 1 as the correct source of a test item, subjects often remembered information about the gender of the source, and tended to select male 2, rather than the other two females as the person who spoke the item. This result suggests that supra-ordinate source information, in this case the gender of the speaker, is utilised in memory judgments. Yonelinas and Jacoby (1996) presented subjects with study words of different sizes on different locations of the computer monitor, and instructed subjects to remember both the words and which side of the screen the words were presented on. At tests, subjects were asked to differentiate test words according to their sizes or locations at study with exclusion questions such as 'was the word in large font?' or 'was the word on the left?' Yonelinas and Jacoby (1996) expected that noncriterial recollection for location information in the size discrimination occurs more frequently than noncriterial recollection for size information in the location discrimination, because location information was better encoded than size information at study. They reported that there were more exclusion errors in size discrimination (e.g., accepting small words when a positive response was required only to large words) than in location discrimination (e.g., accepting left words when a positive response was required only to right words). These different error rates can be explained by the assumption that source judgements are influenced by noncriterial source information retrieved at test.

The influence of partial source information on source monitoring is related to the similarity or relationship existing between different sources, as demonstrated in studies investigating source judgment errors for similar sources (Dodson, Holland, & Shimamura, 1998; Dodson & Johnson, 1996; Gruppuso, Lindsay, & Kelley, 1997; Yu & Bellezza, 2000). The relation between partial source information and source similarity might come from undifferentiated familiarity shared by similar sources. Some studies have shown that accurate source judgments are not necessarily associated with 'Remember' responses, and can instead be associated with 'Know' responses (Conway & Dewhurst, 1995; Hicks, Marsh, & Ritschel, 2002). This finding suggests that source judgments can be made on the basis of undifferentiated familiarity elicited by partial source information (Hicks et al., 2002). On the other hand, the effect of partial source information on source monitoring might also result from the recollection of features shared by similar sources. This proposal relates to the 'feature binding' problem in source memory. Similar sources might have many features in common and relatively few features that can differentiate memory records derived from these sources. When a test item is presented, it might not elicit the specific source information, or the critical feature, that allows it to be assigned to the correct sources. However, it might elicit the recollection of the many well-bound features shared by the two sources. The specific feature that is bound to the inaccurate source might be activated by these shared features, and bias subjects to make inaccurate source judgements. This notion is similar to the 'source activation account' proposed by Dodson and Shimamura (2000) to explain cue dependency effect of source memory. In support of this account, some studies have shown that memory errors occur when items from different sources share common features, such as location, modality, or shape (Chalfonte & Johnson, 1996; Henkel & Franklin, 1998; Henkel, Franklin, & Johnson, 2000).

The two possible mechanisms for the influence of partial source information on source monitoring might not be mutually exclusive. What is interesting and has not been well investigated is how partial source information is used to generate recollection- and familiarity-based source judgments. It is also unclear whether there are different or similar mechanisms underlying accurate source judgement based on specific source information and on partial source information, and between accurate and inaccurate source judgment based on partial source information. If memory errors for similar sources are made on the basis of recollecting features incorrectly bound together, will this kind of recollection be the same as veridical recollection? These are the issues discussed and explored in the experiments reported in this thesis.

2.2.3 Aging and Neuropsychological Studies of Source Memory

Although memory performance declines as people age, not all aspects of memory are impaired equally by aging (for recent reviews on memory decline and ageing, see Balota, Dolan, & Duchek, 2000; Anderson & Craik, 2000). It has been demonstrated that in comparison to item memory, source memory can be disproportionately affected by aging in some conditions (e.g., Ferguson, Hashtroudi, & Johnson, 1992; Henkel, Johnson, & De

Lenoardis, 1998; McIntyre & Craik, 1987; Schacter, Kaszniak, Kihlstrom, & Valdiserri, 1991; Schacter, Osowiecki, Kaszniak, Kihlstrom, & Valdiserri, 1994; Spencer & Raz, 1995). For instance, in a meta-analysis of 85 studies concerning item memory and source memory performance of young and older adults, Spencer and Raz (1995) reported that age-related differences in source memory were larger than those in item memory.

It should be noted, however, that the disproportionate impairment in source memory for older subjects in comparison to item memory does not necessarily occur in all circumstances. With some specific memory tests, the effects of aging on item memory and source memory are not differentiable. For instance, Schacter et al. (1991) found the older subjects exhibited disproportionate source memory impairments when the presentation of study items was blocked according to their sources, but not when they were randomly intermixed. In addition to being influenced by the presentation format of study items, the impairment in source memory of older subjects is also modulated by the kinds of the sources to be discriminated. Hashtroudi, Johnson, & Chrosniak (1989) reported that relative to young subjects, older subjects had more difficulty in external source monitoring and internal source monitoring but not in reality monitoring, suggesting that the similarity between the sources to be discriminated might affect the impairment of source memory in older subjects. These findings indicate that the relation between item memory and source memory in the elders varies across experimental conditions. Thus, the age-related difficulty in source monitoring may not be a general deficit (Hashtroudi et al., 1989).

Given the proposal that source monitoring consists of a variety of processes, it is not surprising to find that the influence of aging on source memory is heterogeneous across different experimental conditions, as different tests might be sensitive to different aspects of source monitoring that are not equally affected by aging. Several studies have been conducted to investigate the influence of aging on different aspects of source monitoring, and how these impairments are related to age-related decline of brain functions. Chalfonte and Johnson (1996) reported that even though older subjects might identify individual features of an episode, such as objects and colours, as well as young adults, older subjects had problems in binding these features together. It is also found that the older subjects were more likely than young adults to make inaccurate judgments of a target memory's source when that memory and other memories from different sources share similar features (Ferguson, Hashtroudi, & Johnson, 1992; Hashtroudi, Johnson, & Chrosniak, 1989; Johnson, De Leonardis, Hashtroudi, & Ferguson, 1995). Chalfonte and Johnson (1996) suggested that this "binding deficit" might be related to lowered medial-temporal lobe function in older subjects. This notion is supported by the finding of Henkel and colleagues (Henkel, Johnson, & De Leonardis, 1998). They reported that the older subjects' tendency to make source judgment errors for memories sharing similar features is correlated with their scores on a neuropsychological test battery used to assess medial-temporal function.

Another brain region frequently linked to the influence of aging on source monitoring is the frontal lobe. Several studies have reported that the source memory performance of older subjects is correlated with their performance on neuropsychological tests that assess frontal lobe functions (e.g., Craik, Morris, Morris, & Loewen, 1990; Glisky, Polster, & Routhieaux, 1995; Henkel, Johnson, & De Lenoardis, 1998; Mather, Johnson, & De Leonardis, 1999). Glisky et al. (1995) assessed frontal lobe functioning in older adults with several neuropsychological tests and found that the older subjects' performance on source memory is correlated with their frontal lobe functions. It has been suggested that the correlation between frontal lobe function and source monitoring impairment in older adults might reflect the fact that the frontal lobe is heavily involved in the systematic evaluation of source information in the time of retrieval (e.g., Henkel et al. 1998). However, the reduced frontal lobe functions of older subjects might also affect feature binding at the time of encoding. This idea is supported by the finding of Glisky and colleagues (Glisky, Rubin, & Davidson, 2001) that the source monitoring performance of older adults with low frontal lobe functions can be improved if the subjects are requested to pay more attention to the relation between an item and its context.

The involvement of the frontal lobe in source memory is also supported by neuropsychological studies of patients with frontal damage. Two studies have reported that frontal patients make more source memory errors than normal control subjects, even when their performance on item memory is equated (Janowsky, Shimamura, & Squire, 1989; Johnson, O'Connor, & Cantor, 1997). Also, studies of source memory in amnesic patients have shown that these patients have disproportionate impairment in source memory tests when they are assessed to have low frontal lobe function (Schacter, Harbluk, & McLachlan, 1984; Shimamura & Squire, 1987). It has been suggested that damage in frontal regions is associated with deficits in the strategic processes, such as systematic evaluation of memory characteristics, monitoring the appropriateness of responses, inhibiting inappropriate responses and so on, that are necessary for accurate source monitoring (Johnson & Raye, 1998; Schacter, Norman, & Koutstaal, 1998).

2.2.4 Summary - Source Memory Errors

Two sets of processes are involved in source monitoring and source memory errors. The first set involves the formation of representations or records of experienced events, and the derivation of the information from these representations necessary to make a source judgement. The second set of processes involves evaluation and monitoring of the information derived from memory representations. The two sets of processes might be related to the medial-temporal lobe and the frontal lobe respectively. It is not surprising that source memory errors occur when the information derived from memory records of events from different origins is similar. What needs further investigation is how memories from confusing sources, or sharing common features, are stored in the brain, such that source judgement errors are induced for these events.

2.3 False Recognition

False recognition, which occurs when people incorrectly claim that they have encountered items that are actually unstudied or novel to them, is one of the most frequently studied types of memory errors. It has been investigated in several different paradigms and explained with different theories. Among these paradigms, the procedure that was initially developed by Deese (1959) and later modified by Roediger and McDermott (1995) has attracted substantial attention because it elicits robust and high levels of false recognition. The following sections review behavioural, aging, and neuropsychological studies of memory errors induced by this procedure. It should be noted that, although false recognition is the main theme of the current review, studies employing the Deese-Roediger-McDermott (DRM) procedure with recall tasks also provide important and relevant information for the memory errors generated with this procedure. Thus, the current review is not restricted to recognition studies, but also includes data from recall studies that employed the DRM procedure.

2.3.1 The Deese-Roediger-McDermott Procedure

Deese (1959) was interested in how associative factors affect recall. He conducted an experiment using word lists that consisted of 12 associates of a nonpresented critical theme word as stimuli. For example, one list included '*thread, pin, eye, sewing, sharp, point, pricked, thimble, haystack, pain, hurt,* and *injection*', which are all associates of the theme word: "*needle*". After studying each list, subjects' memory for these words was tested in a free recall task. For some lists, subjects incorrectly consistently recalled the unstudied theme word. Deese (1959) suggested that the probability of a theme word intruding depended on how strongly it was associated to the words on the study list.

Deese's studies were not well known until Roediger and McDermott (1995) modified and reintroduced the procedure. Roediger and McDermott extended Deese's procedure to a recognition task and showed that critical nonpresented theme words were judged old at almost the same level as real studied words. In their experiment one, six word lists were developed from the materials listed in Deese's (1959) article. After hearing each list, subjects were required to recall items from the list, writing the last few items first. An overall recognition test for all word lists was conducted after all word lists had been read and recalled. In the free recall task, nonpresented critical theme words were recalled with a probability of 40%, about the same as studied items that were presented in the middle of the list. For the final recognition task, the false alarm rates for nonpresented critical words were as high as .84. In the second experiment of Roediger and McDermott (1995), the length of study lists was increased to 15 words. For half the lists, subjects had to solve math problems after listening to the list, while for the other half lists, they were engaged in a recall task. In the final recognition task, the Remember/Know procedure (Tulving, 1985) was applied to investigate participants' subjective experiences. Again, nonpresented critical words were highly likely to be incorrectly recalled (55%) and falsely recognised (81% for study + recall condition, and 72% for study + arithmetic condition). More remarkable is that for those items incorrectly recognised but not incorrectly recalled, 58% were judged as 'Remembered', about the same proportion as for words that were studied but not recalled (52%).

2.3.2 Behavioural Studies of DRM Memory Errors

The striking results of the DRM procedure attracted many follow-up studies to explore different aspects of the nature of this "memory illusion" and to investigate its underlying mechanism. It has been shown that DRM memory errors are very robust phenomenon, which can be observed in a variety of different study and test conditions. For instance, Tussing and Greene (1997) manipulated different encoding conditions and compared the proportions of false alarms to nonpresented critical items obtained under these different conditions with that obtained under the standard DRM procedure. Encoding manipulations in their study included the levels of processing, numbers of repetitions, blocked or intermixed presentation of study items. Tussing and Greene reported that a reliable false recognition effect for nonpresented critical words was obtained in all these conditions, reflecting that the DRM memory error is a very robust phenomenon. However, they found that the false alarm rate for nonpresented critical words was lower than that in the standard DRM procedure when words from different study lists were intermixed, or when the study words were learned incidentally. They also reported that the false alarm rate for nonpresented critical words was not affected by the level of processing of the study lists. This null effect of level of processing on DRM memory errors was also reported by Read (1996), who found that the nonpresented critical item was incorrectly recalled with the same probability whether study items were encoded with elaborate or maintenance rehearsal. Moreover, the proportion of 'Remember' responses to incorrectly recalled nonpresented critical lures were also not affected by level of processing.

Another aspect of DRM memory errors that has been addressed is how persistent they are. McDermott (1996) presented subjects with twenty-four lists, with 15 related words in each list. After studying each list, subjects were either required to recall the words presented in the list immediately, or to recall the words after solving a math problem. McDermott found that although the level of veridical recall in the delayed condition (50%) was attenuated in comparison to the immediate recall condition (58%), the level of incorrectly recall of nonpresented critical theme words in the two conditions (46% vs. 44%) was not significantly different. Two days later, subjects were required to recall all the studied words again. Both the recall rate of studied items and the intrude rate of nonpresented theme words declined. However, the proportion of critical nonpresented theme words recalled (20%) exceeded the proportion of studied items (12%) recalled. The false memory effect was very robust even when tests were delayed or interfered with other tasks. In another experiment of the same study, McDermott gave subjects multiple study-test trials to self correct their performance. Indeed, the hit rates rose across trials while the false alarm rates to nonpresented theme words declined slightly across trials. Nevertheless, recall of the critical items was not eliminated. Moreover, when subjects were required to recall all lists one day later, recall of studied items decreased, whereas intrusion of critical nonpresented items increased.

There are also studies addressing whether DRM memory errors are modulated by the modality in which study items are presented. In the original study of Roediger and McDermott (1995), study items were presented auditorily. Smith and Hunt (1998) reported that the incidence of DRM errors in both recognition and recall tasks was dramatically reduced by shifting from auditory to visual presentation at study. Smith and Hunt argued that more item-specific information is encoded when study items are presented visually than when they are auditorily presented, and that item-specific information is critical in discriminating nonpresented critical items from studied items. In contrast, Maylor and Mo (1999) reported a modality effect on DRM memory errors that was in the opposite direction of the modality effect reported by Smith and Hunt. Maylor and Mo found that the proportion of incorrect recognition for nonpresented critical items reduced by 50% when study items were presented auditorily. Maylor and Mo (1999) argued that it was the auditory modality that provided study items distinct and item-specific information, and that this reduced the false recognition for nonpresented items, that lack such information. However, it should be noted that in the study of Maylor and Mo, the speakers who spoke the study lists were visible to the subjects (cited in Gallo, McDermott, Percer, & Roediger, 2001, p341). This might have provided additional perceptual cues that were not auditory, but were only available when items were presented auditorily. To systematically investigate the influence of modality on DRM memory errors, Gallo et al. (2001) manipulated the presentation of modality in both study and test stages. They reported a modality effect on DRM memory errors in the same direction as that reported by Smith and Hunt (1998), and suggested that the opposite modality effect observed by Maylor and Mo might be a particular case caused by the addition of perceptual cues associated with auditorily presented items. However, the modality effect reported by Gallo et al. (2001) was much smaller than that reported by Smith and Hunt (1998). They also reported that the modality effect was observed when test items were visually presented but not when they were auditorily presented. On the basis of these findings, Gallo et al.(2001) suggested that memory for visually presented information might be easier to discriminate from nonpresented critical items than is memory for auditorily presented information.

Another line of investigation concerns whether there are recollective experiences associated with the DRM memory errors. As already mentioned above, Roediger and

McDermott (1995) found that the proportion of 'Remember' responses attracted by nonpresented critical items was comparable to that attracted by correctly identified studied items. Additionally, it was shown that, when asked to identify the source from which the recognised or recalled items were presented at study, subjects tend to ascribe the nonpresented critical item to the source from which its associates were presented (Gallo et al, 2001; Payne, Elie, Blackwell, & Neuschatz, 1996). These findings suggest that the DRM memory errors, similar to veridical memories, can be accompanied by recollective experiences.

It seems that the false memory induced by the DRM procedure is similar to veridical memory in several ways. (1) In the recognition task, critical nonpresented words are incorrectly classified at a rate that is comparable to the hit rate for studied words. (2) In the recall task, critical nonpresented theme words are incorrectly recalled with a probability comparable to recall of items presented in the middle portion of the list, which is usually thought to represent recall from long-term memory. (3) Subjects gives a significant proportion of incorrectly recalled or recognised nonpresented critical words 'Remember' responses, indicating that they could recollect some experiences associated with these lures as with real studied words. (4) Blocked presentation of items in the study phase (i.e. words of a category are presented together in the study phase) enhances both accurate recall for real studied words and false recall for nonpresented lures relative to random presentation. Sometimes this false memory effect seemed to be more persistent than veridical memories. True memory might decay after one day, while the false memory effect increases (McDermott, 1996; Payne et al. 1996). What is the mechanism that produces the false memory and to endow it with the characteristics of true memories? The mechanisms underlying the false memory effect observed in this paradigm remains the subject of debate. Two sets of theoretical proposals have been put forward to explain DRM memory errors. One is the 'activation/monitoring theory, and the other one is the 'fuzzy-trace/gist theory'.

2.3.2.1 The Activation/Monitoring Theory for DRM Memory Errors

According to the 'activation/monitoring theory' (Gallo & Roediger, 2002; Roediger, Balota, & Watson, 2001; Roediger, Watson, McDermott, & Gallo, 2001), DRM memory errors are a kind of source attribution (Johnson et al., 1993) or reality monitoring error (Johnson and Raye, 1981). This theory proposes that nonpresented critical items might be overtly generated as a response to the associates at the time of study ('implicit associative response', Underwood, 1965) or covertly activated by spread of activation from the associates via semantic related network (Seamon, Luo, & Gallo, 1998; Roediger, Balota, & Watson, 2001). Later, in the recall or recognition stage, subjects are not able to tell whether the nonpresented critical lures were presented in the list or not, and therefore incorrectly classify them as studied items.

The main argument for the activation/monitoring theory comes from the findings of studies that investigated the effect of associative factors between the study items and the nonpresented critical item in the DRM procedure. These studies showed that whether incorrect recall in the DRM procedure occurs or not can be predicted by 'backward associative strength', which refers to the strength of associative connections from the study associates to the nonpresented critical word. It was argued that the higher the backward associative strength is, the more likely the nonpresented critical item will be generated at study, which will then lead to DRM memory errors. For instance, Deese (1959) reported that mean backward associative strength correlates highly with the probability the nonpresented critical lure will intrude in the recall. Similar findings were reported by McEvoy, Nelson, & Komatsu (1999) and Robinson and Roediger (1997), although Robinson and Roediger (1997) suggested that it is the total association strength rather the mean association strength that predicts the probability of an intrusion. They found that the more associates in the study list (higher total backward association strength, and lower mean backward association strength), the higher false alarm rates of nonpresented critical words. Another line of studies focused on the variability in the potency of different lists in producing DRM memory errors. In a multiple regression analysis, Roediger and colleagues (Roediger, Watson, McDermott, & Gallo, 2001) examined 55 lists that had been generated in different studies that provided levels of false recall ranging from .01 to .65. They found that a large proportion (53%) of the variance in generating DRM errors among these lists could be explained by the backward associative strength. Similarly, Gallo and Roediger (2002) compared study lists that have similar 'forward associative strength', which refers to the strength of associative connections from the nonpresented critical word to the study associates, the opposite direction from backward associative strength. They found that both incorrect recall and incorrect recognition are predictable by the backward but not the forward associative strength. In all of these studies it was argued that the backward associative strength, which indexes the likelihood that a nonpresented critical item will be generated at study, predicts whether DRM errors will occur.

Another line of evidence comes from studies that investigated whether the processing of the nonpresented critical item can be facilitated after the presentation of its associates. McDermott (1997) demonstrated perceptual priming for nonpresented critical lures, and viewed this finding as evidence for the notion that nonpresented critical lures were generated consciously in the study phase. She argued that only when nonpresented critical lures were generated or activated at study can this perceptual priming effect occur. Similar results were reported by McKone and Murphy (2000), who replicated McDermott's (1997) finding. Moreover, McKone and Murphy reported that the priming effect for nonpresented critical words was modality-specific, as this effect was reduced when the critical word and its associates were presented in different modalities at test and at study. This modality-specific effect is consistent with the notion that the nonpresented critical word is generated at study and shares the perceptual properties of its associates.

However, some characteristics of DRM errors are not easily explained by activation/monitoring theory. First, if DRM errors are a kind of source monitoring error, then setting a strict criteria should be helpful in avoiding the generation of this kind of error. When subjects are reminded the existence of semantically related lures, an analytic strategy should be adopted to avoid reality monitoring errors originated from the adoption of a heuristic strategy. However, it has been demonstrated that even when subjects are told about this illusory memory phenomenon in advance, and are explicitly warned against making such memory errors, DRM memory errors still cannot be eliminated (Gallo, Roberts, & Seamon, 1997; McDermott and Roediger 1998). It seems that even when subjects are encouraged to use a more analytic strategy, they cannot distinguish the different memory characteristics of veridical and false memories. This indicated that there is something more than source monitoring errors involved in the DRM errors.

Another finding that is difficult to interpret within the activation/monitoring theory is that DRM memory errors can be observed even when the nonpresented critical item is unlikely to have been generated in the time of encoding. Koutstaal and Schacter (1997) presented subjects with exemplars of detailed colour pictures from different categories intermixed with unrelated pictures. At test, subjects were requested to make old/new judgements to test items that included previously studied pictures, unstudied pictures that belonged to one of the study categories, and unstudied pictures that did not belong to any of the study categories. Koutstaal and Schacter observed robust false recognition to unstudied pictures related to study items, especially if subjects saw many instances of the same category. They argued that it is highly unlikely that participants generated these unstudied pictures at the time of encoding, and later made source memory errors for these unstudied pictures. Rather, it appears that this picture version of the DRM procedure resulted in errors due to the 'gist' information, which consists of conceptual and perceptual features common to the highly similar studied pictures. This 'gist' account is in accordance with the 'fuzzy-trace theory' account of the DRM memory errors.

2.3.2.2 The Fuzzy-Trace/Gist Theory for DRM Memory Errors

The fuzzy-trace theory does not use source attribution errors to explain DRM errors. Fuzzy-trace theory specifies that two representations are generated during encoding. These two representations are verbatim representations, which are memory traces corresponding to individual items in the study phase, and a gist representation that stores general semantic information about the whole episode, without specifying individual details (Reyna & Brainerd, 1995; Payne et al, 1996). This theory can explain why there are both high hit rates for studied words and high false alarm rates for nonpresented critical lures in the DRM procedure. In the recall task, subjects may attempt to recall a study list based on the general or gist representation, and incorrectly recall the nonpresented theme word that is representative of this gist representation. In the recognition task, the unstudied critical item presented at test might activate the gist representation of the similar studied items that bias subjects to incorrectly classified the unstudied related item as old. The fact that false memory of nonpresented critical items is more persistent than veridical memory also accords with another principle of fuzzy-trace theory: verbatim memory traces are forgotten more quickly than gist representations (Brainerd & Reyna, 1998; Brainerd, Reyna, & Brandse, 1995; Murphy & Shapiro, 1994; Payne et al., 1996). One problem for fuzzy-trace theory is that it is difficult to explain why subjects make high proportions of 'Remember' responses to incorrectly recalled or recognised nonpresented critical items (Robinson and Roediger, 1997), given that this memory illusion is based on a general, semantic gist representation.

Schacter, Norman, and Koutstaal (1998) provided an account of DRM errors which is very similar to fuzzy trace theory. In their 'constructive memory framework', they do not specify different representations for individual items and gist. However, they propose that failure of pattern separation (i.e., not enough information is encoded to differentiate similar episodes or events, see McClelland, 1995) may bias subjects to rely on gist information. Because studied items in the DRM procedure are highly similar and associative, distinctive and item-specific information may not be well encoded and utilised in the following recall or recognition test. Subjects are forced to rely on the memory for gist, which leads to excellent memory for what the items have in common but poor memory for discriminating studied items and nonpresented critical theme words. Evidence supporting this account comes from the studies of Mather, Henkel, & Johnson (1997) and Norman and Schacter (1997). Both studies examined the qualitative characteristics of illusory memories for the semantic lures. They found that item-specific information is seldom retrieved. However, subjects retrieved semantic associations when making both true and false recognition responses. In another study, Israel and Schacter (1997) offered subjects more item-specific information by presenting line drawings with items in the study phase. In comparison to subjects who did not see line drawings, subjects who saw line drawings showed lower false alarm rates for nonpresented critical theme words. These results can be seen as evidence for a gist account: once subjects are given the opportunity to encode and utilise item-specific information, they do not have to rely on a gist representation, and show lower false alarm rates to gist lures.

2.3.3 Aging Studies of DRM Memory Errors

A number of studies have shown that older people are relatively more susceptible than young adults to DRM memory errors (e.g., Kensinger & Schacter, 1999; Norman & Schacter, 1997; Schacter, Israel, & Racine, 1999; Tun, Wingfield, Rosen & Blanchard, 1998), and this age-related deficit might result from the older adults' reliance on gist in making memory judgements (see Schacter, Koutstaal, & Norman, 1997 for review). Some studies focused on whether young and older adults differ in their recollective experience associated with DRM errors. Norman and Schacter (1997) reported that when questions about the contents of recollective experiences were asked, young adults reported more contextual details in conjunction with correctly classified study items than with incorrectly identified nonpresented critical items. However, this recollective difference between veridical memory and DRM memory errors is less pronounced for older adults, suggesting that these subjects rely more on general information when making memory judgements than do young adults. Tun et al (1998) reported that even when the strategy of relying on gist memory was de-emphasised, older people still made more DRM memory errors than did young adults. Moreover, older adults' response latencies for DRM errors were fast, and similar to those associated with veridical memories.

Particularly strong evidence for the notion that reliance on gist memory is responsible for older peoples' susceptibility to DRM errors comes from the findings of Koutstaal and Schacter (1997). As mentioned above, young and older adults were presented with coloured pictures of objects at study. Some of these pictures belonged to object categories that consisted of varied numbers of exemplars shown in the experiment. The other pictures were isolated objects that did not belong to any particular category. In a following old/new recognition test, Koutstaal and Schacter found that the false alarm rates for unstudied pictures, which were exemplars of study categories, were larger for older than for young subjects, and this false recognition effect exhibited by older subjects was modulated by category size of studied objects. Moreover, although the hit rates for categorised study items were comparable for older and young subjects, older subjects exhibited significantly lower hit rates for isolated uncategorised studied items than young subjects did. These findings are supportive for the fuzzy-trace/gist account for the DRM errors. Objects belonging to the same category generally share some perceptual or conceptual similarity. The more exemplars from the same category that are presented at study, the more likely that a strong gist for this category was formed. This can explain why the older subjects showed both high false alarm rates and high hit rates for unstudied and studied exemplars of study categories, and why these two kinds of response categories were modulated by the category size. In contrast, weak gist memories were formed for isolated objects because there were no other similar exemplars shown at study. Identification of these studied isolated objects relies on item-specific information associated with these objects, which is encoded by young but not by older subjects. Thus, relative to young adults, the older subjects showed lower hit rates for isolated objects.

It should be noted that some aspects of the finding of Koutstaal and Schacter (1997) can be explained by the activation/monitoring theory. For instance, the aging-related deficit on source monitoring ability, as reviewed in previous sections, can explain why older subjects made more DRM memory errors than young subjects. The effect of study category size on false recognition may reflect the fact that source memory errors tend to occur when a novel item is preceded by many study items that share similar conceptual and perceptual features. However, it is difficult for activation/monitoring theory to explain why the above results were accompanied by the finding that older subjects had difficulties in identifying isolated studied objects. In comparison to studied category items that were presented with many other items that shared similar perceptual and conceptual properties, studied isolated items were not confused with other items in the following test. It seems that the lack of item-specific information, and reliance on gist memories, could explain older subjects' impairment in hit rates for isolated studied items better than the proposal that they were simply making source confusions between perceived and imagined items. Together with the idea that it is not likely nonpresented objects were imagined during study phase, it is argued that the generation of DRM errors is better accounted for by fuzzy-trace/gist theory than by activation/monitoring theory.

2.3.4 Neuropsychological Studies of DRM Memory Errors

Neuropsychological studies of DRM memory errors, similar to those of source memory, have focused on patients with impairments in two brain regions: the medial-temporal and the frontal lobes. Specifically, these studies have asked whether amnesia due to medial-temporal damage with or without frontal impairment, as well as nonamnesic patients whose damage is restricted to the frontal lobe, are as susceptible to DRM memory errors as normal people are. Different rates of DRM memory errors have been exhibited by medial-temporal and frontal impaired patients, and these might reflect the different roles played by these two regions in memory.

Some studies have demonstrated that amnesic patients with damage restricted to the medial-temporal lobe showed reduced levels of DRM memory errors. Schacter, Verfaellie, & Pradere (1996) used semantically associated words, similar to those used by Roediger and McDermott (1995), to test amnesic patients with the DRM procedure. They reported that, relative to matched control subjects, amnesic patients showed lower hit rates for studied items and higher false alarm rates for unrelated new items. However the amnesic patients were less susceptible to false recognition for nonpresented related lures than were matched controls. The lower rate of DRM memory errors in amnesic patients suggests that the medial-temporal lobe is involved in generating and retrieving gist memories for related items, which are utilised by normal subjects in making old/new judgements. The damage in the medial-temporal lobe is presumably responsible for the amnesics' deficit in identifying studied items. However, the inability to form and utilise gist memory due to the medial-temporal impairment prevents amnesics from making DRM memory errors. The reduction of DRM memory errors for amnesic patients is not restricted to semantically related items such as the associated word lists used by Roediger and McDermott (1955). Schacter, Verfaellie, & Anes (1997) extended the results of Schacter et al. (1996) to the domain of false perceptual recognition. They reported that after studying lists of orthographically and phonologically similar words (e.g., fade, fame, fake, mate etc.), amnesic patients made fewer false alarms to nonpresented but perceptually similar lures (e.g., fate) than did matched controls. This finding suggests that gist memory is not restricted to semantically related items but instead can be formed for different aspects of the relations between stimuli. A similar finding and conclusion was reached by another study that used abstract novel objects, all of which were exemplars of different category prototypes (Koutstaal, Schacter, Verfaellie, Brenner, & Jackson, 1999).

It should be noted that some patients in the study of Schacter et al. (1996) were alcoholic Korsakoff amnesics, in which there is often frontal involvement. Given that the prefrontal cortex might be involved in operations such as strategic search, monitoring, and verification (Moscovitch, 1989; 1995), it is possible that amnesic patients with or without Korsakoff's syndrome might behave differently in respect of their susceptibility to DRM memory errors. Schacter, Verfaellie, Anes, and Racine (1998) tested amnesic patients with or without Korsakoff's syndrome in a study that repeated the same study-test of associated word lists five times, and compared performance on old/new judgements across the five trials. Consistent with Schacter et al. (1996), both amnesic groups made fewer DRM memory errors than did their matched control subjects at the first trial. However, differential effects of repetition on DRM memory errors were found for the two groups of amnesic subjects. As study-test blocks were repeated, controls showed reduced false recognition for nonpresented critical words. Korsakoff amnesic patients showed increased DRM memory errors as the study-test repeated, whereas non-Korsakoff amnesic patients showed fluctuating levels of false recognition across trials. Schacter et al. also reported a consistent increase in the proportion of old responses to studied words for both amnesics and controls, although the hit rate for amnesics remained lower than that of controls.

Schacter et al. (1998) suggested that as the study lists were repeatedly presented, controls encoded rich item-specific information related to each studied word that helped them subsequently to identify the words. Controls also benefited from item-specific information when rejecting nonpresented critical words that were in accordance with gist memories, but lack item-specific information. This account can explain the increased hit rate for studied items and reduced false recognition across the trials exhibited by normal subjects. In contrast, amnesic patients encoded limited item-specific information during the repetition of the study list, as reflected in their higher hit rates at later trials. Crucially, amnesics also formed gist memories for study lists when they were repeatedly presented. The fluctuating levels of DRM memory errors found in non-Korsakoff amnesics reflects the fact that the limited item-specific information acquired during repetition was not sufficient to suppress the influence of gist memories. On the other hand, Korsakoff patients exhibited increasing DRM memory errors across the trials. This finding might be related to the frontal deficit that made Korsakoff amnesics unable to evaluate or monitor retrieved information. This idea is supported by the signal-detection analyses conducted by Schacter et al. (1998), which showed that the response criteria adopted by Korsakoff patients were much more liberal than those adopted by control and non-Korsakoff subjects.

2.3.5 Summary of DRM Memory Errors

The false recognition observed in the DRM procedure is a robust memory illusion. It has been observed with different stimuli, such as word lists and nonverbal stimuli. Moreover, DRM memory errors are persistent over time and have been reported to be associated with recollective experiences, as indexed by the Remember/Know procedure. The activation/monitoring theory, and the fuzzy trace/gist theory, have both been proposed to explain why DRM memory error occurs. These two accounts differ mainly in their views on the memory representations from which DRM memory errors are derived. The activation/monitoring theory proposes that nonpresented critical items are consciously or unconsciously activated when theirs associates are encoded. If this theory is correct, then there is a memory representation for the nonpresented critical item available at test similar to what have existed if the nonpresented critical item had been presented at study. While there might be subtle differences between the representations for nonpresented and studied items, these subtle differences are not detected by subjects, so that at test the nonpresented item is incorrectly identified as having been encountered at study. On the other hand, the fuzzy-trace/gist theory proposes that when a series of associated items are encountered, the general properties of these items are extracted and stored so as to form a gist memory. The gist memory is like a prototype for these related items. When a nonpresented critical item is presented at test, it is incorrectly identified as old because of its conformity with the gist memory for its associates. An important question is what constitutes the gist memory? In the original definition proposed by Reyna and Brainerd (1995), gist memory functions similarly to the undifferentiated familiarity induced by nonpresented critical items because it is consistent with those studied item and is highly familiar. However, in some studies (e.g., Koutstaal & Schacter, 1997; Schacter, Norman, & Koutstaal, 1998), gist memory is viewed as a composite representation containing features that are common to the related item that might or might not be separate from the representations for individual studied items. It is possible that both theories are to some extent true and contribute to the occurrence of DRM memory errors. However, the finding of Koutstaal and Schacter (1997) that DRM memory errors occur even to items that are unlikely to have been generated at study suggests that the gist account plays a more prominent role in the generation of DRM memory errors.

2.4 Concluding Remarks

One point in common to source memory errors and DRM memory errors is that both types of memory errors are related to the similarity of, or the general properties shared by, studied items, or between studied items and nonpresented items that are incorrectly identified as old. The idea of partial source information in source monitoring is very similar to the idea of gist memory discussed in respect of DRM memory errors. Both are related to information that is not specific enough to identify individual items, such that items that are consistent with the partial information, or gist memory is highly likely to be incorrectly classified as old. However, it is not clear what partial information, or gist memories are composed of. On the one hand, it might be a vague or general representation that acts like familiarity in recognition memory in the absence of any specific features about the studied items. In this case, false memories based on the gist might be functionally equivalent to incorrectly attributed familiarity. On the other hand, it is also possible that partial information or gist memory is actually a composite of features shared by many different episodes. By activating gist memory, non-common features that are specific to individual items might also be activated. In this case, just as occurs for inappropriately bound features, new items that have partial common features, or features belonging to related but distinct episodes might be incorrectly identified. It would be of interest to explore what constitute a gist memory and what are the necessary conditions for such memories to be formed.

Chapter 3. Event-Related Potentials

3.1 Introduction

The aim of cognitive neuroscience is to understand the identity and organisation of information-processing operations underlying cognitive functions, as well as how these operations are implemented by the nervous system (Rugg, 2001). Given the belief that all cognitive functions are based on neural activities carried out in the brain, it is useful to acquire measures of brain activity that can inform and constrain information-processing models of human cognition. One aspect of the nervous system that can be utilised for this measuring purpose is that neural activity is an electrochemical process that engenders electrical fields. When large populations of neurons are active together, the engendering activity is measurable as variations of electrical potentials over time at human scalp, constituting the electroencephalogram or EEG. To acquire electrophysiological signals associated with cognitive functions, the EEG is recorded as epochs that are synchronised with or time-locked to a particular event, such as the presentation of an experimental stimulus. Event-related potentials (ERPs), which reflect the neural processing of experimental stimuli, are extracted from epochs of EEG associated with stimuli of the same category.

The application of ERPs in cognitive studies is achieved by presenting subjects with different types of stimuli (e.g., old and new items in recognition memory experiments) and comparing the recorded ERPs contingent on subjects' responses to these stimuli (e.g. hit, miss, false alarm, and correct rejection). Similar to other neuroimaging methods, such as fMRI or PET that measure haemodynamic correlates of neural activity, ERPs can be employed to investigate cognitive functions and their neural correlates using three approaches (Rugg, 2001). The first one concerns 'functional localisation', which refers to mapping cognitive operations onto their corresponding neural correlates. The second case concerns 'functional fractionation', which refers to separating and identifying cognitive operations by demonstrating that different neural correlates are associated with them. The third approach concerns 'neural monitoring of cognitive functions'. In this case, pre-experimental knowledge of the relation between cognitive operations and their neural correlates is utilised to determine whether a specific cognitive operation is involved or engaged in certain cognitive tasks.

In comparison to other neuroimaging techniques such as fMRI and PET, ERP is particularly suitable for functional fractionation and neural monitoring of cognitive functions because of its high temporal resolution (in the order of milliseconds). This advantage endows ERPs with the ability to track neural activity in real time, providing important information about the time course of cognitive processing. However, ERP suffer from poor spatial resolution, and this makes them unsuitable for mapping cognitive functions to specific brain regions. The low spatial resolution results from the 'inverse problem', which states that the same pattern of electrical activity recorded at the scalp can originate from indeterminate numbers of possible configurations of sources inside the brain. Although the generators of ERPs could be inferred with some mathematical models, it is not an easy task to determine the neural generators of an ERP scalp field. Another limitation of the ERPs is that some cognitive operations cannot be reflected by ERPs. Only electrical activity generated by neurons with certain configurations and orientations in the brain can be detected at the scalp. Therefore cognitive operations supported by brain regions whose neural activities are not detectable on the scalp would not be reflected by ERPs.

The following sections briefly introduces technical aspects of employing ERPs in cognitive studies, including how ERPs are generated, recorded, analysed, and different approaches in interpreting ERP data. The material derives mainly from Coles and Rugg (1995), Kutas and Dale (1997), Picton, Lins, and Scherg (1995), as well as Rugg and Coles (1995).

3.2 Electrogenesis

Neurons transmit signals by changing their permeability to charged ions, which results in current flows along and through the membrane of neurons. The transmembrane current flows, resulted from the all-or-none action potential along the axon or the graded post-synaptic potentials along the dendrites, produce electrical potential differences between different locations in extracellular space (Wood, 1987). It is suggested that the electrical fields picked up at the scalp originate from the exhibitory and inhibitory post-synaptic potentials (EPSP and IPSP respectively) rather than action potentials, as cortical surface ERPs and intracellular post-synaptic potentials persist at deep levels of anesthesia sufficient to block action potentials, (Wood & Allison, 1981).

The localised electrical fields generated by individual neurons summate over space. One factor that determines whether or not the spatially summated electrical fields propagate through the brain tissue and skull to be detected as EEG/ERPs at scalp is the shape of the neurons. The regions of a neuron's membrane where there are net current outflows and net current inflows are called 'current sources' and 'current sinks' respectively. As a law of electricity, the charge of the sink and the source of a neuron must be equal, making the neuron equivalent to a 'dipole' (Kutas and Dale, 1997). The shape of a neuron determines the relative positions of the sources and sinks and whether the electrical field generated by the dipole is restricted to the region around the neuron. When the neuron is asymmetrical, such as the pyramidal neurons with long apical dendrites, an 'open field' (figure 3.1.1) that can be detected outside the region of the neuron is generated. In

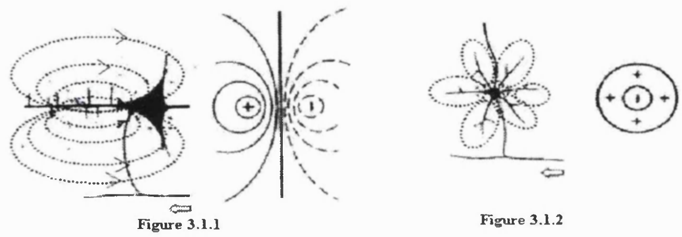

Figure 3.1. Open and Closed electrical fields generated by pyramidal cells (Figure 3.1.1) and stellate cells (Figure 3.1.2) respectively. Adapted from Picton et al. (1995).

contrast, a 'closed field' (figure 3.1.2) restricted to the region of the neuron is generated when the neuron is radial symmetric, such as the stellate cells that have symmetrically oriented dendrites (Picton, Lins, & Scherg, 1995).

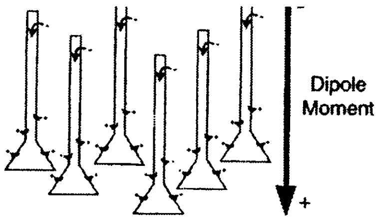

Figure 3.2. Open field source configuration. Adapted from Kutas and Dale (1997).

The generation of open fields also relies on the parallel alignment and temporal synchronisation of the neurons that contribute their localised fields to the summated electrical field (figure 3.2). The electrical fields generated by neurons that are randomly oriented or do not activate in synchronisation might cancel each other such that the summated electrical field is zero (figure 3.3). The brain structure that best satisfies all the above constraints to generate open fields is the neocortex. About 70% of the cells in the neocortex are pyramidal cells organised by groups in column oriented perpendicular to the surface of the cortex (Nunez, 1981). The pyramidal neurons in the neocortex are believed to be the primary source of the EEG/ERPs recorded at the scalp.

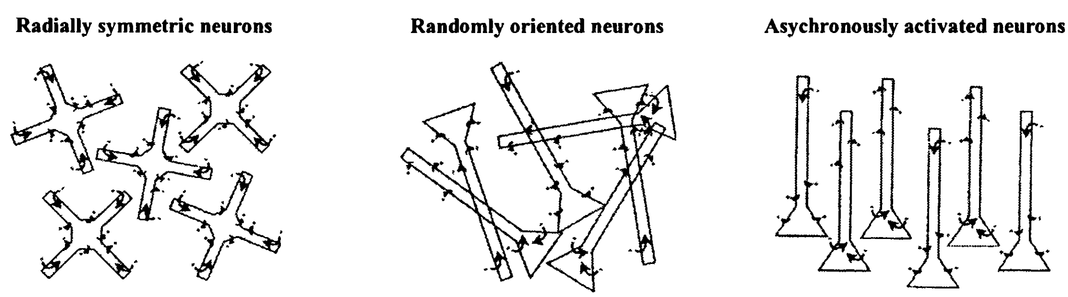

Figure 3.3. Self-cancelling closed field source configurations. Adapted from Kutas & Dale (1997)

3.3 ERP Recording

To record EEG/ERP signals, electrodes are placed on the head of a willing participant according to a selected montage, which specify the locations of the electrodes on the scalp, as well as how these electrodes are connected to the different channels of the amplifier. One channel of the amplified is assigned as the reference, and the output of the amplifier reflects the variation in voltage over time from each scalp site relative to the reference channel. The EEG activities recorded from the electrodes to the amplifier are analog signals and are filtered before they are sampled as digital signals through analog-digital conversion. To collect good-quality ERP signals, it is essential that the equipment and parameters are employed optimally in the above mentioned ERP recording procedure.

The interface between the electrical activity on the scalp and the input circuit of the amplifier are the electrodes, which are attached to the head with an electrolyte solution as conductive medium. The electrical characteristics of the electrodes have great effects on the quality of ERP recording. The transmission of signals from the scalp to the amplifier is distorted if a 'electrical double layer' is formed by the ions exchanged between the electrode and the electrolyte. This ion layer acts as a capacitor and makes the electrode interface a filter for low-frequency signals. It is suggested that 'reversible' electrodes, such as those made of silver/silver chloride (Ag/AgCl), should be employed to avoid the electrical double layer (Picton, Lins, & Scherg, 1995). Another possible source of distortion is the quality of the connection between the electrode and the scalp. The impedance between the electrode-skin interface should be less than the input impedance of the amplifier by a factor of at least 100. The skin-electrode impedance can be decreased by abrading the skin beneath the electrodes. It is common practice to keep the impedance below 5k Ohm.

Electrodes are usually located on the scalp according to the 10-20 system (Jasper, 1958; American Electroencephalographic Society, 1991) in which electrode locations are specified with respect to brain areas and hemisphere. The number and locations of recording sites can be adjusted according to the aim of the research. A densely spaced electrode array might be needed if the topographic distributions of the ERPs are to be plotted. A general rule is that the electrodes should cover the whole scalp area evenly.

As EEG/ERP is a record of the difference in potential between two points on the scalp over time, all ERP recordings are made with respect to a reference electrode. It is important to select an appropriate reference point to collect reliable signals. Two kinds of reference point are often used in ERP studies. The first one is the 'average reference', in which the mean voltage across all electrodes is computed and serves as the baseline, and is then subtracted from the voltage obtained at each recording site. The second one is the 'common reference', in which all electrodes are connected to the same reference site. This reference could be a single electrode located at a relatively inactive part of the head, such as the nose tip, or a pair or electrodes linked together, such as the mastoids behind the two ears. One problem for the linked-mastoid reference is that the 'virtual' reference point is hard to determine, as the amount of activity contributed from the two mastoids might vary. One method to overcome this problem is to employ a midline electrode as reference point during recording, and monitor whether there are asymmetric electrical activities among the two mastoids. The recorded signals are then 're-referenced' to the linked-mastoid reference obtained with algebraic calculation (Picton, Lins, & Scherg, 1995).

The connection between electrodes and the amplifier can be either direct coupling or through a capacitor. The direct coupling (DC) is used for studying very slow potential shifts that in theory contain potential changes of 0HZ. By contrast, the coupling with the capacitor filters out sustained potential differences (Picton, Lins, & Scherg, 1995) as the capacitor acts as a low-frequency (or high-pass) filter that reduces the amplitude of signals whose frequency is lower than a certain level. Most ERP studies can be conducted with capacitor coupling unless it is required to record very slowly changing potentials (<.05 Hz).

The voltage differences between the inputs are amplified to a range that can be digitised accurately. However, the brain potential recorded from the scalp is very small in comparison to other electromagnetic noise from the environment picked up by the electrode. Therefore, it is essential that the in-phase noise signals common to all electrodes (known as 'common mode signals') are cancelled by using a differential amplifier. Along with amplification, the signals are usually filtered at the same time. The aim of analog filtering is to enable the recording system to pick up target signals while reject frequencies that are unlikely to reflect the activity of interest. The bandpass of an analog filter is specified by the high and low cut-off frequencies, at which the filtered power is half (-3db) the unfiltered power (Picton, Lins, & Scherg, 1995).

After amplification, the analog signals from the electrodes are converted into digital form to facilitate the following data analysis. The rate of the analog/digital conversion, usually in the form of 'samples per second' is referred to as the sampling rate. The sampling rate must be at least twice the highest frequency present in the analog signal (Nyquist frequency) to avoid 'aliasing', which refers to the distortion that frequencies twice higher than the sampling rate appear in the digital record as spurious low frequency components. Considering that the analog filter in the amplifier has a slope to the cut-off frequency, it is suggested that the sampling rate should be four times the high cut-off frequency (Picton, Lins, & Scherg, 1995) to guarantee that the aliasing distortion would not happen.

3.4 ERP Extraction

In comparison to the on-going EEG and the electrical activity from the environment that constitutes the 'noise' picked up by the electrodes, the ERP signals elicited by experimental events are much smaller. To extract the ERP signals from the background noise for analyses, the signal-to-noise ratio must be increased. The most widely used signal extraction procedure is to average multiple epochs of EEG time-locked to the same class of experimental events. The assumption underlying the averaging procedure is that the ERPs elicited by the same type of experimental events are constant across multiple trials, whereas the EEG and the noise vary across trials. Therefore averaging the multiple trials will cancel the background noise and reveal the ERP signal. The signal-to-noise ratio improves as a function of the square root of the number of trials used for averaging (Picton, Lins, & Scherg, 1995).

However, not all noise can be cancelled by averaging. Some artefacts might be more or less time-locked to the stimulus and thus cannot be removed by averaging multiple trials. It is essential that trials containing these artefacts should be identified and rejected or corrected prior to analyses. These artefacts arise from two main sources. The first one is the physical events occurred in the environment, including the recording equipment, that induce electrostatic potentials on the subject or the electrodes. The second one is the physiological events that generate electrical potentials unrelated to cerebral neural activities, such as movements of eyes as well as muscles of the scalp, neck, and face. The artefacts caused by the physical interference and the muscle movements are usually reflected in baseline drifts or saturation, in which a linear slope or a continuous flat line is observed thorough the recording epoch. Trials containing these artefacts should be rejected before averaging. Eye movements include saccades and blinks. In the ERP studies reported in this thesis, trials containing saccadic eye movements are rejected, whereas those containing blinks are corrected by a correction algorithm. After signal extraction, digital filters are usually applied to further improve the signal-to-noise ratio, and to smooth the ERP waveforms.

3.5 ERP Components

The term 'component' in ERP literature refers to the parts of a waveform that were analysed according to some concept of the waveform's structure (Picton et al., 2000). The structure could be the deflections of the waveforms. The waveforms, or the voltage change along the recording epoch, comprise a series of peaks and troughs, which are usually named according to their latency and polarity (e.g., P300, N400, etc.) relative to the pre-stimulus baseline. Traditionally, these peaks and troughs were identified with

ERP components. However, there are problems with such 'peak-picking' approach in identifying these deflections as ERP components and linking them to cognitive functions. This difficulty arises from the fact that the observed waveforms may be the summation of electrical activities generated by more than one source in the brain with different time courses. Thus the deflections might actually result from many spatially and temporally overlapping neural generators, and may not be identified as a single component (Coles & Rugg, 1995).

There are two main approaches to identify ERP components. The 'physiological' approach emphasises anatomical localisation of ERPs. In this approach, the defining characteristic of an ERP component is its anatomical source within the brain. An ERP component is defined in terms of the contribution of a single generator, or a distributed neural circuit, to an ERP field. How the generators are related to psychological processes is not the main concern for those who take the physiological approach. A variety of methods have been used to identify the source. Some of these methods, such as intracranial recording in human and single/multiple-unit recording in animals, provide indirect information that can constrain the locus and number of sources for a given ERP effect. There are also methods developed to infer the generators from the scalp ERP fields. Analytical procedures, such as the Brain Electrical Source Analysis procedure (BESA; Scherg, 1990), assume that ERP waveforms represents the summation of the activity of a number of different generators; These generators can be modeled as 'equivalent dipoles' with different locations, orientations, strengths inside the brain and activate in different time-courses. The contribution of each source to the ERP field is viewed as an independent component. As already noted in the earlier sections, the main challenge for the 'source localisation' is the 'inverse problem'. To obtain the best-fit solution of the inverse problem, neuroanatomical knowledge and information acquired from intracranial recordings and fMRI or PET activation in analogous tasks are used to constrain the localisation of the sources.

In contrast to the physiological approach that focuses on the neural sources of ERPs, the 'functional' approach focus on the relations between ERPs and information processing operations. An ERP component is defied as a specific feature of the waveforms (e.g., peaks or troughs) that is related to a specific psychological process. To isolate a component, ERPs elicited in different experimental conditions are subtracted from each other. The functional characteristic of the ERP component is then related to the cognitive process that is thought to differ between the experimental conditions. For those who take the functional approach, an ERP component is not necessarily associated with only one neural generator. However, if more than one generator contribute to a component, the contributing brain structures must form a homogeneous functional processing system. A challenge for such subtraction method is the assumption of 'pure insertion' (Donders, 1868/1969), which states that experimental conditions used to identify an ERP component must differ only with respect to the process of interest but are equivalent in all other respects (see Friston, Price, Fletcher, Moore, Frackowiak, & Dolan, 1996, for a critique of pure insertion and subtraction method). A once-popular method to extract different components from the ERP waveforms associated with psychological processes is Principal Component Analysis (PCA). This procedure identifies sources of covariance in the ERP data that can be attributed to or associated with different experimental variables, which correspond to the manipulation of cognitive operations. However, as noted by Coles and Rugg (1995), the use of PCA might be misleading as the same ERP component might be elicited by different conditions at different latencies, such that spurious components are identified. It has also be shown that PCA can 'misallocate' variances between components that are supposedly to be orthogonal to each other (Wood & McCarthy, 1984). It is therefore unwise to employ the PCA as the sole means in identifying ERP components (Coles & Rugg, 1995).

Ultimately, ERP waveforms should be understood from both the physiological and functional aspects. It has been suggested that an optimal means to examine ERPs is to use both psychological and physiological based manipulations as a way of defining the sources of variability in ERP waveforms (Picton & Stuss, 1980).

3.6 Functional Interpretation of ERP Effects

ERP is particularly suitable for separating and identifying cognitive operations because of its high temporal resolution. Another reason why ERP is useful for such 'cognitive fractionation' is that there is sufficient variability in the temporal and spatial features of ERPs that might reflect at least some of the richness of the neural activity associated with different cognitive processes (Rugg & Coles, 1995). As stated in the previous section, ERPs elicited in different experimental conditions are compared with each other to make inferences about the cognitive functions involved in the experimental manipulation. The differences between the ERPs elicited in different experimental conditions, whether in latency, amplitude, or scalp distribution, indicate that the neural processing of the eliciting stimuli in these conditions is not equivalent. Nevertheless, the absence of ERP differences between different conditions does not necessarily imply that stimuli in these conditions are associated with identical neural processing, as some brain activity might not be detectable to scalp electrodes, or the effects might be too weak to be detected at the scalp.

Note that in order to make functional inferences from ERP data, it is necessary to assume that there is an invariant relation between cognitive processes or states and their supporting neural substrates. Without such 'invariance assumption' between functional and physical states, there is no basis to separate and identify cognitive processes by demonstrating different patterns of brain activity associated with these processes. The differences between the ERPs across experimental conditions can be categorised as 'quantitative' or 'qualitative'. A quantitative difference refers to the case that the ERPs differ across experimental conditions in amplitude or latency but not in their distributions over the scalp. The absence of the difference between ERP scalp distribution implies that a common set of neural processes is engaged in the different experimental conditions. The functional interpretation would therefore be that similar cognitive processes are engaged in these conditions to different degrees or intensity. By contrast, a qualitative difference refers to the case that the scalp distributions of the ERPs differ across experimental conditions, or across different time windows within a single condition. Such qualitative differences can arise because neural processes in different brain regions contribute to the ERPs, or because identical brain regions contribute to the ERPs with different levels of relative activation. In either case, different patterns of neural activities are involved in different experimental conditions. Based on the invariance assumption, qualitative differences in ERPs can be viewed as supporting evidence for the engagement of functionally distinct cognitive processes. It should be noted, however, that different scalp distributions of ERPs provide a necessary but not a sufficient condition to draw the conclusion that functionally distinct cognitive processes are identified, as scalp difference might result from neural processes not related to cognitive functions of interest.

An important point to note while establishing the functional significance of ERP data is that ERPs, as with other neuroimaging techniques, are correlational in nature. An ERP effect does not necessarily reflect the neural processes supporting the cognitive functions manipulated by the experimenter, but might reflect the neural processes contingent upon the actual processes of interest. To establish a casual relationship between cognitive function and ERP data, invasive techniques, such as transcranial magnetic stimulation (TMS), must be employed. With such techniques, the neural processes thought to instantiate cognitive operations are manipulated and the functional consequences of these manipulations can be examines (Rugg, 2001).

The forgoing discussion denotes the assumptions commonly adopted to make functional claims on ERP data. Differences in the amplitude, latency, and scalp distribution are the basis of the functional interpretations of ERP effects related to recognition memory. In the ERP experiments contained within this thesis, recognition memory ERP effects reviewed in the next chapter were utilised following the approach of neural monitoring of cognitive function to examine the cognitive processes underlying veridical and erroneous memories.

Chapter 4. Event-Related Potentials, Memory, and Memory Distortion

4.1 Introduction

Event-related potentials have been employed in memory research for more than two decades (for reviews see Rugg & Allan, 2000; Friedman & Johnson, 2000). A general goal of these studies is to investigate the identity and organisation of cognitive operations contributing to various aspects of memory, such as working memory, implicit memory, explicit memory, and so on. The current chapter reviews ERP studies of memory to provide a context for the ERP experiments reported in this thesis.

As the main theme of this thesis is false recognition of confusing item-source pairings, the review will focus on studies that investigate the encoding and retrieval of episodic memory, primarily those employing recognition as the memory task. A common method employed by these studies is the study-test procedure, in which ERPs are recorded when subjects are presented with items to learn at study, and/or when they are requested to discriminate studied old items from unstudied new items at test. For studies addressing retrieval processes, the ERPs recorded at test are categorised according to the subjects' correct and incorrect judgements to old and new test items, i.e., hits and misses to old items as well as false alarms and correct rejections to new items. The differences between the ERPs associated with these response categories under different experimental manipulations provide information about the cognitive processes involved in retrieval. Most of these studies focused on the differences between the ERPs associated with hits and correct rejections, which are usually referred to as 'ERP old/new effects'.

For studies addressing encoding processes in episodic memory, the ERPs recorded at study are sorted according to whether the eliciting study items are subsequently correctly identified as old or incorrectly classified as new in a later test phase. The ERP differences between these two classes of study items are usually referred to as 'subsequent memory effects' (Rugg, 1995) or 'Dm' effects (Paller, Kutas, and Mayes, 1987), standing for

'*D*ifference in subsequent *m*emory'. In addition to the study-test procedure, another method employed in some studies is the continuous recognition procedure. Items in this procedure are presented in a single series, and the task of the subjects is to discriminate between those being shown for the first and the second time. ERPs are recorded for each item, and are categorised according to whether the eliciting item is presented for the first or the second time and the response accuracy.

The following review is organised into four sections. The first section addresses three ERP effects that have been frequently observed in the retrieval of episodic memory. These three effects are related to the recollection and familiarity components of recognition proposed by dual-process theories (reviewed in Chapter 1), as well as the monitoring and/or evaluation processes that might be involved in retrieval. The second section focuses on the subsequent memory effect, aiming at identifying the neural correlates of encoding processes that are related to performance in the subsequent memory test. The functional interpretations of the encoding and retrieval ERP effects, as reviewed in the first two sections, then serve as the basis to investigate the neural correlates of the cognitive processes involved in source memory errors and gist-based false recognition, which are reviewed in the third section. A discussion of the encoding and retrieval ERP effects is provided in the final section, which also outlines the theoretical questions the current thesis aimed to investigate.

4.2 ERP Studies of Retrieval

A consistent finding of early ERP studies of recognition memory is that the ERPs elicited by correctly identified old items are more positive-going than those elicited by correctly rejected new items (e.g., Karis, Fabiani, & Donchin, 1984; Neville, Kutas, Chesney, & Schmidt, 1986; Rugg & Nagy, 1989; Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980). Later studies that employed large arrays of electrodes and longer recording epochs suggest that the ERP differences between hits and correct rejections have broad temporal and spatial distribution, and can be decomposed into at least three spatio-temporally specific effects (Friedman & Johnson, 2000; Mecklinger, 2000).

4.2.1 The Parietal Old/New Effect

The parietal old/new effect typically takes the form of a positive-going wave associated with correctly identified old items in comparison to correctly rejected new items in recognition memory tasks. This effect is maximal over the temporoparietal scalp, onsets around 400 ms post-stimulus and lasts about 400-600 ms. The parietal old/new effect is usually left lateralised in study-test designs employing verbal stimuli (e.g., Wilding & Rugg, 1996). However, bilateral parietal old/new effect has also been observed, particularly in tests of continuous recognition (e.g., Rugg, Brovedani, & Doyle, 1992) or in study-test designs employing nonverbal stimuli (e.g., Graham & Cabeza, 2001). Initially the parietal effect was frequently referred to as the 'late positive component' (LPC, see figure 4.1), and was interpreted in terms of the functional significance of a

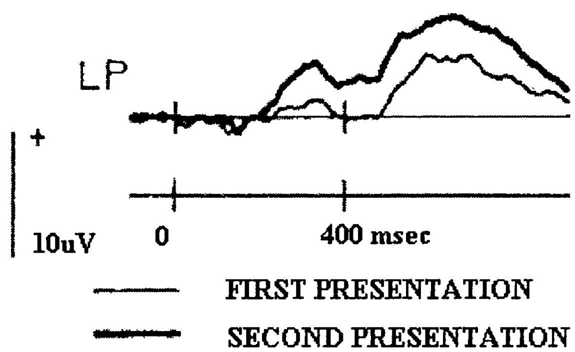

Figure 4.1. The 'late positive component'. ERPs associated with correctly classified repeated items (second presentation) and correctly classified new items (first presentation) at the left parietal site in a direct test of recognition memory. Adapted from Rugg et al. (1992).

heavily studied P300 potential, rather than being related to the retrieval processes per se. A subcomponent of the P300, the P3b, has been thought to reflect the 'context updating' of the working memory, and its amplitude is known to be inversely correlated with the subjective probability of the occurrence of eliciting stimuli (see Donchin, 1981; Donchin & Coles, 1988; Pritchard, 1981 for reviews of P300). It was suggested that correctly identified old items are associated with lower subjective probability of occurrence and higher 'targetness' in comparison to correctly rejected new items, hence elicit larger P3b (Karis et al., 1984; Neville et al., 1986).

However, a number of studies have shown that the parietal old/new effect is independent from the P3b, and is related to the processes involved in the retrieval of episodic memory. Smith and Guster (1993) manipulated the proportions of old and new items (80:20 or 20:80), as well as whether old or new items served as targets to be responded to. The parietal old/new effect was found to be associated with old items whether they served as targets or nontargets, and irrespective of the proportion of their occurrence. It should be noted, however, that in the experiment of Smith and Guster (1993) the test words were sampled from a small set of 10 items, and the ERPs were acquired from midline electrodes only, which constrained the generality of their findings. In a recent study Herron, Quayle, and Rugg (2003) compared ERPs associated with correctly classified old and new items across three different ratios of old to new items: 25:75, 50:50 and 75:25. It was reported that the parietal old/new effect was not influenced by this manipulation. These findings therefore rule out the possibility that the parietal old/new effect reflects the modulation of the 'targetness; and subjective probability of old items on the P3b component. The demonstration that the parietal old/new effect was not associated with false alarms or misses (Neville et al., 1986; Rugg & Doyle, 1992) further suggested that this effect reflects processes that contribute to recognition memory rather than response categories or stimulus repetition.

Different functional interpretations have been proposed to link the parietal old/new effect to either the 'recollection' or the 'familiarity' component of recognition memory proposed by dual-process models. An early proposal was that the parietal old/new effect reflects familiarity-based recognition (Friedman, 1990; Johnson, Pfefferbaum, & Kopell, 1985; Potter, Pickles, Roberts, & Rugg, 1992; Rugg & Doyle, 1992). This notion was mainly motivated by the finding that the parietal old/new effect was sensitive to variables that assumed to affect familiarity more than recollection. For instance, Rugg and Doyle

(1992) had subjects engage in recognition memory test for high and low frequency words. They reported that in comparison to high frequency items, low frequency words gave rise to better recognition performance and elicited a larger parietal old/new effect. Based on the assumption that the superior recognition performance for low frequency words was results of these words' high level of relative familiarity (i.e. the disparity between pre- and intra-experimental familiarity), Rugg and Doyle (1992) identified the parietal old/new effect as correlates of familiarity-based recognition.

The proposal of Rugg and Doyle (1992) that the parietal old/new effect reflects familiarity-based recognition was, however, undermined by the finding that the superior recognition performance for low frequency words might actually be attributed to recollection rather than to familiarity (Gardiner & Java, 1990). A number of ERP studies that investigate recollection with different approaches suggest that the parietal old/new effect is associated with recognition based on recollection rather than familiarity. Paller and colleagues had subjects study two groups of words with deep and shallow encoding tasks respectively, and then engage in a word identification task (Paller & Kutas, 1992) or lexical decision task (Paller, Kutas, & McIssac, 1995; Gonsalves & Paller, 2000) in which studied and unstudied words were presented. Paller and colleagues reported that the parietal old/new effect associated with old words was larger for those that were deeply encoded than for those shallowly encoded. With the assumption that recollection is selectively influenced by depth of processing (Jacoby & Dallas, 1981), and may occur spontaneously in the implicit memory tests used in their experiments, Paller and colleagues argue that the parietal old/new effect for deeply encoded words reflects the recollection associated with these words. The finding that the parietal old/new effect is sensitive to depth of processing is not restricted to studies employing indirect memory tests as those conducted by Paller and colleagues. Studies that employed direct recognition tests also reported that the parietal old/new effect elicited by recognised old items is sensitive to the depth these items were processed at study (Rugg, Mark, Walla, Schloerscheidt, Birch, & Allan, 1998).

Smith (1993) adopted the Remember/Know procedure to investigate the nature of the parietal old/new effect. The idea was that if the parietal old/new effect is the electrophysiological correlate of recollection, than this effect should be correlated with the conscious recollective experience reported by the subjects. Smith (1993) found that although the parietal old/new effect was present for both R and K judgements, this effect was significantly larger for the former than for the latter responses. Based on the assumption that R responses represent conscious recollective experience, Smith interpreted this finding as supporting that the parietal old/new effect reflects the degree to which recollection occurs in recognition memory. A similar finding was reported by Duzel and colleagues (Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997), who found a parietal old/new effect associated with R but not K responses to both studied old items and unstudied semantically related lure items. Assuming that conscious recollective experience is the same for old items and lures, Duzel et al. (1997) argued that the parietal old/new effect for true and lure targets reflects conscious recollection.

The research reviewed above demonstrated that the parietal old/new effect is sensitive to variables assumed to influence recollection. However, the conclusion that the parietal old/new effect is the electrophysiological correlate of recollection drawn from these studies is not unequivocal, as the interpretations of these studies stand on assumptions that are not fully verified. For instance, the conclusion of Paller and colleagues (Paller & Kutas, 1992; Paller, Kutas, & McIssac, 1995) is based on the assumption that depth of processing affects only recollection but not familiarity, which has been called into question (e.g., Toth, 1996). Specifically, the familiarity component of recognition was indexed by the priming effect in the indirect memory test in their studies (faster and more correct responses in lexical decision and word identification tasks respectively). As the priming effect was of similar size for deeply and shallowly encoded items, Paller and colleagues argued that familiarity was not influenced by depth of processing, and hence the ERP effect could be exclusively attributed to recollection. However, the equivalence between familiarity and implicit memory has been questioned (Wagner, Gabrieli, & Verfaellie, 1997), implying that familiarity might be affected by depth of processing.

Similarly, there are also uncertainties in studies employing the Remember/Know procedure to investigate the parietal old/new effect. The finding of Smith (1993) that K responses, assumed to reflect familiarity, elicited a sizeable parietal old/new effect cast doubts into the exclusive connection between the parietal old/new effect and recollection.

The problems of using depth of processing and Remember/Know procedure to investigate recollection are mainly related to the lack of a variable that is specifically linked to recollection but not familiarity. An operational definition of recollection is therefore needed in studies trying to clarify the relation between recollection and the parietal old/new effect. As the main difference between recollection and familiarity is that context information is available in the former case but not in the latter case, correct source judgements can be utilised as an operational definition of recollection. Thus the functional significance of the parietal old/new effect can be assessed by investigating whether the effect is sensitive to source accuracy. In light of this consideration, Wilding and colleagues (Wilding, Doyle, & Rugg, 1995; Wilding & Rugg, 1996; Wilding & Rugg, 1997b) conducted a series of studies employing a source memory procedure to compare the ERPs elicited by correctly recognised old items that are assigned to accurate and inaccurate study contexts. In the study phase of the two experiments reported by Wilding et al. (1995), subjects engaged in a lexical decision task during which the stimuli were presented either visually or auditorily. Later at test, subjects made old/new judgements to visually (experiment 1) or auditorily (experiment 2) presented words. For test words judged old, subjects made a subsequent source judgement, i.e. they specified the sensory modality the test words had been presented at study. Wilding et al. found that a left-lateralised parietal old/new effect for recognised old items that were assigned to the correct study source. However, for those recognised old items that attracted incorrect source judgements, the parietal old/new effect was either absent (experiment 1), or of smaller amplitude and shorter duration. Because source judgement relies on the recollection of study context, this finding suggests that the left parietal old/new effect reflects recollection-based recognition.

One confounding factor in Wilding et al. (1995) that might undermine using source judgement accuracy as an index of recollection was that half of the test words were presented in the same modality as at study. For these test items, greater perceptual fluency might be engendered as opposed to cross-modality test items and served as the basis for modality judgements without recollecting the original study context. Consequently, it was possible that the parietal old/new effect associated with source judgement accuracy was correlated with the familiarity induced by perceptual priming rather than recollection. To avoid this confounding, Wilding and Rugg (1996, 1997a) manipulated the source variable within the same modality. Subjects listened to words spoken in either a male or female voice at study, and then made old/new judgements to visually presented words at test. The source task for identified items was to specify whether the test words had been spoken in a male or female voice at study. Consistent with the prior finding, the parietal old/new effect was larger for recognised old items that were assigned to the correct study source than for those assigned to the wrong source (see figure 4-2).

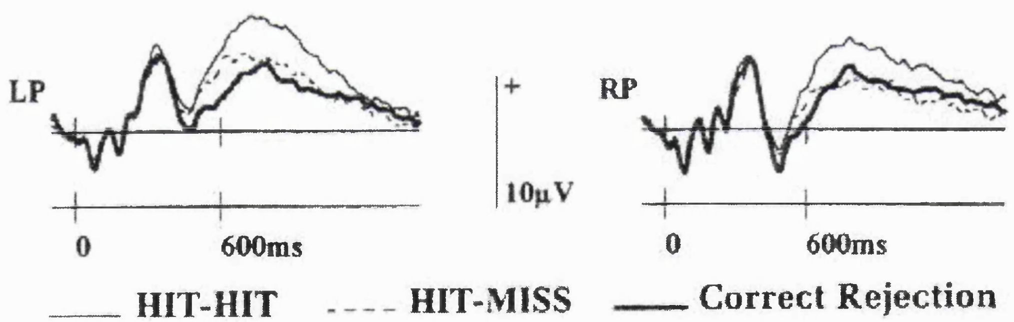

Figure 4.2. The left parietal old/new effect. ERPs associated with correctly classified studied items associated with the successful (i.e. 'HIT-HIT') and unsuccessful (i.e. 'HIT-MISS') retrieval of contextual information, and ERPs associated with correctly classified new items ('Correct Rejection') at parietal sites. Adapted from Wilding and Rugg (1996).

In addition to source judgement accuracy, the finding that associative recognition relies on recollection (Yonelinas, 1997) was utilised by Donaldson and Rugg (1998) to verify the idea that the parietal old/new effect reflects recollection. In their experiment 1, subjects studied unrelated word pairs and then discriminated test pairs composed of old words from those composed of new words. For test pairs judged old, subjects were also requested to judge whether the two words were in the same pairing as at study or in a different pairing. Donaldson and Rugg (1998) found that the parietal old/new effect was larger when elicited by pairs of old words whose members maintained their study pairing than it was for pairs where members were rearranged between study and test. A similar finding was found in their experiment 2 when subjects were requested to discriminate between old and new pairs without judging whether the pair was the same or rearranged. Again, these findings suggest that the parietal old/new effect reflects successful recollection of the associative information.

Another piece of evidence supporting the proposal that the parietal old/new effect reflects recollection comes from studies showing that this effect is absent in neurological patients whose recollection is impaired. An early such study was conducted by Smith and Halgren (1989), who recorded ERPs from patients with right- and left-sided anterior lobectomy and from normal control subjects. Subjects in their study engaged in a series of recognition test blocks containing the same study words and different new words across the blocks. Smith and Halgren reported that the recognition performance of left-sided patients, although improved across the test blocks, was worse than that of right-sided patients and controls. They also reported that the parietal old/new effect was exhibited by the normal controls and right-sided patients, but not by the left-sided patients. Smith and Halgren argued that the low but not eliminated recognition performance of the left-sided patients was resulted from impaired recollection and reserved familiarity. Together with the finding that the parietal old/new effect was not modulated by the repetition of old words across blocks, which was assumed to influence familiarity, Smith and Halgren suggested that the parietal old/new effect is indeed the signature of recollection. Similar results were reported by recent studies recording ERPs in patients with Alzheimer's Disease (Tendolkar, Schoenfeld, Golz, Fernandez, Kuhl, & Heinz, 1999) and with amnesia (Duzel, Yonelinas, Vargha-Khadem, Heinze, & Mishkin, 2001). Tendolkar et al. (1999) reported that the parietal old/new effect was absent in Alzheimer patients who, although exhibited unimpaired recognition, failed to recollect contextual information, which implies impairment in recollection. Duzel et al. (2001) reported that the parietal old/new effect was absent in an amnesic patient who suffered early hippocampal damage. The recognition performance of this amnesic patient was impaired in comparison to controls, but was above chance level. It was argued that the preserved recognition memory of these subjects relies on familiarity, and the absence of the parietal old/new effect in these patients indexes their impairment in recollection.

Wilding and Rugg (1996) linked the parietal old/new effect to processes dependent on the 'medial temporal lobe memory system' (Squire, 1992), which is thought to support the retrieval of item and contextual memory. However, given that scalp electrodes are largely insensitive to neural activity generated within the hippocampus and adjacent structures, it is unlikely that the parietal old/new effect originates from this region. Instead, it has been suggested that the parietal old/new effect reflects 'stimulus-locked changes in cortical activity resulting from the cortico-hippocampal interactions' during episodic memory retrieval (Rugg & Allan, 2000). This hypothesis is difficult to test directly because the intracerebral generators of ERP effects are not easy to identify. Indirect evidence comes from a PET study (Rugg, Fletcher, Frith, Frackowiak, & Dolan, 1997) showing that the left hippocampal formation and regions of left temporal and frontal cortex were more activated when deeply instead of shallowly processed words were recognised. This finding paralleled reports that the amplitude of the parietal old/new effect is sensitive to the depth of processing (Rugg, Mark, et al., 1998). It was conjectured that the parietal old/new effect is the electrophysiological correlate of the left cortical activation identified in the PET study (Rugg, Walla, et al., 1998).

The recently developed technique of 'event-related fMRI' (Josephs, Turner, & Friston, 1997) is capable of providing trial-by-trial measures time-locked to individual events, and hence is suitable to separate recollection from familiarity in recognition memory with trial-based analyses. The first event-related fMRI study attempted to identify the neural correlates of recollection was conducted by Henson, Rugg, Shallice, Josephs, and Dolan (1999), who employed the Remember/Know procedure. Subjects were presented with a mixture of studied and unstudied words at test, and were instructed to make R, K, and N responses corresponding to whether a test word was judged old on the basis of recollection, judged old solely because of its familiarity, or judged as an unstudied new word, respectively. Henson et al. (1999) reported higher activation in left inferior parietal, left superior parietal, posterior cingulate regions, and left anterior superior frontal gyrus for R than K responses. Henson et al. (1999) pointed out that the left superior parietal maximum was very close to the area associated with retrieving contextual information observed in a previous study (Henson, Shallice, & Dolan, 1999), and may underlie the left parietal old/new effect. Henson et al. also identified a medial posterior region of left hippocampus that showed greater activation for R responses than for N responses, but no different activation for K and N responses. They suggested that this result supports the notion that hippocampus is crucial for recollection but not for familiarity. However, it should be noted that the direct contrast between R and K judgment in this region failed to reach significance. Eldridge and colleagues (Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000) employed the Remember/Know procedure with a slight difference from Henson et al.'s study. Subjects in their experiment were asked to make two responses at test, with the first one signaling their old/new decision for the test item and the second a Remember/Know judgment. Eldridge et al. argued that this two-stage response method prevented subjects from using R and K labels to indicate strong and weak memories, and instead encouraged them to categorize memory judgments on the basis of phenomenal experience. Their results were quite similar to those of Henson et al.'s study, with the exception that they reported a enhanced left hippocampal activation for R judgments relative to K judgments. Moreover, there was no difference between activities elicited by K and N judgments in the hippocampus. Eldridge et al. suggested that their results supported the notion that hippocampus is necessary for memories accompanied by recollection, but provided no evidence that hippocampus is necessary for familiarity-based recognition.

In summary, it is generally agreed that the parietal old/new effect is an electrophysiological correlate of recollection-based recognition. In some studies, however, a weak version of the parietal old/new effect was present for recognition assumed to be familiarity-based. For instance, this effect is associated with recognised items accompanied by 'K' responses (Smith, 1993; Trott, Friedman, Ritter, Fabiani, & Snodgrass, 1999) or incorrect source judgements (Wilding et al., 1995; Wilding & Rugg, 1996), with a smaller amplitude and shorter duration in comparison to those associated with 'Remember' responses or accurate source judgements. Moreover, no evidence shows that the topographical distributions of the ERP effects associated with these two classes of recognised items are different, suggesting that the processes associated with the two kinds of responses sharing similar neural generators. Such results led some to argue that the parietal old/new effect indexes recollection in a graded, rather than all-or-none fashion, and is sensitive to the amount and quality of retrieved information (Wilding, 2000; Wilding & Rugg, 1996). The weak parietal old/new effect associated with 'K' responses or incorrect source judgements might index partial or weak recollection that allows subjects to make old/new judgements without specific contextual information for source decisions or 'R' responses.

4.2.2 The Right Frontal Effect

Another ERP effect related to recognition memory is the 'right frontal effect', which was described initially by Wilding and Rugg (1996). This effect, which is maximal over the right frontal scalp, onsets at about the same time as, or later than, the parietal old/new effect, and often lasts until the end of the recording epoch (see figure 4-3). Similar to the parietal old/new effect, the right frontal effect was found to be larger for recognised words that were correctly assigned to their source than for words that were assigned to an incorrect source. Wilding and Rugg (1996) suggested that the right frontal effect indexes functions that operate on the products of the retrieval operation as reflected by the parietal effect, and is necessary for recovering and integrating contextual information to form a coherent representation of the experienced episode. The link between the frontal effect and source information was also evident in a study conducted by Senkfor and Van Petten (1998), who compared the ERPs elicited in recognition memory tests that either did or did not require source judgements. Senkfor and Van Petten reported that a late bilateral (instead of right-lateralised) frontal effect was present when source and old/new judgements were made concurrently but not when only old/new judgements were required. Senkfor and Van Petten also found that the frontal effect was insensitive to accuracy of source judgement. These authors suggested that the late onset of the frontal effect relative to the parietal effect, and its insensitivity to source accuracy, reflected the fact that source information was searched for after item information was retrieved, consistent with the time courses for retrieving these two types of information proposed by the SMF (Johnson et al., 1994; McElree et al., 1999).

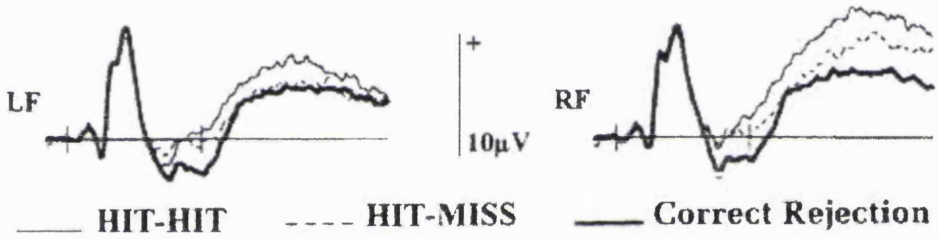

Figure 4.3. The right frontal effect. ERPs associated with correctly classified studied items associated with the successful (i.e. 'HIT-HIT') and unsuccessful (i.e. 'HIT-MISS') retrieval of contextual information, and ERPs associated with correctly classified new items ('Correct Rejection') at frontal sites. Adapted from Wilding and Rugg (1996).

However, there have been studies showing that the right frontal effect is not specific for source memory. For instance, Allan and Rugg (1997) found that this effect was present in an old/new recognition memory test where source information was not manipulated. Donaldson and Rugg (1998), in their experiment 2, demonstrated that the right frontal effect was present when subjects made old/new judgements to study pairs without differentiating intact and rearranged pairs. These findings indicate that the explicit retrieval of source information is not necessary to elicit the right frontal effects. Furthermore, it has been suggested that the right frontal effect is not even necessarily contingent on recollection. One study demonstrating this point was conducted by Wilding and Rugg (1997b), who employed a recognition memory 'exclusion task' to investigate the functional interpretations of the left parietal and right frontal effects. The exclusion task was derived from the processing dissociation procedure (Jacoby, 1991, see chapter 1), in which a studied item at test is responded to as old or new depending on whether it is a 'target' or 'nontarget' specified by the experimenter. Subjects in the study of Wilding and Rugg (1997b) were presented with words spoken in either a male or a female voice, and were required to perform different encoding tasks according to the gender of the voice. In the following test, studied words and new words were presented visually. Subjects were required to make 'old' responses to one of the two classes of studied items ('targets', e.g., words spoken in the male voice) but make 'new' responses to the other class of studied items ('nontargets', e.g., words spoken in the female voice) as well as unstudied new items. Wilding and Rugg (1997b) reported that the parietal old/new effect, thought to reflect recollection, was present for correctly recognised targets and rejected nontargets. However, the right frontal effect was observed only for recognised targets but not for rejected nontargets, This finding suggests that the right frontal effect indexes cognitive processes that do not operate on the products of recollection indexed by the parietal old/new effect obligatorily. Complementarily, it has also been shown that the right frontal effect can be present in the absence of recollection. In a study that manipulated depth of processing Rugg, Allan, and Birth (2000) reported that the parietal old/new effect was present for deeply encoded items but not for shallowly encoded items. By contrast, the right frontal effect was only observed for words that had been studied in the shallow task. Taken together, the data suggest that recollection is not either necessary or sufficient to elicit the right frontal effect.

It is now thought that that the right frontal effect might reflect post-retrieval monitoring or evaluation processes that operate on the products of a retrieval attempt in a strategic or goal-directed manner (Allan, Wolf, Rosenthal, & Rugg, 2001; Ranganath & Paller, 1999, 2000; Wilding, 1999). For instance, Rugg et al. (2000) suggested that more monitoring or evaluation processing was elicited by shallowly studied words than by deeply studied words, with the hypothesis that the former class of items were recognised with a lower degree of confidence than the latter class of items. Specifically, the right frontal effect is elicited when the retrieved information is in need of evaluation or monitoring prior to responding. One study demonstrating this point was conducted by Wilding (1999), who showed that the magnitude of the right frontal effect was modulated by the type of source information subjects were required to retrieve. Wilding (1999) had subjects study words that were spoken in different voices and assigned to different encoding tasks. At test, subjects engaged in different source memory tests that focused on either the 'voice 'or the 'task' the old item had been presented in at study. Wilding found that the magnitude of the right frontal effect was larger for the 'task' than for the 'voice' source judgements, indicating that the effect can be modulated by different mnemonic content.

There have been studies conducted to investigate the cognitive variables that can modulate the right frontal effect, or specifically, under what circumstances will the monitoring processes indexed by this effect be engaged and to what degree? Ranganath and Paller (1999) reported that the right frontal effect was modulated by whether perceptual details of study items were required to be retrieved at recognition test. They presented subjects with test items that consisted of unstudied pictures dissimilar to any studied item, previously studied pictures, and unstudied pictures that were perceptually similar to studied items. A critical manipulation at test was that unstudied but similar items were to be classified as 'old' along with studied items in one condition (the 'general' test), and as 'new' along with unstudied and dissimilar items in another condition (the 'specific' test). Ranganath and Paller (1999) found that the right frontal effect was larger during the general test than during the specific test. This was a surprising result given that monitoring and evaluation processes should be demanded extensively when specific perceptual details were required to make memory judgements. Another study that might shed light on the functional interpretation of the right frontal effect was conducted by Ullsperger, Mecklinger, and Muller (2000), who employed a 'directed forgetting' procedure in their study. Subjects were presented with study words followed by one of two cues that instructed them to 'remember' or 'forget' the just presented item. In the following recognition test, both to-be-remembered (TBR) and to-be-forgotten (TBF) studied words were presented with unstudied new items. Subjects were asked to identify studied words without considering they were TBR or TBF as instructed at study. Ullsperger et al. found that recognition performance was significantly lower for TBF than for TBR items. Moreover, the parietal old/new effect was elicited by TBR but not by TBF words, indicating that recollection was not, or only weakly, elicited by the latter items. However, the right frontal effect was larger for TBF items than for TBR words. Based on this finding, Ullsperger et al. suggested that post-retrieval monitoring processes, as indexed by the right frontal effect, were engaged extensively when retrieved information is poor (e.g., the absence of the parietal old/new effect for TBF items) or salient (e.g., lower hit rate for TBF than for TBR items).

The right frontal effect has been linked to the activity in the right prefrontal cortex during episodic retrieval (Rugg & Allan, 2000; Mecklinger, 2000). Evidence from haemodynamic imaging studies suggests that right prefrontal regions show a greater response for recognised items that require a greater degree of evaluation. For instance, in the event-related fMRI study employing the Remember/Know procedure conducted by Henson et al. (1999a), right midlateral prefrontal cortex showed greater responses to K judgments than R judgments. Similarly, in a later study greater right frontal activities was found for low-confident than high-confident memory judgments (Henson, Rugg, Shallice, & Dolan, 2000). Although the association between the right frontal effect and post-retrieval monitoring/evaluation processes is generally agreed, it is less than clear what are the conditions in which this effect will be engaged, and what are the cognitive variables that modulate this effect. The proposal that low confidence in, and poor quality of, the product of retrieval operation demand extensive evaluation processes seems very appealing.

4.2.3 The Early Frontal Old/New Effect

In addition to the left parietal and right frontal effects, some ERP studies have demonstrated an early frontal old/new effect related to recognition memory (Curran, 1999; Curran, 2000; Curran & Cleary, 2003; Rugg et al., 1998; Tendolkar et al, 1999;

Ullsperger et al, 2000). This early frontal effect takes the form of a positivity associated with items correctly judged old in comparison to items correctly classified as new, with a maximum over superior frontal sites between approximately 300-500 ms after stimulus onset (see figure 4-4). The early frontal effect has been linked to recognition based on familiarity because of its relative insensitivity to variables that affect recollection more than familiarity. For instance, Rugg et al. (1998) reported that the early frontal effect was observed for correctly identified old items, whether these items had been deeply or shallowly processed at study. As the early frontal effect was not observed for incorrectly rejected old items (miss trials), this effect does not simply reflect priming-related processes. The insensitivity of the early frontal effect to depth of processing suggest that it reflects neural activities associated with processes other than recollection, and familiarity is a very likely candidate. However, as the idea that depth of processing can dissociate recollection and familiarity has been questioned (e.g., Toth, 1996), the linkage between familiarity and the early frontal effect is uncertain.

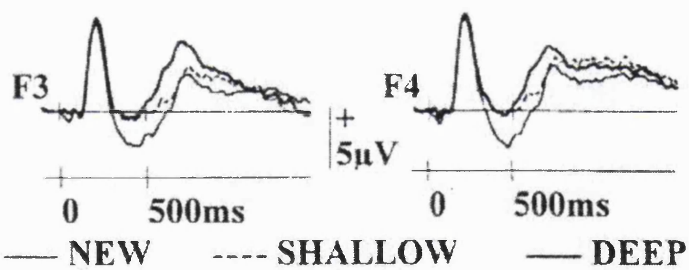

Figure 4.4. The early frontal effect. ERPs associated with correctly classified shallowly studied ('SHALLOW') and deeply studied ('DEEP') items, and ERPs associated with correctly classified new items ('NEW') at left and right frontal sites. Adapted from Rugg et al. (1998).

In a study designed to compare ERP old/new effects elicited in incidental and intentional retrieval (Curran, 1999), subjects were presented with words and pronounceable pseudowords at study. In the later test phase, subjects engaged in a lexical decision task and an old/new recognition task, both containing new and repeated items. Curran (1999) reported that a parietal effect was elicited by words in both tasks, but was not elicited by pseudowords, suggesting recollection in association with the former but not the latter class of test items. By contrast, the early frontal effect was of similar magnitude for words and pseudowords in both tasks. Together with previous reports that recognition of pseudowords relies mainly on 'Know' responses (Curran, Schacter, Norman, & Galluccio, 1997; Gardiner & Java, 1990), Curran argued that the early frontal effect reflects recognition based on familiarity. However, the old/new effect referred to in Curran (1999) was actually stimulus repetition effect, as ERPs of both correct trials (hit and correct rejections) and incorrect trials (miss and false alarms) were included in the analyses. It is therefore uncertain whether the early frontal effect observed in this study can be unequivocally viewed as the electrophysiological correlate of familiarity-based recognition.

In their following studies Curran and colleagues (Curran, 2000; Curran & Cleary, 2003) provided converging evidence supporting the link between the early frontal effect and familiarity. Subjects in these studies discriminated between studied items, highly similar lures, and new items. It was assumed that studied items were identified on the bases of both recollection and familiarity, whereas similar lures would be endorsed as old only on the basis of familiarity in the absence in recollection. Therefore the ERP old/new effects associated with hits to studied items but not with false alarms to similar lures might reflect recollection. On the other hand, the ERP effects observed in both hits to old items and false alarms to similar lure items might reflect the familiarity component of recognition.

Curran (2000) had subjects study lists of singular and plural words (e.g., TABLE, CUPS) and engage in an old/new recognition test consisting of studied words in the same or reversed plurality together with unstudied singular and plural new words. Subjects were required to discriminate test items that were in the same plurality as at study (e.g., TABLE) from those in the opposite plurality (e.g., CUP) and unstudied new words. Curran (2000) reported a parietal old/new effect that was associated only with hits to studied items but not with false alarms to plurality-reversed lures, suggesting that recollection was involved in the former but not in the latter response category. Additionally, Curran (2000) found an early frontal effect elicited by both correctly identified studied items and incorrectly endorsed plurality-reversed items. Assuming that the familiarity of studied and plurality-reversed lures was comparable, Curran (2000) suggested that the early frontal effect is the correlate of familiarity-based recognition. Moreover, the early onset time of this effect in comparison to the parietal old/new effect was consistent with prior behavioural findings that subjects could perform old/new discrimination (at approximately 400 ms) before plurality discrimination (at approximately 550 ms) (Hintzman & Curran, 1994; 1997). These findings accord very well with the notion that familiarity is faster acting than recollection in recognition processes. The correspondence of the early frontal effect with familiarity was tested in another study that employed pictures as stimuli. Curran and Cleary (2003) had subjects study asymmetric pictures of common objects and engage in a recognition test consisting of studied pictures, new pictures, and similar pictures that were left/right mirror reversals of studied pictures. Only test pictures that were shown in the same orientation as at study should have been responded to as old. Following the same logic underlying the word-plurality study (Curran, 2000), the incorrect endorsement of orientation-reversed pictures was argued to depend on familiarity in the absence of recollecting the orientation of the picture. Curran and Cleary (2003) reported that the early frontal effect was associated with hits to studied pictures and false alarms to orientation-reversed lures. This finding again demonstrated the connection between the early frontal effect and familiarity-based recognition. Other supporting evidence comes from a study employing the directed-forgetting procedure mentioned in the previous section (Ullsperger et al., 2000). The finding that the parietal old/new effect was associated with TBR but not with TBF items suggested that recollection was involved in recognising items that had been instructed to be remembered at study, but not in recognising items that were instructed to be forgotten. By contrast, the early frontal effect was associated with both TBR and TBF items, consistent with the notion that familiarity was involved in the recognition of both classes of items (Ullsperger et al., 2000).

The neuropsychological studies of patients with impaired recollection (as reviewed in the previous section) also shed light on the functional significance of the early frontal effect. The Alzheimer patients in the study of Tendolkar et al. (1999), who showed relatively unimpaired recognition but failed to recollect contextual information, exhibited only the early frontal effect but not the parietal old/new effect. Similarly, the hippocampal-damaged amnesic patient reported in the study of Duzel et al. (2001), who recognition performance was impaired but above-chance, exhibited the early frontal effect. By contrast, the controls in both studies showed both the early frontal and the parietal old/new effects. It was argued that the preserved recognition memory performance for both the amnesic and Alzheimer patients was based on familiarity in the absence of recollection, and therefore the early frontal effect observed in both cases must reflect familiarity-based recognition.

However, it has been recently suggested that the early frontal effect may not be an obligatory correlate of familiarity-based recognition. In a study investigating context effects on the neural correlates of recognition memory, Tsivilis, Otten, & Rugg (2001) presented subjects with objects superimposed on landscape scenes that served as contexts. At test, subjects were required to identify studied objects without considering the contexts they were paired with. The early frontal effect was observed for objects paired with the same study context (SAME pairs) and those paired with different studied contexts (REARRANGED pairs), but not with objects paired with unstudied new contexts (OLD/NEW pairs). Crucially, the behavioral performance in a later Remember/Know experiment did not differ between REARRANGED and OLD/NEW pairs, suggesting that the contribution of recollection and familiarity to these two classes of items were almost identical. Based on these findings, Tsivilis et al. suggested that the early frontal effect might not be directly related to familiarity-based recognition, but might reflect processes 'downstream' from those responsible for computing familiarity, such as novelty detection.

4.3 ERP Studies of Encoding: Subsequent Memory Effect

Numerous studies have shown that the ERPs elicited by study items are different according to whether the eliciting items are remembered or forgotten in the subsequent memory test. The ERP subsequent memory effect typically takes the form of a positivity associated with items that are subsequently remembered as opposed to the items that are subsequently forgotten. However, the magnitude, time-course, and scalp distribution of the subsequent memory effect have been found to be affected by many factors, such as study material, encoding task, and test format (for detailed reviews, see Friedman & Johnson, 2000; Rugg, 1995; Wagner, Koutstaal, & Schacter, 1999). It has been suggested that the subsequent memory effect might reflect not a unitary but a set of task-dependent processes. One of the early studies showing a subsequent memory effect was conducted by Sanquist and colleagues (1980), who investigated the effects of depth of processing on recognition memory. Subjects were required to make same-different judgements to word pairs at study according to orthographic, phonological, or semantic criteria. In phonological and semantic tasks, where sufficient trials from a subset of subjects were available for analyses, Sanquist et al. (1980) found that the ERPs elicited by study items that were subsequently recognised were more positive-going over midline parietal scalp than those that were subsequently forgotten. However, as most remembered and forgotten items were given positive (same) and negative (different) responses respectively during encoding, it was possible that the subsequent memory effect observed in their study actually reflected the different response categories at study.

The relation between depth of processing at study and subsequent memory effect was further examined in a later study by Paller, Kutas, & Mayes (1987). Subjects in this study engaged in one of four encoding tasks. Two of the tasks were shallow processing tasks whereas the other two were deep processing tasks. Subjects had to make positive (yes) or negative (no) responses to study items according to their semantic and structural attributes in the deep and shallow tasks respectively. Across all four tasks, remembered items elicited more positive-going ERPs than forgotten items between 400-800 ms after stimulus onset, showing a reliable subsequent memory effect. The magnitude of this effect was larger for items in semantic tasks than in non-semantic tasks, indicating a role for semantic processing in successful and unsuccessful encoding. However, the finding that the magnitude of the subsequent memory effect was also different between the two semantic tasks suggested the involvement of some factors other than semantic processing in this effect. Paller et al. (1987) also reported that the subsequent memory effect was present only when items attracting positive responses at study were included in the analysis, indicating that the subsequent memory effect could not simply be attributed to different response categories during encoding.

Although the subsequent memory effect has frequently been found to be sensitive to depth of processing, it has been shown that engaging in semantic processing is not a necessary condition to elicit the effect. One study conducted by Friedman and colleagues (Friedman, Ritter, & Snodgrass, 1996) showed that the subsequent memory effect can also be observed for items encoded in a shallow, non-semantic way. The shallow task they employed was an alphabetic classification task, in which subjects judged whether the first and the last letters of a study item was in alphabetical order. Friedman et al. (1996) reported that the ERPs to these shallowly studied words were more positive-going for items that were recalled in the following cue-recall task than for those that were not successfully recalled. A recent study conducted by Otten and Rugg (2001) also demonstrated subsequent memory effects following both deep and shallow encoding tasks, although the pattern of the effects were different for shallowly and deeply encoded items. In the animacy judgement task, words subsequently recognised elicited more positive-going ERPs than words that were subsequently forgotten. By contrast, in the alphabetic judgement task, the ERPs elicited by words subsequently recognised were more negative-going than the ERPs elicited by words subsequently forgotten. This finding suggested that the processes involved in successful encoding might be at least partially different according to the encoding task.

In addition to single words, subsequent memory effects were also present when word pairs were used as stimuli. Weyerts, Tendolkar, Smid, and Heinze (1997) had subjects study unrelated word pairs in two types of deep encoding task. In one task, subjects made a semantic association between the two members of each word pair, whereas in the other task, subjects made semantic judgments separately to each of the two words. At test, subjects differentiated studied words pairs, which had been shown either in the associative or non-associative encoding tasks, from unstudied new pairs. Weyerts et al. (1997) found that ERPs recorded during the associative task for word pairs that were subsequently recognised elicited a more positive-going waveform compared with word pairs that were not subsequently recognised. This subsequent memory effect, which was maximal over right frontal sites, was however not present for word pairs shown in the non-associative task. The interesting point of this finding is that, although semantic processing might prompt successful encoding as indexed by the subsequent memory effect, it is critical that the semantic attributes to be processed during encoding correspond to the attributes to be recognised at subsequent test. It would be interesting to know whether a reversed pattern would be observed if single words rather than word pairs were recognised at test.

The subsequent memory effect has also been examined with the Remember/Know procedure at test in an effort to index the conscious experience associated with recognised items during retrieval. As 'R' and 'K' responses might map onto the recollection and familiarity components of recognition, a difference in subsequent memory effects for these two classes of responses implies the involvement of different encoding processes in subsequent recollection- and familiarity-based recognition. However, the results of two studies addressing this issue were mixed. Smith (1993) found that, in spite of a reliable subsequent memory effect between study items subsequently remembered and forgotten, this subsequent memory effect did not differ as a function of whether the study item was associated with a 'R' or a 'K' judgement during the recognition test. This non-significant finding led Smith to suggest that the conscious experience associated with recognised item was affected only by retrieval processes but unrelated to encoding processes.

A different finding was reported in a recent study conducted by Friedman and Trott (2000) that investigated age-related difference in encoding. Young and old subjects were asked to memorise two unassociated nouns embedded in sentences belonging to two temporally distinct lists. In the following recognition test, for words identified as old, subjects had to make a Remember/Know judgement. Friedman and Trott (2000) found that both young and old subjects showed a reliable subsequent memory effect for items that were subsequently associated with a 'R' response. However, the old but not the young subjects showed a reliable subsequent memory effect for items that were subsequently associated with a K response. Friedmand and Trott (2000) noted that there was a correspondence between the subsequent memory effect recorded during encoding and the parietal old/new effect recorded during retrieval for the two different age groups. In a supplementary study Trott et al. (1999) showed that young participants exhibited a larger parietal old/new effect for recognised items associated with R than those associated with K responses. By contrast, old participants exhibited a small parietal old/new effect to recognised items, which was not differentiated by R and K responses. Such correspondence seems to suggest that if recollection is heavily relied on at test, as for the young participants, the subsequent memory effect might reflect encoding processes correlated with subsequently recollection-based recognition. By contrast, if familiarity is the main process underlying recognition, as for the old participants, the subsequent memory effect might reflect encoding processes correlated with subsequent familiarity-based recognition. These results run counter to the conclusion of Smith (1993) that the conscious experience associated with recognised item was affected only by retrieval processes but unrelated to encoding processes.

Friedmand and Trott (2000) argued that old subjects did not show subsequent memory effects for Remember and Know responses perhaps due to a failure to use elaborative encoding strategies, more lenient retrieval criteria, or a deficit in attentional resources. Mangels, Picton, and Craik (2001) thus addressed the issue of whether R and K responses involve differentiable neural activity and whether ERP components associated with these responses are influenced by changes in attentional resources. Mangels et al. varied attention at encoding by having subjects focusing their attention on visually presented words (focused attention condition) or dividing their attention between the words and an auditory-motor task. They also varied attentional demands by using easy and difficult versions of the secondary task (easy and difficult divided attention conditions). At test, subjects first recalled studied words and then engaged in a recognition test with Remember/Know judgement. ERPs recorded at encoding were averaged as a function of subsequent memory performance and as a function of attention at encoding. Mangels et al. found that study words that subsequently attracted K judgements were distinguished from subsequently missed items by an enhanced left fronto-temporal negative wave (N340). For study words that subsequently attracted R judgements, in addition to N340, they were also distinguished from subsequently missed items by a negative posterior sustained potential and a positive frontal sustained potential. An interesting finding was that the differences between items subsequently attracted R and K responses at the frontal and inferior sustained potentials were larger under easy divided attention condition than under focused attention condition. Mangels et al. argued that the enhanced N340 reflects item-specific conceptual processing, which is sufficient to produce familiarity-based recognition, and the frontal/posterior sustained potentials reflect additional elaborative processing that is necessary for subsequent conscious recollection. When there was mild distraction during encoding, such as in the easy divided attention condition, the basic semantic processing of items reflected by N340 was not interfered. However, it was difficult to engage in elaborative processes, which resulted in the difference between the sustained potentials associated with items attracted subsequent R and K responses. The results of Mangels et al. therefore demonstrated that the revelation of subsequent memory effect for R and K responses might contingent on the attentional resources devoted to study items during encoding.

4.4 ERP Studies of Memory Errors

The ERP effects related to recognition memory, as reviewed in the previous sections, can provide information about the cognitive processes involved in memory errors. Based on the functional interpretations of these ERP effects, which are derived from studies focused on veridical memory, the mechanisms underlying various types of memory errors could be revealed. For instance, if a certain kind of memory error is found to be consistently associated with the early frontal effect but not with the parietal old/new effect, it might be inferred that this type of memory error is related to familiarity unopposed by recollection. Reciprocally, the ERPs associated with memory errors can advance our understanding of the ERP effects explored in studies of veridical memory. The knowledge of memory errors obtained from previous behavioural studies can be utilised to test and verify the functional significance of the ERP effects.

4.4.1 Source Memory Errors

Although many behavioural studies have shown that source memory is subject to errors due to various factors (reviewed in Chapter 2), only a handful of ERP studies have been conducted to investigate such errors. A general theme of these studies has been to examine whether the above mentioned left parietal and right frontal effects are sensitive to source accuracy, focusing on the implications of this question for the functional interpretation of the two effects. Different dimensions of source information were manipulated in these studies. The results and conclusions of these studies were not fully consistent.

In a study designed to compare the brain activity elicited in item and source memory tasks, Senkfor and Van Petten (1998) recorded ERPs during recognition tasks for spoken words (item memory task) or for both spoken words and the voice of the speaker (source memory task). Three ERP effects were reported in this study. First, in both item and source memory tasks, successfully recognised items elicited more positive-going ERPs than corrected rejected new words, starting at around 400 ms after stimulus onset. This old/new effect varied little in amplitude across the scalp sites in the item memory task, but was larger over the left than the right posterior region in the source memory task. Senkfor and Van Petten (1998) suggested that this effect might reflect the retrieval of item information. Second, a late bilateral (instead of right-lateralised) frontal effect was present in the source memory task but not in the item memory task. However, different from the right frontal effect reported by Wilding and Rugg (1996), the late frontal effect reported by Senkfor and Van Petten was of similar magnitude for items associated with correct and incorrect source judgements. This insensitivity to source accuracy led Senkfor and Van Petten (1998) to suggest that the late frontal effect reflects the search for contextual information. Third, in the source memory task, recognised old items associated with accurate source judgements elicited more positive-going ERPs over posterior recording sites than those associated with inaccurate source judgements, starting at around 700 ms after stimulus onset. Senkfor and Van Petten (1998) related this effect to source memory, but did not assign a clear functional role to this effect. Given its sensitivity to source accuracy and scalp distribution, the effect resembles the parietal old/new effect reviewed in the previous sections. However, the comparison between the ERPs elicited by items associated with incorrect source judgements and by new items was not reported by Senkfor and Van Petten (1998), hence it was not possible to know whether there was weak recollection involved in inaccurate source judgements. These ERP results were replicated in a subsequent study that manipulated the location of line drawings of objects as spatial source information (Van Petten, Senkfor, & Newberg, 2000).

The parietal old/new effect was also found to be sensitive to source accuracy when source discrimination concerned the temporal order of words. Trott et al. (1999, also Trott, Friedman, Ritter, & Fabiani, 1997) presented young and old subjects with two study lists of sentences. Subjects were instructed to memorise two unassociated nouns contained in each sentence and their list membership. In the subsequent recognition memory test, all possible pairings of old and new nouns were presented in sequence, and subjects had to make speeded old/new judgement to each noun. For each noun that had been judged old, subjects also had to make a Remember/Know judgement as well as a source judgement concerning in which list the noun had been presented. In comparison to young subjects, the old subjects showed a greater decrement in source memory than item memory performance. However, for both age groups, a parietal old/new effect was found to be larger for accurate than for inaccurate source judgements. It was also reported that the parietal old/new effect was significant in the comparison between correctly recognised items associated with inaccurate source judgements and new items. These results led Trott et al. (1999) to argue that the parietal old/new effect did not reflect recollection processes, as otherwise this effect should be correlated with the different source performance for young and old subjects. Instead, Trott et al. suggested that the parietal old/new effect reflected the retrieval of item information accompanied by a small amount of contextual information. It was also found that the right frontal effect was exhibited by the young but not by the old subjects. Interestingly, in contrast to the finding of Wilding and Rugg (1996), the right frontal effect was found to be of a greater magnitude for inaccurate than for accurate source judgements. It was argued by Trott et al. (1999) that the right frontal effect reflects a strategic search process for temporal source information. The old subjects had difficulties engaging in such search processes and hence exhibited reduced source performance in comparison to the young subjects.

In one particular study that manipulated the colours of object pictures as sources (Cycowicz, Friedman, & Snodgrass, 2001), the parietal old/new effect was found to be insensitive to source accuracy. Subjects in this study were presented with pictures of objects outlined in one of two colours, and then engaged in two types of tasks. In the inclusion/item memory task, subjects had to identify studied pictures without considering the colour an item had been presented in at study. In the exclusion/source memory task, only studied pictures presented in one specified colour (targets) at study should be responded as 'old'. Studied items presented in the other colour at study (nontargets), together with unstudied pictures, should be responded to as 'new'. Therefore recollection of the source information, i.e. the colour was required to correctly identify the targets and reject the nontargets in the exclusion task. Cycowicz et al. reported a parietal old/new effect both for correctly recognised items in the item recognition task, and for correctly classified targets and nontargets in the exclusion task. However, the parietal old/new effect was present for both incorrectly classified targets and nontargets in the exclusion task. Cycowicz et al. therefore argued that this effect might actually reflect familiarity rather than recollection.

In addition to examining the ERP effects during the retrieval phase, a few studies have also investigated the 'subsequent memory effect' for source memory errors. Senkfor and Van Petten (1998) compared the ERPs elicited by spoken words that were subsequently recognised along with accurate versus inaccurate voice source judgements. No significant ERP effects during encoding were found to be correlated with the accuracy of the subsequent source memory judgement, although they did found that study items elicited more positive-going ERPs in the source memory task than in the item memory task. Similarly, Friedman and Trott (2000) found that the subsequent memory effect was not predictive of whether a recognised word would be correctly assigned to temporally distinct study lists. A more exciting result was reported by Gonsalves and Paller (2000), who employed a reality monitoring task. Gonsalves and Paller showed subjects concrete nouns at study and asked them to visualise the referent of each word to make a size judgement. The critical manipulation was that in half of the study trials, the 'word-plus-picture trials', a picture of the object was presented after the word. In the other half trials, the word-only trials, the study word was followed by a blank rectangle. In the following test phase, subject listened to spoken test words and decided whether that word had been presented at study with a picture. Gonsalves and Paller found that study items in the word-only study trials elicited more positive-going ERPs at parietal and occipital sites between 600-900 ms after stimulus onset when, in the subsequent test, these words were incorrectly identified as being presented with pictures than when they were correctly rejected. This finding indicated that the accuracy of source judgement errors could be predicted by the brain activity recorded during the encoding phase. Based on a previous finding that the posterior ERPs might be modulated by the vividness of visual imagery (Farah, Peronnet, Weisberg & Monheit, 1990), Gonsalves and Paller suggested that the subsequent memory effect for source memory errors could be interpreted as more vivid visual imagery for those items. It is interesting to note that subsequent memory effects for veridical memories might not reflect a unitary pattern but rather a collection of task-dependent processes (Wagner et al, 1999). This might also be true for the subsequent memory effect for source memory errors. The protocol adopted by Gonsalves and Paller (2000) was reality monitoring and hence vivid perceptual experiences acquired in the encoding phase might be critical for both veridical memory and source judgement errors. A different pattern of ERP subsequent memory effect for source memory errors might be revealed if a different type of source information was manipulated.

4.4.2 Gist-Based False Recognition

There have been ERP studies conducted to investigate the brain activity involved in the gist-based false recognition elicited in the DRM procedure (reviewed in Chapter 2). One early such study was conducted by Johnson and colleagues (Johnson, Nolde, Mather, Kounios, Schacter, & Curran, 1997), who compared the brain activity associated with veridical and false recognition in different test formats. Subjects in their experiment listened to lists of associated words and engaged in recognition memory test in two different formats. For half of the subjects, studied old words, unstudied lure words, and unstudied new words were presented in different blocks, whereas for the other half of subjects, the three types of test items were presented intermixed. Johnson et al. (1997) found that in the blocked condition, the ERPs elicited by correctly identified old items were more positive-going than the ERPs elicited by incorrectly endorsed lure items, particularly at frontal and left parietal sites. However when the presentation of test items of different types was intermixed, the ERPs associated with correct and false recognition were indistinguishable.

Johnson et al. (1997) argued that when test stimuli were intermixed, old/new judgements were made on the basis of an 'overall feeling of semantic familiarity', which might not be qualitatively different for true targets and lures, and hence similar waveforms were recorded for these two types of stimuli. In contrast, when the test stimuli were blocked, it was difficult to distinguish successive items within a block on the basis of relative semantic familiarity. Subjects would therefore rely on assessing the perceptual and contextual attributes of memories, which were more available for veridical memories than for false memories. The more extensive evaluation of perceptual and contextual attributes in the blocked condition was reflected in the different waveforms elicited by the true old items and lure items. It is not clear, however, why perceptual and contextual information, presumed to be critical for differentiating old and lure items, was not utilised in the intermixed condition, when both types of stimuli were presented together. Nevertheless one interesting point implied in the proposal of Johnson et al. (1997) is that veridical recognition for true old items might rely on the recollection of contextual and perceptual information, whereas false recognition of the semantic associated lure items might rely on a feeling of semantic familiarity. This point was not explicitly verified, however, as Johnson et al. (1997) did not examine any known ERP memory effects in their studies, although visual inspection of the waveforms suggests that the parietal old/new effect was present for both true and false recognition.

The three ERP effects related to recognition memory reviewed in the previous section have been examined in some studies that employed the DRM procedure. Duzel et al. (1997) incorporated a two-stage Remember/Know procedure with the DRM procedure to identify the ERP correlates of states of consciousness awareness in memory. During the test phase, subject made an initial old/new judgement, and then made a second Remember/Know judgement for those words judged to be old. Duzel et al. (1997) reported that the parietal old/new effect was present for the ERPs associated with 'Remember' responses to both old items and semantically related lures, indicating the involvement of recollection in gist-based false recognition. Additionally, a right frontal effect was also present for the ERPs associated with both 'R' and 'K' responses to old and lure items. This finding suggests that post-retrieval processes, as indexed by the right frontal effect, were engaged to monitor/evaluate the outcome of the retrieval attempt to old items and lure items, and these post-retrieval processes were not restricted to recollective experience. The early frontal effect was not reported in this study. However, 'Know' responses to old and lure items were found to be associated with a positivity in comparison to new items over temporoparietal sites between 300-600 ms after stimulus onset, which might reflect the familiarity component of recognition memory.

The ERP effects associated with true and false recognition in the study of Duzel et al. (1997) were indistinguishable, suggesting that the involvement of recollection and familiarity were not differentiated by whether the eliciting item had really been presented at study or was a semantically related lure. The equivalence between the ERP effects for true and false recognition might result from the fact that the lure items consisted of a theme word and its highest associates in a semantic category, such that the association between the lure items and the studied words might be even higher than the association between the studied words themselves. This point was examined in a study conducted by Nessler, Mecklinger, & Penny (2001), in which the lure items were as strongly related to the unpresented theme word as were the studied words. Nessler et al. (2001) reported that the early frontal, the left parietal, and the right frontal effects were all present for true and false recognition. However, although the early frontal and the right frontal effects were of similar magnitudes for true and false recognition, recognised old items elicited a larger parietal old/new effect than incorrectly endorsed lure items. Nessler et al. (2001) therefore argued that less conscious recollection occurred for false recognition than for true recognition. In an additional analysis, Nessler et al. divided the subjects into two groups according to the rate of false recognition. Interestingly, they found that poor performers (i.e., high false alarm rate to lures) exhibited similar early frontal and parietal old/new effects for true and false recognition, whereas good performers (i.e., low false alarm rate to lures) showed such effects only for true recognition. These results led Nessler et al. to suggest that individual differences in encoding strategy might affect the processes underlying the later false recognition.

The notion that encoding strategy might affect the processes underlying false recognition was tested in the second experiment of Nessler et al. (2001). Subjects were presented at study with words belonging to different categories, and were required either to focus on the conceptual similarity between these words by categorizing them ('Category' group), or to focus on item-specific information by making animacy judgments ('Item' group). In the later recognition test, Nessler et al. found that the parietal old/new effects associated with the true and false recognition in the Category group were indistinguishable, while the parietal effect in the Item group was smaller for false recognition than for true recognition. Moreover, the early frontal effect was observed for both true and false recognition in the Category group, but only for true recognition in the Item group. Nessler et al's interpretation of their data focused on the early frontal effect associated with false recognition in the Category group. They suggested that it was the conceptual similarity between items encoded at study that led to familiarity-based false recognition. However, the different parietal effects for false recognition in the Category and Item groups suggests that conceptual similarity between study items also contributed to the involvement of recollection in false recognition.

The findings of Nessler et al. (2001) that the ERP effects associated with true and false recognition varied for good and poor performers were recapitulated in a study conducted by Curran and colleagues (Curran, Schacter, Johnson, & Spinks, 2001), but in a different way. Curran et al. (2001) reported that for both high and poor performers, the early frontal effect was not evident in either true or false recognition. However, there was a parietal old/new effect for studied items as opposed to lures for poor performers, which was not observed for good performers. The comparison between the ERPs to lures and new words during the period of the parietal old/new effect was not reported by Curran et al. (2001), but visual inspection of the waveforms suggested that a parietal old/new effect was elicited by lures for good but not for poor performers. By contrast, for good performers only, a right frontal effect was elicited by both studied words and semantically related lures in comparison to new words, and was of similar magnitude for these two classes of items. These results led Curran et al. (2001) to argue that post-retrieval monitoring processes, as indexed by the right frontal effect, was more readily engaged by good performers than poor performers. Moreover, because of effective post-retrieval monitoring processes, old items with low retrieval quality would be more often recognised by good than by poor performers, such that on average the amplitude of the parietal old/new effect was higher for poor than for good performers. However, if the magnitude of the parietal old/new effect is viewed as an index of the quality of recollection, it is not easy for the proposal of Curran et al. (2001) to explain why recollection was elicited to a greater degree by recognised lure items in good than in poor performers.

Gist-based false recognition induced in the DRM procedure has also been examined with haemodynamic neuroimaging techniques. In a PET study, Schacter, Reiman et al. (1996) reported that both veridical recognition and false recognition were characterized by significantly increased blood flow in the left-medial temporal lobe in comparison to the baseline condition. However, there was no significantly different blood flow between veridical recognition of true targets and false recognition of false targets in the same area. The difference between veridical and false recognition was observed in the left temporoparietal cortex, where there was greater blood flow for veridical than for false recognition. Additionally there was a trend for a blood flow increase in prefrontal cortex, orbitofrontal cortex, and cerebellum in false recognition compared with veridical recognition. Schacter, Reiman, et al.(1996) suggested that the greater blood flow in the left temporoparietal cortex for veridical than for false recognition reflects the memory for the auditory or phonological information at study, which occurred for true targets but not for false targets. The trend for greater activation in prefrontal cortex and cerebellum for false recognition than for veridical recognition was interpreted as reflecting more effort paid to examine the sense of familiarity or recollection associated with false recognition. The similar blood flow increase in left medial temporal cortex for veridical and false recognition may reflect conscious recollection of semantic attributes shared by both veridical and false recognition.

In an event-related fMRI study, Schacter, Buckner et al. (1997) demonstrated that brain activity associated with veridical and false recognition is affected by whether test stimuli was blocked or intermixed. Schacter, Buckner, et al. (1997) found that areas including medial and lateral parietal cortex, bilateral anterior prefrontal cortex were significantly activated for both true and false recognition in the blocked and the intermixed condition. For the blocked trials, the right anterior prefrontal area appeared more activated during the false alarms (false recognition) than during the hits (true recognition). However this difference was not observed when stimuli of different types were intermixed. From time-course analyses of intermixed trials, it was also observed that in comparison to other activated regions, the anterior prefrontal regions showed a relatively late onset and sustained duration. This delayed onset was consistent with the hypothesis that anterior prefrontal regions are involved in post-retrieval monitoring processes.

In a further event-related fMRI study of DRM errors, Cabeza, Rao, Wagner, Mayer, and Schacter (2001) created conditions that would increase the likelihood of finding differences in brain activity associated with veridical and false recognition. At study, subjects watched a videotape segment in which two speakers taking turns to read a list of semantically related words, and were instructed to try to remember each word was said by which speaker. With this design, study words were associated with some perceptual input that was not shared with nonpresented semantically related lures. At test, subjects made old/new judgements to studied words, semantically related lure words, and unstudied new words. Similar to the finding of Schacter, Reiman et al. (1996), the anterior medial temporal lobe region was similarly activated for recognised studied words and critical lures as opposed to rejected new words, which may reflect the recollection of the semantic information common to the studied words and the critical lures. By contrast, a left posterior parahippocampal region showed enhanced activity for old words relative to critical lures and new words, which Cabeza et al. interpreted as reflecting the recovery of sensory information. This finding suggested that some sensory information of studied items can leave a trace or signature in the brain, although such information was not sufficient to reject nonpresented lure items.

Because the lure items in the DRM procedure are not shown at study, it is not possible fort the subsequent memory effect for false recognition to be examined. However, there has been one study conducted by Fabiani and colleagues (Fabiani, Stadler, & Wessels,

2000) addressing whether perceptual details encoded at study might leave 'sensory signatures' in the brain activity that differentiates true from false recognition. In the study phases of their experiment, subjects studied words from associated lists presented randomly to the left or right of fixation, with the constraint that words from the same list were all displayed on the same side. In the test phase, studied words, together with lures and new words were presented in the centre of the monitor. Consistent with a previous finding that there is a lateralised ERP effect associated with recognised items contingent on the side the items presented at study (Gratton, Corballis, & Jain, 1997), Fabiani et al. reported that the ERPs to studied words were more positive-going over the hemisphere contralateral rather than ipislateral to the visual field the items were presented in at study. However, this lateralised ERP effect was not present for semantically lure items, indicating that this effect is a sensory signature specific to true recognition. Nevertheless, this perceptual information retained at retrieval apparently was not utilised to reject lure items. It is possible that the information indexed by the lateralised effect was not consciously accessible.

4.5 Discussion and Studies in this Thesis

As shown in the studies reviewed in this chapter, several ERP effects related to recognition memory, including the old/new effects and subsequent memory effects observed during retrieval and encoding respectively, have been identified. Some of the ERP effects have been well studied and their functional significance is generally agreed. These ERP effects can be utilised as tools to monitor the involvement of specific cognitive processes in memory tasks. However, some aspects of the nature of these ERP effects are uncertain and remain in debate. Among the three ERP effects identified during retrieval, the parietal old/new effect has been viewed as the electrophysiological correlate of recollection based on converging evidence from studies employing various procedures. One interesting point is that the parietal old/new effect could be graded, indexing the quality or quantity of recollected information. For instance, Wilding (2000) demonstrated that the magnitude of the parietal effect varied with the number correct source judgements that were made. However, it is not clear whether the parietal effect would also index 'full-blown' and partial/imprecise recollection in a graded fashion. The right frontal effect has been thought to reflect post-retrieval monitoring or evaluation processes that operate on the products of a retrieval attempt in a strategic or goal-directed manner. However, it is not clear what are the conditions for this effect to be engaged, and what are the cognitive variables that modulate this effect.

The parietal old/new effect and the right frontal effect have both been investigated in studies of memory errors, including source memory errors and gist-based false recognition. For studies of source memory errors, the results and conclusions are not consistent. The parietal old/new effect was found to be sensitive to source accuracy when the source discrimination concerned the gender of voices (Senkfor & Van Petten, 1998; Wilding & Rugg, 1996), temporal order of words (Trott et al, 1997, 1999), and location of line drawings (Van Petten et al., 2000). However, it was not sensitive to source accuracy when the source discrimination concerned the colour of pictures of objects (Cycowicz, 2001). There are also inconsistent findings regarding whether the right frontal effect is sensitive to source accuracy. In contrast to the findings of Wilding and Rugg (1996), Trott et al. (1999) found that the right frontal effect was larger for items assigned to the incorrect source than those assigned to the correct source. Senkfor and Van Petten (1998, also Van Petten et al., 2000) reported a late bilateral frontal effect that was insensitive to accuracy of source judgement.

These different results could have resulted from the different materials and designs employed in the various studies. They reveal the need to systematically examine the relation between the processes reflected by these ERP effects and source memory errors. The experiments reported in this thesis attempted to deal with this issue by investigating whether the characteristics and underlying mechanisms of source errors, as reflected by the left parietal and right frontal effects, are modulated by the similarity or the relationship between the different source-item pairings from which the attribution errors are generated. This question is interesting because both SMF and dual-process theories propose that old/new recognition can be based on familiarity, while source judgments rely on the recollection of attributes specific to different events. It has also been proposed that the specificity of source information varies along a continuum from vaguely to vividly remembered, and even partial or vague information about the source of an item can be utilised in memory judgments.

The utilisation of partial information closely resembles the exploitation of the 'gist', or the general similarity, of experienced episodes in recognition memory. In both cases, specific, distinctive information about individual items is not used when making memory judgments. Instead, more general information common to a group of items is employed. As reviewed above, the parietal old/new effect has been found to be associated with gist-base false recognition elicited in the DRM procedure (Curran et al., 2001; Johnson et al., 1997; Duzel, et al., 1997; Nessler et al, 2001), providing the grounds for the prediction that different processes are involved in source judgement errors for confusable and non-confusable source-item pairings. Recollection processes might be involved in such errors when the sources to be discriminated are confusable and form a gist memory with the items paired with them. Partial information about the confusable source-item pairings derived from gist memory might be recollected at test and prompt subjects to make inaccurate source judgments. In contrast, non-confusable source-item pairings do not share attributes likely to be coalesced into a gist memory, and thus there would be no recollection of partial source information in association with source judgement errors for non-confusable source-item pairings. On the other hand the finding that the early frontal effect was elicited in the DRM procedure (Nessler et al, 2001) also raise the possibility that gist-based recognition may receive a contribution from familiarity as well as recollection.

In addition to the ERP old/new effects identified during retrieval, the subsequent memory effects recorded during encoding have also been investigated in a few studies of source memory errors. This effect was found to be sensitive to source accuracy in a reality monitoring study (Gonsalves and Paller (2000), in which perceptual details encoded during study are critical for later source judgements. However, when the sources to be discriminated are in same modality, no such effect was observed (Senkfor & Van Petten, 1998; Friedman & Trott, 2000). It is not clear whether the subsequent memory effect could be observed only when the sources to be discriminated are perceptually distinct. This issue was investigate by examining the neural correlates of successful and unsuccessful 'feature binding' when episodes sharing semantically related components are encoded.

Chapter 5. General Methods

5.1 Introduction

This chapter describes the methodology common to the five experiments contained within this thesis. Experimental procedures specific to each experiment are detailed in the method sections of the chapters reporting these experiments. The Remember/Know procedure was employed in Experiments 1 and 3. The instruction for subjects to make 'Remember' and 'Know' judgements were identical for these two behavioural experiments. ERPs were recorded in the test phase of Experiments 2, 4, and 5, and the in the study phase of Experiment 5. The ERP recording parameters were identical for the three experiments. All experiments were approved by the joint ethics committees of the University College London and the University College London Hospitals.

5.2 Subjects

All five experiments employed the same selection criteria for subjects. Experimental subjects were recruited from the undergraduate and postgraduate student populations of UCL, or solicited through advertisement. All subjects were healthy, right-handed, native English speakers. They were aged between 18 and 35, and had normal or corrected-to-normal vision. Each Subject was paid at the rate of £5.00 per hour (Experiments 1, & 2) or £7.50 per hour (Experiments 3, 4 & 5).

5.3 Materials

The stimuli used in each experiment were lists of word pairs. The initial members of the word pairs were associated words selected from the Birkbeck Word Association Norms (Moss & Older, 1996) to have an association strength greater than 65%. The second members of the word pairs were the semantic associates of the theme words listed by Stadler and colleagues (Stadler, Roediger, & McDermott, 1999), or groups of unrelated words selected from the Francis and Kucera corpus (1982), whose mean frequency was matched with that of the semantic associates.

The stimuli used in the experiments are given in Appendix One to Four. The procedures used to create study and test lists are detailed in the method section for each experiment. In each experiment stimuli were presented visually in lower case on a computer monitor (in white on a black background). All stimuli were presented in central vision (individual method sections provide further details).

5.4 Experimental Procedures

The study-test procedure was employed in all five experiments, although the number of study-test cycles and the number of lists in each study block varied between experiments (see individual method sections for further details). The study lists in each study-test cycle were presented consecutively. In Experiments 1 to 4, the study pairs of each list were shown on the screen concurrently, with each pair occupying a separate row. Subjects were instructed to read the word pairs aloud from top to bottom and memorise them under the supervision of the experimenter. In Experiment 5, the study pairs were presented one at a time. Subjects were instructed to memorise and read the word pairs silently. They were requested to avoid any muscle activities associated with the silent reading. The study pair was presented on the monitor with one word above and the other below a fixation character. Across the five experiments, it was emphasised that the relationship between the two words of each pair was important for the following test.

The test phase followed the study phase after an interval of approximately 5 minutes, during which subjects engaged in a short backward counting task and then rested. Subjects made old/new judgements in response to the presentation of each test pair. They were instructed that only test pairs presented in exactly the same pairing as at study should be responded to as old. Test pairs that contained words from different study pairs or contained new words should be responded to as new. In Experiments 1 and 3, subjects made Remember/Know judgements if a test pair had been identified as old. Subjects were instructed that a 'Remember' response should be made when the recognition of the word pair is accompanied by a clear recollection of its prior occurrence in the study phase, such as a particular association, image, or the appearance or position of the word pair. By contrast, a 'Know' judgement should be made when they recognise the word pair but cannot consciously recollect anything about its actual occurrence or what was experienced at the time of its occurrence. Similar to the old/new judgement, subjects were instructed that the Remember/Know responses should be made on the basis of their memory for the word pairs rather than individual word members. ERPs were recorded in the test phase of Experiments 2, 4, and 5, as well as the study phase of Experiment 5. Subjects in these experiments did not make Remember/Know judgements.

5.5 ERP Recording

Subjects in Experiments 2, 4, and 5 were fitted with an ERP recording cap (described below) prior to the experiment, and were then seated in a sound-attenuated recording booth situated approximately one metre in front of a computer monitor. Subjects were instructed to relax, to keep still, and to maintain fixation at the centre of the screen.

EEG was recorded from 31 silver/silver chloride electrodes, 29 of which were embedded in an elastic cap (these 29 sites were a subset of the 'montage 10' provided by the supplier of the electrode cap *http://www.easycap.de/easycap/english/schemae.htm*; see figure 5-1 for montage). The remaining two electrodes were placed on right and left mastoid processes. All channels were referenced to Fz (electrode number 8), and re-referenced off-line to represent recordings with respect to linked mastoids. Vertical and horizontal EOG were recorded bipolarly from electrodes placed above and below the right eye, and on the outer canthi of each eye respectively. Data were sampled at a rate of 8 ms per point and digitised with 12-bit resolution. The duration of the recording epoch was 2048 ms with a 104 ms pre-stimulus baseline period. All channels were amplified with a bandpass of 0.032-35 Hz (3dB points). Linear regression was used to estimate and correct the contribution of blink artefact to the EEG. Trials containing horizontal eye movement, non-blink vertical eye movement, A/D saturation, or with a baseline drift exceeding 55 microvolts in any channel, were rejected.

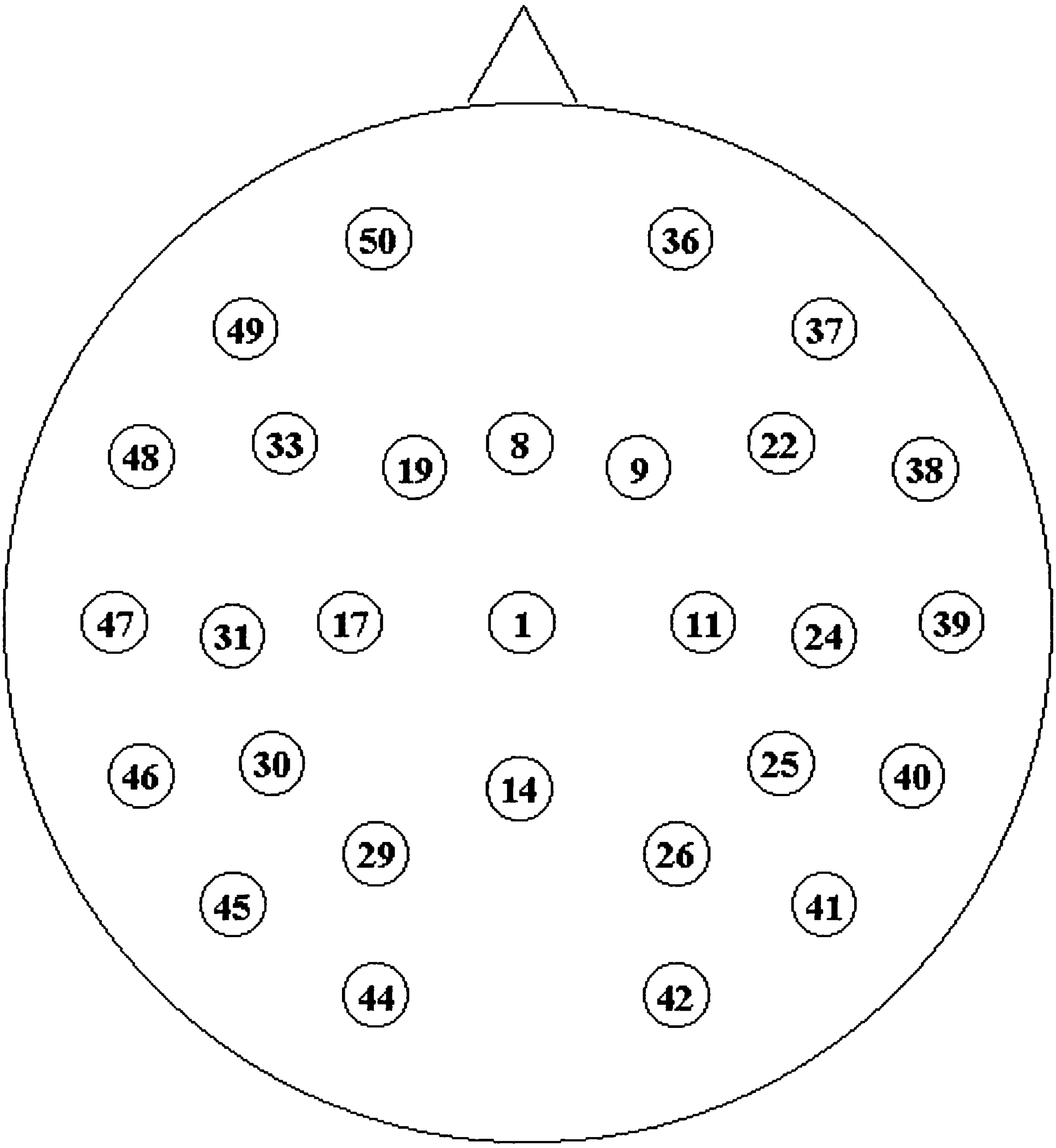

Figure 5.1. Selected sites from the 'montage 10' 61 channel equidistant montage employed in Experiments 2, 4, and 5.

5.6 Data Analyses

Repeated measures ANOVAs were used to analyse the behavioural and ERP data. The Greenhouse-Geisser correction for non-sphericity (Greenhouse & Geisser, 1959) was applied when necessary. F ratios are reported with corrected degrees of freedom.

5.6.1 Remember/Know Judgements

Two sets of analyses were conducted on the data of Remember/Know. In the first set, the raw proportion of 'R' responses and corrected proportion of 'K' responses were employed as dependent variables. The 'K' responses were corrected according to the formula, 'CK=K/(1-R)', suggested by Yonelinas and Jacoby (1995), where CK, K, and R stands for corrected proportion of 'K' responses, raw proportion of 'K' responses, and raw proportion of 'R' responses respectively. Results from the analyses on the raw and corrected proportions of 'R' and 'K' responses provide separate information about how the pure amounts of recollection and familiarity, assumed to be independent from each other in the dual-process theories, are modulated by the characteristics of different types of test pairs. In the second set of analyses, the ratio between the proportion of 'R' response and the proportion of 'Old' response ('Remember/Old' ratio') were employed as the dependent variable, as suggested by Rajaram (1993). Results from the analysis on the 'Remember/Old' ratio provide information about the differential influences on overall recognition and recollective experience from the characteristics of the different test items.

5.6.2 ERP Amplitude Analyses

Averaged ERPs were formed for each of the response categories of experimental interest, and were contrasted to determine the whether the ERPs associated with these response categories differed in amplitude.

ERPs recorded in the test phase of Experiments 2, 4, and 5 were quantified by measuring the mean amplitudes of 300-600, 600-900, 900-1400, and 1400-1900 ms time regions relative to the mean of the pre-stimulus baseline. These time regions were chosen on basis of preliminary analyses of consecutive 100 ms latency intervals and to accord roughly with those used in previous studies of associative recognition (Rugg & Donaldson, 1998). Averaged ERP waveforms were formed for each of the response categories of experimental interest (defined within each experimental chapter) for each subject. Only subjects contributing a minimum of 16 artefact-free ERP trials to each of the critical response categories were included in subsequent statistical analyses both of ERP and of behavioural data. This criterion was imposed in order to achieve an adequate signal-to noise ratio in the ERP data. Two sets of analyses were conducted to separately investigate the left parietal/ right frontal effects, as well as the early frontal effect respectively. In the first set, an overall ANOVA was first conducted for each time region on the data from 18 electrode sites. These sites were located over 6 scalp regions: left frontal (electrodes 48,33,19), right frontal (electrodes 38,22,9), left central (electrodes 47,31,17), right central (electrodes 39,24,11), left parietal (electrodes 46,30,29), and right parietal (electrodes 40,25,26). Factors entered into the global ANOVA were Response Category, Hemisphere (left, right), Location (frontal, central, parietal), and Site (superior, medial, and inferior). Subsidiary ANOVAs for pairwise comparison between response categories were conducted when there were significant effects involving response categories in the overall ANOVA. The second set of analyses were conducted on data of the 300-600 ms, focusing on the midfrontal sites (19, 8,9) at which the early frontal effect was maximal in previous studies (Rugg et al., 1998; Maratos, Allan, & Rugg, 2000; Tsivilis, Otten, & Rugg, 2001).

ERPs recorded in the study phase of Experiments 5 were quantified by measuring the mean amplitudes of 1000-1400 ms time region relative to the mean of the pre-stimulus baseline. This region, which was chosen by visual inspection, shows maximal differences between the waveforms. Repeated measures ANOVAs were conducted in this latency region on the data from 18 lateral electrode sites and the midline electrode sites. Additional ANOVAs were also conducted on data from different latency regions and electrode sites when potential differences between ERPs of different subsequent response categories were observed.

5.6.3 ERP Topographic Analyses

Topographic analyses were conducted to compare the scalp distributions of ERP effects associated with different response categories and different time regions. Prior to the topographic analyses, ERP data were 'rescaled' in order to avoid the confounding between any differences in the magnitude the ERP effects and the differences in scalp distribution. The ERP data were rescaled with the method suggested by McCarthy & Wood (1985), which computed the size of the ERP effect of interest at each electrode sites relative to the size of the effect at all other sites. Specifically, the maximum and the minimum amplitudes in the two response categories, which were contrasted with each other to generate the ERP effect of interest, were obtained in the first step. Then the difference between the value of each electrode site and the minimum value was divided by the difference between the maximum and the minimum value. This method maintains the pattern of relative differences in effect size across the scalp but removes amplitude differences.

Chapter 6. The Modulation of Gist Memories on the Involvement of Recollection in Source Memory Errors: Experiments One and Two

6.1 Introduction

Experiments One and Two investigated whether partial source information derived from gist memories formed during encoding might modulate the involvement of recollection in source judgement errors. It has been proposed that the specificity of source information varies along a continuum from vaguely to vividly remembered (Johnson et al., 1993), and even partial or vague information about the source of an item can be utilised in memory judgments (e.g., Dodson et al, 1998; see Chapter 2). The utilisation of partial source information closely resembles the exploitation of the 'gist', or the general similarity (Reyna & Brainerd, 1995, 1998), of experienced episodes in recognition memory. In both cases, specific, distinctive information about individual items is not used when making memory judgments. Instead, more general information common to a group of items is employed.

Some ERP studies have demonstrated a left parietal old/new effect in association with the gist-based false recognition elicited in the DRM procedure. For instance, Duzel et al. (1997) employed the Remember/Know procedure and observed a left parietal old/new effect for 'Remember' responses to both old items and lure items. Likewise, Nessler et al. (2001) reported that the left parietal effect was observed in ERPs associated with false recognition of lure items. This effect also appears to be evident in a study by Johnson and colleagues (1997), although the relevant statistical analyses were not reported. The finding that DRM errors are associated with the left parietal ERP effect provides the grounds for the prediction that different processes are involved in source judgement errors for confusable and non-confusable source-item pairings. Recollection processes might be involved in such errors when the sources to be discriminated are confusable and form a gist memory with the items paired with them. Partial information about the confusable source-item pairings derived from gist memory might be recollected at test and prompt subjects to make inaccurate source judgments. In contrast, non-confusable source-item pairings do not share attributes likely to be coalesced into a gist memory, and thus there would be no recollection of partial source information in association with source judgement errors for non-confusable source-item pairings.

6.2 Experiment One

To investigate source judgement errors associated with confusable and non-confusable source-item pairings, subjects in the present study were presented with lists of word pairs at study, the initial words of which served as the different sources. Two characteristics of the word pairs rendered the source-item pairings from the same list difficult to discriminate: First, all the initial words of study pairs belonging to the same list were one of two associated words (e.g. wife and husband). Second, the two words were paired with a cohort of semantically related words (e.g. glass, curtain, pane, sill, breeze, door, etc).

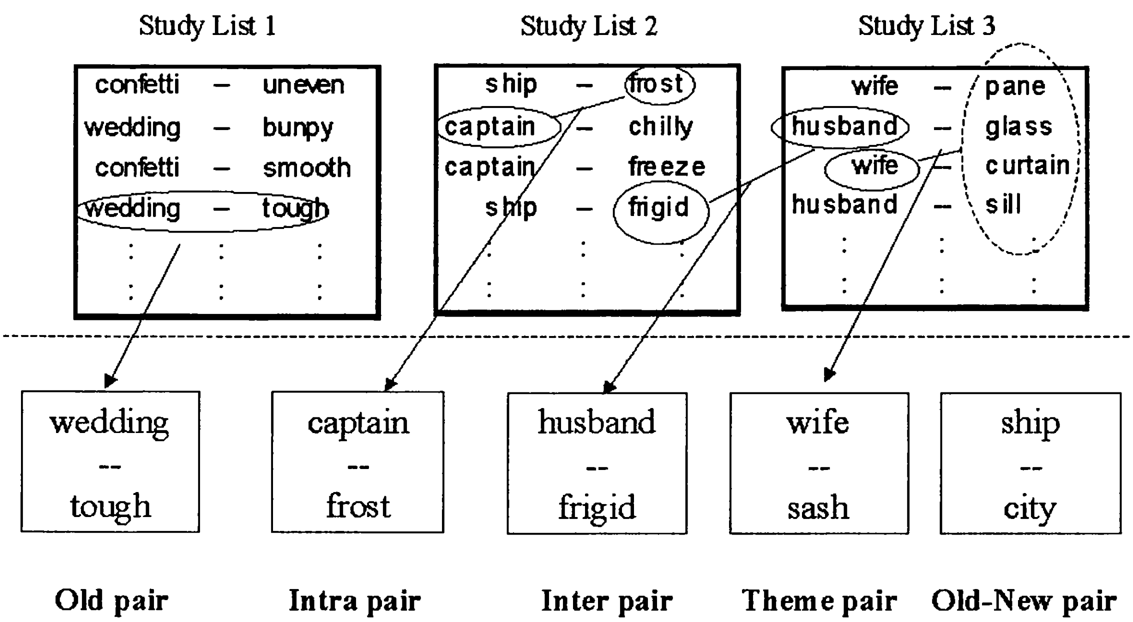

Figure 6.1. Illustration of the formation of one study list and the five types of test pairs generated from this list in Experiment 1.

By incorporating this DRM-like feature into the design, the formation of a gist memory for all word pairs belonging to the same study list was encouraged. At test, subjects discriminated 'Old' pairs, whose pairings between the initial and second words remained unchanged, from 'Intra', 'Inter', 'Theme', and 'Old-New' pairs (see figure 6.1 for illustration). Intra pairs and Inter pairs were both rearranged items, which were generated by re-pairing word pairs originally studied on the same list or on two different lists respectively. Theme pairs and Old-New pairs were generated by pairing an old initial word with a new second word that was semantically related and unrelated respectively to the second words the initial word had been presented with during the study phase.

It was expected that Intra pairs would attract a substantial number of false alarms because of their correspondence to the gist formed at study. By contrast, there was no such correspondence for Inter pairs, so that the false alarm rate for Inter pairs would be lower than that for Intra pairs. The difference between the false alarm rates for these two classes of rearranged pairs could be utilised to evaluate whether gist memories were formed for the source-item pairings presented at study, and whether partial source information was utilised at memory test. It should be noted, however, that although a substantial number of false alarms to Intra pairs was expected, the incorrect endorsement for Intra items might result from poor encoding of the source-item pairing at study. The semantic associations between study pairs might have encouraged subjects to encode each study list as a unit that lacks any pair-specific information. In this case, the false alarms to Intra pairs might not be viewed as memory errors, as what subjects encoded in the first place was a vague memory about the association between two concepts. This possibility was examined by comparing the false alarm rates for Intra pairs and Theme pairs. If the incorrect endorsement of Intra pairs was solely due to vague memory resulted from poor encoding of pair-specific information, the Theme pairs, which contain unstudied but semantically related second words, would attract similar number of false alarms with Intra pairs. By contrast, if poor encoding is not the sole mechanism for making incorrect source-item pairing judgements to Intra pairs, the false alarm rate would be higher for Intra pairs than for Theme pairs.

The Remember/Know procedure was employed to examine whether recollection was involved in source-item pairing judgement errors. If partial information derived from the gist memories was utilised in making memory judgements, recollection would be involved in hits to Old pairs and false alarms to Intra pairs, since both types of items should serve as effective cues for the recollection of gist memories of their respective study lists. By contrast, false alarms to Inter pairs were unlikely to be based on partial information derived from gist memories. The different involvement of recollection for partial source information in false alarms to Intra and Inter pairs should be reflected in the performance of Remember/Know judgements to these two classes of rearranged items.

6.2.1 Method

6.2.1.1 Subjects

A total of 16 right-handed healthy subjects participated in this experiment. Each subject was paid at the rate of £5 per hour. Eight of the 16 subjects were female.

6.2.1.2 Stimuli and Design

Study lists. Twenty-four sets of words were used to generate twenty study lists. Each set comprised a pair of strongly associated words and a group of sixteen words, all of which were related to a common unpresented theme word. The two associated words were selected from the Birkbeck Word Association Norms (Moss & Older, 1996) to have an association strength greater than 65%. The related word group consisted of fifteen associates of one of the theme words listed by Stadler and colleagues (Stadler, Roediger, & McDermott, 1999), plus an additional associate selected from association norms. The theme word was not included as a stimulus item because of its strong relation with all other list members, a property not shared by any of its associates. Thus, word pairs containing the theme words might be distinct and encoded differently from those containing the associates. Each of the two associated words was paired with six of the related words to construct a study list of sixteen word pair, and hence four related words were not shown at study. In each word pair, the associated word was assigned as the initial word and the related word was assigned as the second word. The twenty-four study lists were assigned to eight study-test cycles, with three lists in each cycle. Each subject engaged in four of the eight study-test cycles. The allocation of the lists to the cycles was counterbalanced across subjects, while the presentation order of the three lists in each cycle was randomly assigned for each subject.

Test list. There was one test list in each study-test cycle, containing sixty-two word pairs. Two pairs were fillers while the remaining pairs belonged to one of five categories (see figure 6.1 for illustration). (1) Four pairs from each of the three study lists were assigned as 'Old' pairs and maintained their studying pairings. (2) Another four pairs from each study list were re-paired with items from the same list to form 'Intra' pairs. (3) Four other pairs from each study list were re-paired with other words from one of the other two study lists to form 'Inter' pairs. (4) The two initial words employed on each study list were each paired with two related words that were not shown at study to form a total of twelve 'Theme' pairs. (5) The six initial words employed on the three study lists were each paired with two new words each to generate twelve 'Old-New' pairs. The new words were selected from the Francis and Kucera corpus (1982), and their mean frequency was matched with that of the old words.

6.2.1.3 Procedure

Study phase. The three study lists in each study-test cycle were presented consecutively. The twelve pairs of each list were shown on the screen concurrently, with each pair occupying a separate row. The concurrent presentation of the study pairs was intended to enhance the formation of gist memories for each study list. Subjects were instructed to read the word pairs aloud from top to bottom and memorise them under the supervision of the experimenter. It was emphasised that the relationship between the two words of each pair was important for the following test. The study list remained on the screen until the subject read all the word pairs and then the experimenter moved on to the next list.

Test phase. The test phase followed the study phase after an interval of approximately 5 minutes, during which subjects engaged in a short backward counting task and then rested. Each trial started with the presentation of a fixation character '+' for 1000 ms on the centre of the screen, followed by the presentation of the test word pair. The test pair was shown on the screen horizontally for 1000 ms and was then replaced by a blank screen in the following 3000 ms duration. Subjects made old/new judgements in response to the presentation of each test pair during the one-second exposure time plus the three-second time window. They were instructed that only test pairs presented in exactly the same pairing as at study should be responded to as old. Rearranged pairs, which contained words from different study pairs, as well as Theme and Old-New pairs, which contained new words, should be responded to as new. An 'R/K?' prompt was shown on the screen after the three-second blank screen, signaling subjects to make the Remember/Know response if the test pair had been identified as old. Prior to the test phase, subjects were explained that 'Remember' refers to be conscious awareness of some aspect or aspects of what happened or what was experienced at the time the word pair was presented. Subjects were instructed that a 'Remember' response should be made when the recognition of the word pair is accompanied by a clear recollection of its prior occurrence in the study phase, such as a particular association, image, or the appearance or position of the word pair. By contrast, a 'Know' judgement should be made when they recognise the word pair but cannot consciously recollect anything about its actual occurrence or what was experienced at the time of its occurrence. Similar to the old/new judgement, subjects were instructed that the Remember/Know responses should be made on the basis of their memory for the word pairs rather than individual word members. Responses to the old/new judgements were made by pressing one of two response keys with the index finger of each hand. The mapping of the hand to response category (old vs. new) was counterbalanced across subjects. Responses to the Remember/Know judgements were made by pressing one of two response keys with the middle or ring finger of the hand whose index finger was assigned to make 'old' response in the old/new judgement. The mapping of the middle and ring fingers to 'R' and 'K' responses was also counterbalanced across subjects.

6.2.2 Results

Table 6.1 displays the proportion of 'Old' and 'New' responses to the five classes of test item, together with their associated response times. The performance of Remember/Know judgements and their associated response times are listed in table 6.2.

Table 6.1. Mean proportion of responses (SD) and mean reaction times (SD) for each response category in Experiment 1.

Stimuli Type	Response Category	Proportion (SD)	RT(SD)
Old Pair	Hits	.64 (.10)	1885 (311)
	Miss		1883 (371)
Intra Pair	False alarm	.55 (.09)	1903 (287)
	Correct rejection		1866 (342)
Inter Pair	False alarm	.22 (.14)	2083 (384)
	Correct rejection		1799 (349)
Theme Pair	False alarm	.28 (.16)	2050 (369)
	Correct rejection		1741 (431)
Old-New Pair	False alarm	.07 (.06)	2184 (497)
	Correct rejection		1588 (371)

6.2.2.1 Old/New Recognition

A priori tests revealed that the hit rate to old pairs was significantly higher than the false alarm rate for Intra pairs (t_{15}=2.97, p=.01). In addition, Intra pairs were more likely to be identified as 'old' than Inter pairs (t_{15}=14.27, p<.001), and Theme pairs (t_{15}=7.45, p<.01). There were also more old responses to Inter pairs and Theme pairs than to Old-New pairs

(t_{15}=5.6, p<.01 and t_{15}=5.53, p<.01, respectively. The false alarm rates for Inter pairs and Theme pairs were not significantly different (p=1.32). Thus, Intra pairs elicited the highest false alarm rate, followed by Inter and Theme pairs, and then Old-New pairs.

A repeated measure ANOVA was conducted on the response time data associated with old/new responses to Old, Intra, Inter, and Theme pairs (but not to Old-New pairs, as three subjects did not make any old response to this stimulus type). It was revealed that the main effect of response type (old vs. new) was significant [$F(1,15)=6.96$, $p<.05$], indicating that the response time associated with 'old' responses were longer than that associated with 'new' responses. In addition, the interaction between response type and stimuli type (Old, Intra, Inter, and Theme) was significant [$F(2.3, 34.56)=7.2$, $p<.01$)]. A separate one way ANOVA was conducted on the response times associated with 'old' responses to the four types of stimuli, and exhibited a significant main effect [$F(1.9, 28.5)=5.19$, $p<.05$]. Newman-Keuls post hoc tests revealed that the response times associate with hit trials and false alarms to Intra pairs did not differ, and were both significantly shorter than the response times associated with false alarms to Inter and Theme pairs.

6.2.2.2 Remember/Know Judgement

Two sets of analyses were conducted on the data of Remember/Know judgements to the five classes of stimulus types. In the first set, the raw proportion of 'R' responses and corrected proportion of 'K' responses were employed as dependent variables. The 'K' responses were corrected according to the formula, 'CK=K/(1-R)', suggested by Yonelinas and Jacoby (1995), where CK, K, and R stands for corrected proportion of 'K' responses, raw proportion of 'K' responses, and raw proportion of 'R' responses respectively (all these three measures are listed in the third columns of table 6.2). Results from the analyses on the raw and corrected proportions of 'R' and 'K' responses provide separate information about how the pure amounts of recollection and familiarity, assumed to be independent from each other in the dual-process theories, are modulated by the characteristics of different types of test pairs. In the second set of analyses, the ratio between the proportion of 'R' response and the proportion of 'Old' response ('Remember/Old' ratio, listed in the fourth column of table 6.2) were employed as the dependent variable, as suggested by Rajaram (1993). Results from the analysis on the 'Remember/Old' ratio provide information about the differential influences on overall recognition and recollective experience from the characteristics of the different test items.

Table 6.2. Mean proportion of Remember responses (SD), mean proportion of Know responses (SD), mean corrected proportion of Know responses (SD), mean ratio of Remember/Old (SD), and mean reaction times (SD) for each response category for the Remember/Know judgement in Experiment 1.

Stimuli Type	R/K Response	Proportion (SD)	Remember/Old ratio (SD)	RT(ms)
Old Pair	*Remember*	.29 (.14)	.45 (.18)	1754 (269)
	Know(raw)	.34 (.11)		2025 (397)
	Know (corrected)	.48 (.11)		
Intra Pair	*Remember*	.17 (.10)	.31 (.16)	1773 (312)
	Know(raw)	.37 (.09)		1970 (324)
	Know (corrected)	.45 (.10)		
Inter Pair	*Remember*	.06 (.07)	.31 (.28)	2007 (308)
	Know(raw)	.16 (.11)		2179 (542)
	Know (corrected)	.17 (.12)		
Theme Pair	*Remember*	.05 (.06)	.19 (.26)	1891 (661)
	Know(raw)	.23 (.14)		2096 (408)
	Know (corrected)	.25 (.15)		
Old-New Pair	*Remember*	.01 (.01)	.09 (.18)	1775 (418)
	Know(raw)	.06 (.06)		2212 (477)
	Know(corrected)	.06 (.05)		

The repeated measure ANOVA conducted on the raw proportion of 'R' responses, with the stimulus type as independent variable, revealed a significant main effect [$F(1.89,28.28)=38.16$, $p<.001$]. Newman-Keuls post hoc tests showed that the proportion of 'R' responses to Intra pairs were lower than that to Old pairs, but were higher than the proportion of 'R' responses to Inter, Theme, and Old-New pairs. By contrast, the proportions of 'R' responses to Inter pairs and Theme pairs were not significantly different. The ANOVA carried out on corrected proportion of 'K' responses also revealed a main effect [F(3.17,47.55)=78.87, p<.001]. Post hoc tests revealed that both Old pairs and Intra pairs attracted more 'K' responses than other stimulus types, but the corrected proportions of 'K' responses associated with Old and Intra pairs were not significantly different. The main effect of stimulus type was also significant in the ANOVA conducted on the 'R/Old' ratio [F(2.75,41.17)=9.92, p<.001)]. Post hoc tested showed that the ratio for Old pairs were significantly higher than that for other stimulus types. The 'Remember/Old' ratio for Intra pairs was higher than the ratio for Theme pairs, but was not significantly different from that for Inter pairs.

As several subjects did not make 'R' responses to Inter, Theme, and Old-New pairs, the response time analyses for the Remember/Know judgements were restricted to Old and Intra pairs. A two-way ANOVA showed that the main effect of response type (R vs. K) was significant [F(1,15)=16.26, p=.001], indicating that the response time associated with 'R' responses was shorter than the response time associated with 'K' responses. Neither the main effect of stimulus type (Old vs. Intra) nor the interaction between stimulus type and response type were significant (p=.68, p=.31 respectively).

6.2.3 Discussion

The two kinds of rearranged stimuli, 'Intra' and 'Inter' pairs, gave rise to markedly different false alarm rates, with the former items yielding the higher rate. This finding suggests that the aim of generating confusable vs. non-confusable source-item pairing discriminations was achieved. As intended, the discrimination was more difficult for word pairs from the same study list than those from different lists. It is assumed that this difficulty arose from the semantic relation between the two initial words, as well as between the second words of word pairs from the same list. These two sets of semantic relationships together encouraged the formation of a gist memory for each study list.

Partial information about the source-item pairing retrieved from these gist memories allowed the rejection of Inter pairs that contained initial words incongruent with a gist memory. However, the same partial information biased subjects to accept Intra pairs, whose replaced initial words were congruent with the gist.

It might be argued that the false alarms to Intra pairs should not be considered as memory errors. The concurrent presentation of, and the semantic associations between study pairs might have encouraged subjects to encode each study list as a unit that lacks any pair specific information. Thus, the high false alarm rate to Intra pairs merely reflects the subjects' 'true' memories of what has been learned at study. For this argument to stand, subjects would have had to encode the study lists without attending to pair-specific information. They were, however, instructed to read aloud and attend to each pair monitored by the experimenter, making it unlikely that they failed to discriminate which of the two initial words a second word was paired with. Moreover, the different false alarm rates for Intra and Theme pairs provide evidence against the notion that false alarms to Intra pairs resulted exclusively from poor encoding of pair-specific information. Theme pairs were generated by pairing an old initial word with a second word that was unstudied but semantically related to the second words the initial word were paired with at study. Therefore, similar to Intra pairs, this class of test pairs also corresponded to the gist memory. If what subjects encoded from each study list was a vague memory of the association between the initial and second words without any pair-specific information, then Theme pairs should be as likely as Intra pairs to be incorrectly identified as studied items. However, as shown in the data, the false alarm rate for Theme pairs was markedly lower than the false alarm rate for Intra pairs, supporting the notion that false alarms to Intra pairs were not based solely on poor encoding quality.

The involvement of recollection and familiarity in memory judgements was examined by evaluating the recollective experience, self-reported by subjects in the Remember/Know procedure, associated with the five kinds of test pairs. It is obvious that there were more 'K' responses than 'R' responses to the five classes of test items, even for studied Old pairs. Taken together with modest hit rate for Old pairs and low false alarm rate for Old-New pairs, it is suggested that strict criterion were adopted by subjects in both the Old/New recognition test and the Remember/Know judgement. A larger number of 'R' responses were assigned to Old pairs in comparison to the other four types of test pairs. Specifically, the different numbers of 'R' responses to Old and Intra pairs suggested that at least some recollective experience could not be attributed to the correspondence between the test pairs and the gist memory formed during encoding. The different recollective experience associated with Old and Intra items might reflect the contribution of pair-specific information retrieved from Old pairs during retrieval, which was not available for Intra pairs during the test phase. Interestingly, the corrected proportions of 'K' responses to Old pairs and to Intra pairs were not significantly different. Based on the assumption that familiarity is indexed by the corrected proportion of 'K' responses (Jacoby & Yonelinas, 1995), this finding suggests that the involvement of familiarity in endorsing Old pairs and Intra pairs as studied items was similar. Considering both the raw proportion of 'R' and corrected proportion of 'K' responses, it is suggested that the excessive rate of endorsement to Old pairs in comparison to Intra pairs was due to more or stronger recollection elicited by the former than by the latter test pairs. This is consistent with the result from the analysis on the 'Remember/Old' ratio, which revealed that the percentage of 'old' responses assigned with the 'R' judgement was larger for Old pairs than for Intra pairs.

The main issue addressed in this experiment was whether the involvement of recollection in incorrect source-pairing judgments would be modulated by the partial information derived from the gist memory formed during encoding. This question was investigated by comparing the recollective experience associated with false alarms to Intra pairs and Inter pairs. As revealed in the section of results, both the raw proportion of 'R' responses and the corrected proportion of 'K' responses were larger for Intra pairs than for Inter pairs. These findings suggested that the correspondence with the gist memory rendered Intra pairs more likely than Inter pairs to be incorrectly identified as studied items, and these excessive false alarms to Intra pairs was contributed by both the recollection of the partial information and familiarity. However, the 'Remember/Old' ratio was not different for Intra and Inter pairs, indicating that a similar percentage of endorsed items was assigned the 'R' response for these two classes of rearranged pairs. Thus, although Intra pairs elicited more recollection than Inter pairs, proportionally the contribution of recollection to memory judgement errors did not increase when the source-item pairing of test stimuli was consistent with the gist memory. An additional finding in this experiment was the difference in the recollective experience associated with false alarms to Intra pairs and Theme pairs. Both the raw proportion of 'R' responses and the 'Remember/Old' ratio were higher for the former than for the latter items. This finding is essential for the argument that gist-based source-pairing discrimination errors are different from, and can not be ascribed to incorrect memory judgements resulted from poor encoding.

In summary, the different false alarm rates for Intra pairs and Inter pairs suggested that gist memories were formed for the study lists where several source-item pairs sharing similar semantic association were presented. The more 'R' and 'K' responses to Intra pairs in comparison to Inter items suggested that partial source information derived from the gist amplified the involvement of both recollection and familiarity in making source-item pairing judgement errors. Importantly, the high false alarm rate for Intra pairs could not be exclusively attributed to the poor encoding of pair-specific information, as Theme pairs, which might be viewed as the baseline for false alarms due to vague memory, attracted many fewer false alarms and 'R' responses than Intra items.

6.3 Experiment Two

It was shown in Experiment 1 that the involvement of recollection in source-item pairing discrimination errors might be modulated by the partial information derived from the gist memory formed during encoding. However, although the raw proportion of 'R' responses was higher for Intra pairs than for Inter pairs, a certain number of Inter items were associated with 'R' responses. If 'R' responses are viewed as the index of recollective experience and therefore recollection-based recognition, the observation of 'R' responses to Inter pairs suggests that recollection is involved in source-item pairing judgement errors even when the lure pairs are not consistent with the gist memory. Specifically, the 'Remember/Old' ratios for Intra and Inter items were not significantly different from each other. This fining casts doubts on the notion that recollection is differently involved in the false alarms to Intra and Inter pairs.

Experiment Two investigated whether recollection is differently involved in source judgement errors associated with confusable and non-confusable source-item pairings by recording ERPs during the memory test. In this ERP experiment, Theme pairs were not included as test pairs for two reasons. First, Theme pairs were included in Experiment One to serve as the control condition for source judgement errors resulted from poor encoding. It was shown that the false alarm rate, the raw proportion of 'R' responses, and the 'Remember/Old' ratio for were significantly lower for Theme pairs than for Intra pairs. This finding provides supportive evidence for the notion that false alarms to Intra pairs did not result solely from subjects' inability to encode study pairs properly. Therefore, it is not necessary, although would be interesting, to compare the ERPs elicited by incorrectly identified Theme pairs and Intra pairs. Second, in order to get an adequate signal/noise ratio, the valid ERP trials of the critical response categories must be larger than a certain number, which was set at 16 in the current experiment. Given the low false alarm rate for Inter pairs, it was essential to increase the number of Inter pairs so that sufficient false alarms to Inter pairs could be included in ERP analyses. If both Theme pairs and Inter pairs were included, there would be too many trials. As the main issue addressed in this experiment was whether recollection was differently involved in false alarms to Intra and Inter pairs, Theme pairs were therefore not included as test pairs.

6.3.1 Method

6.3.1.1 Subjects

A total of 21 right-handed healthy volunteers participated in the experiment. Each subject was paid at the rate of £7.50 per hour. Data from 2 subjects were discarded due to equipment failure. Data from another subject were discarded because of very poor task performance. Of the remaining 18 subjects, 9 were female.

6.3.1.2 Stimuli and Design

Study lists. Twenty sets of words were used to generate twenty study lists. Each set comprised a pair of strongly associated words and a group of sixteen words, all of which were related to a common unpresented theme word. These twenty pairs of associated words and twenty groups of related words were selected in the same way as in Experiment One. Each of the two associated words was paired with eight of the related words to construct a study list of sixteen word pairs (see figure 6.2 for illustration). In each word pair, the associated word was assigned as the initial word and the related word was assigned as the second word. The twenty study lists were assigned to five study-test cycles, with four lists in each cycle. The allocation of the lists to the cycles was counterbalanced across subjects, while the presentation order of the four lists in each cycle was randomly assigned for each subject.

Test list. There was one test list in each study-test cycle, containing seventy-four word pairs. Two pairs were fillers while the remaining pairs belonged to one of four categories (see figure 6.2 for illustration). (1) Four pairs from each of the study lists were assigned as 'Old' pairs and maintained their studying pairings. (2) Another four pairs from each study list were re-paired with items from the same list to form 'Intra' pairs. (3) Six other pairs from each study list were re-paired with other words from one of the other three study lists to form 'Inter' pairs. (4) The eight initial words employed on the four study lists were paired with two new words each to generate 'Old-New' pairs. The new words were selected from the Francis and Kucera corpus (1982), and their mean frequency was matched with that of the old words.

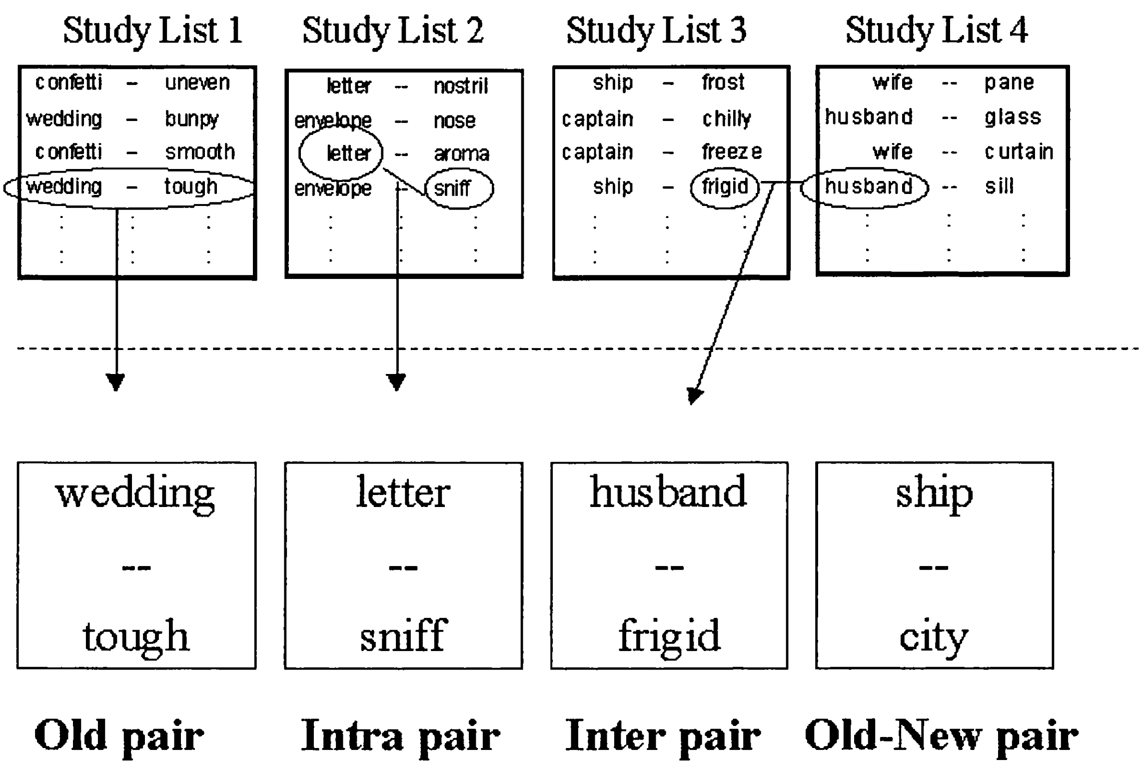

Figure 6.2. Illustration of the formation of one study list and the four types of test pairs generated from this list in Experiment 2.

6.3.1.3 Procedure

Study phase. The four study lists in each study-test cycle were presented consecutively. The sixteen pairs of each list were shown on the screen concurrently, with each pair occupying a separate row. The concurrent presentation of the study pairs was intended to enhance the formation of gist memories for each study list. Subjects were instructed to read the word pairs aloud from top to bottom and memorize them. It was emphasized that the relationship between the two words of each pair was important for the following test. The study list remained on the screen until the subject informed the experimenter they were ready to move on to the next list.

Test phase. The test phase followed the study phase after an interval of approximately 5 minutes, during which subjects engaged in a short backward counting task and then rested. Each trial started with the presentation of a fixation character '@' for 1000 ms on the center of the screen, followed by a second fixation character '--'. Five hundred ms after the presentation of the second fixation character, the two words of the test pair were presented on the screen, with one word above fixation and the other word below. The two words were shown for 500 ms. The maximum vertical and horizontal visual angles of the words were approximately 1^{o} and 1.7^{o} respectively. The second fixation character stayed on the screen for 2500 ms after the offset of the test pair. The first fixation character then returned to signal the beginning of the next trial.

Subjects made old/new judgments in response to the presentation of each test pair. They were instructed that only test pairs presented in exactly the same pairing as at study should be responded to as old. Rearranged pairs, which contained words from different study pairs, and Old-New pairs, which contained new words, should be responded to as new. Responses were made by pressing one of two response keys with the index finger of each hand. The mapping of the hand to response category (old vs. new) was counterbalanced across subjects.

ERPs were recorded during the test phase. The ERP recording procedure was the same as that described in Chapter 5.

6.3.2 Results

6.3.2.1 Behavioural Results

Table 6.3 displays the proportion of 'Old' and 'New' responses to the four classes of test item, together with their associated response times. A priori t-tests showed that the hit rate to Old pairs and the false alarm rate for Intra pairs did not differ significantly (t_{17}=1.36). In addition, Intra pairs were more likely to be identified as 'old' than Inter pairs (t_{17}=10.05, p<.001), and there were more old responses to Inter pairs than to Old-New pairs (t_{17}=6.89, p<.001). Thus, Intra pairs elicited the highest false alarm rate, followed by Inter pairs and then Old-New pairs.

The response times for false alarms to Intra pairs were similar to the response times for hits, and were shorter than the response times for false alarms to Inter pairs and Old-New pairs. A one-way ANOVA on these response times revealed a significant main effect for the four categories of test pairs [F(1.2, 20.6)=13.04, p=.001]. Newman-Keuls post hoc tests revealed that the response times on hit trials and response times for Intra false alarms did not differ, and were both significantly shorter than those for Inter pairs.

Table 6.3. Mean proportion of responses (SD) and mean reaction times (SD) for each response category in Experiment 2.

Stimuli Type	Response Category	Proportion (SD)	RT(SD)
Old Pair	Hits	.67 (.12)	1597 (271)
	Miss		1692 (341)
Intra Pair	False alarm	.63 (.12)	1593 (270)
	Correct rejection		1706 (353)
Inter Pair	False alarm	.24 (.13)	1754 (351)
	Correct rejection		1624 (288)
Old-New Pair	False alarm	.09 (.08)	1888 (640)
	Correct rejection		1474 (248)

6.3.2.2 ERP Results – Amplitude Analyses

Averaged ERPs were formed for four response categories based on data from all 18 subjects: hits to old pairs, false alarms to Intra pairs, correct rejections to Inter pairs, and correct rejections to Old-New pairs (hereafter abbreviated to Hit, Intra FA, Inter CR, and Old-New CR respectively), with the mean trial numbers (range in brackets) of 46 (22-68), 44(25-60), 79 (32-107), and 62(28-80) respectively. Six subjects contributed fewer than 16 false alarms to Inter pairs (hereafter abbreviated to Inter FA), and these subjects' data were excluded from analyses involving this response category. The mean trial numbers of the 12 subjects contributing ERPs for Hit, Intra FA, Inter FA, Inter CR, and Old-New CR were 45 (29-68), 46 (30-60), 32 (16-61), 75 (51-99), and 60 (40-73) respectively. Another three subjects contributed fewer than 16 correct rejections to Intra pairs (hereafter abbreviated to Intra CR), and these subjects' data were excluded from analyses involving this response category. The mean trial numbers of the 15 subjects contributing ERPs for Hit, Intra FA, Intra CR, Inter CR, and Old-New CR were 48 (29-68), 44 (30-60), 29 (18-44), 83 (54-107), 65 (50-80).

Grand average ERP waveforms overlaid by condition are shown in figures 6.3-5. As can be seen from the figures, in each case the waveforms diverge from approximate 400 ms after stimulus onset. Notably, the waveforms associated with Hits and Intra FA are more positive-going than the waveforms associated with Old-New CR. This positive shift is initially larger over the left than the right hemisphere at parietal sites, but is larger over the right than the left hemisphere at frontal sites later on in the recording epoch. Furthermore, as illustrated in figure 6.4, these effects appear to be absent for the Inter FA response category. ERPs were quantified by measuring the mean amplitudes of four time regions: 300-600, 600-900, 900-1400, and 1400-1900 ms. These time regions were chosen on basis of preliminary analyses of consecutive 100 ms latency intervals and to accord roughly with those used in previous studies of associative recognition (Rugg & Donaldson, 1998).

Two sets of analyses were conducted to separately investigate the left parietal/ right frontal effects, as well as the early frontal effect respectively. In the first set, an overall ANOVA was first conducted for each time region on the data from 18 electrode sites. These sites were located over 6 scalp regions: left frontal (electrodes 48,33,19), right frontal (electrodes 38,22,9), left central (electrodes 47,31,17), right central (electrodes 39,24,11), left parietal (electrodes 46,30,29), and right parietal (electrodes 40,25,26). Factors entered into the global ANOVA were Response Category (Hit, Intra FA, Inter FA, Inter CR, Old-New CR for 12 subjects; Hit, Intra FA, Intra CR, Inter CR, Old-New

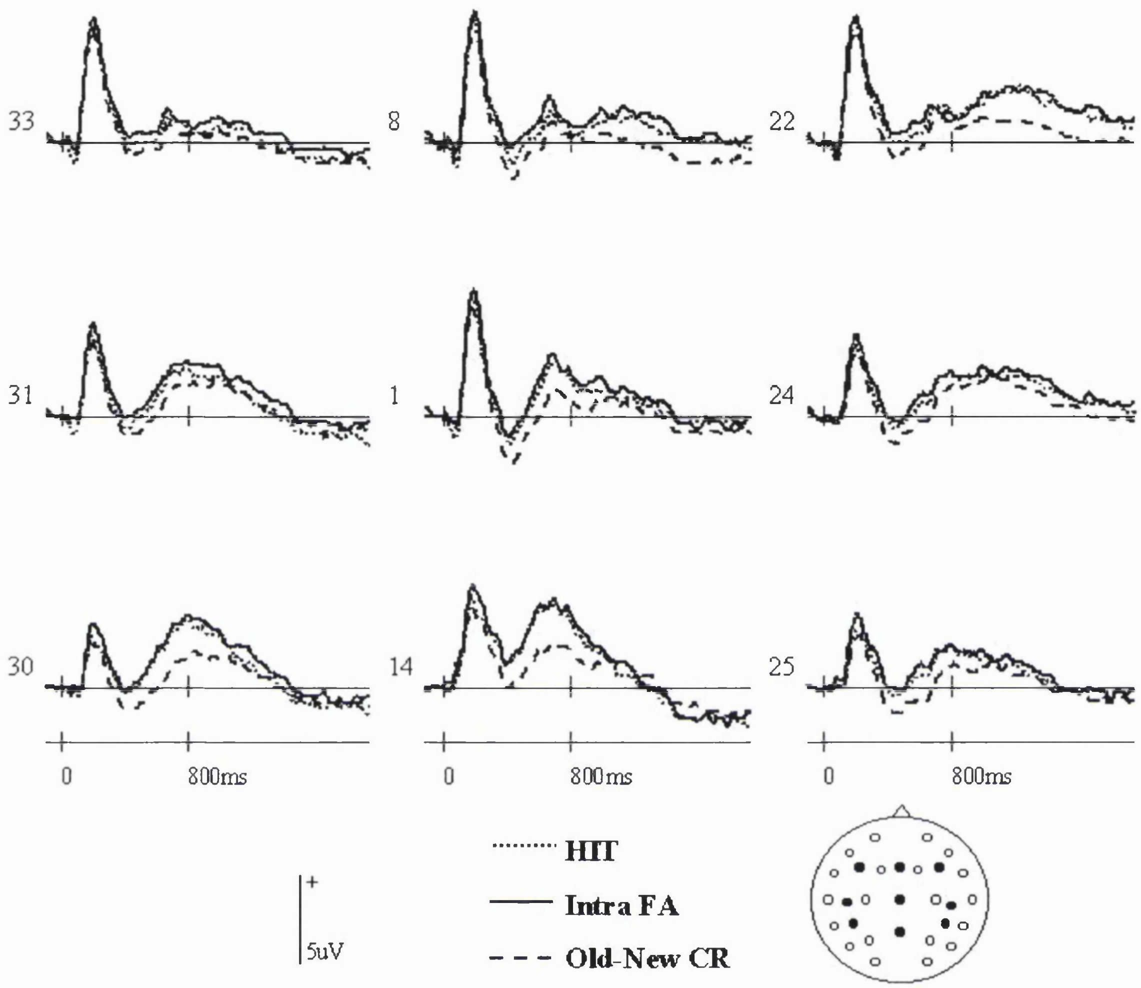

Figure 6.3. Grand average waveforms (N=18) for Hit, Intra FA, and Old-New CR in Experiment 2. The locations of the sites are indicated as the number of the electrodes in the montage.

CR for 15 subjects; Hit, Intra FA, Inter CR, Old-New CR for all 18 subjects), Hemisphere (left, right), Location (frontal, central, parietal), and Site. Subsidiary ANOVAs for pairwise comparison between response categories were conducted when there were significant effects involving response categories in the overall ANOVA. The second set of analyses were conducted on data of the 300-600 ms, focusing on the midfrontal sites (19, 8,9) at which the early frontal effect was maximal in previous studies (Rugg et al., 1998; Maratos, Allan, Rugg, 2000; Tsivilis, Otten, & Rugg, 2001).

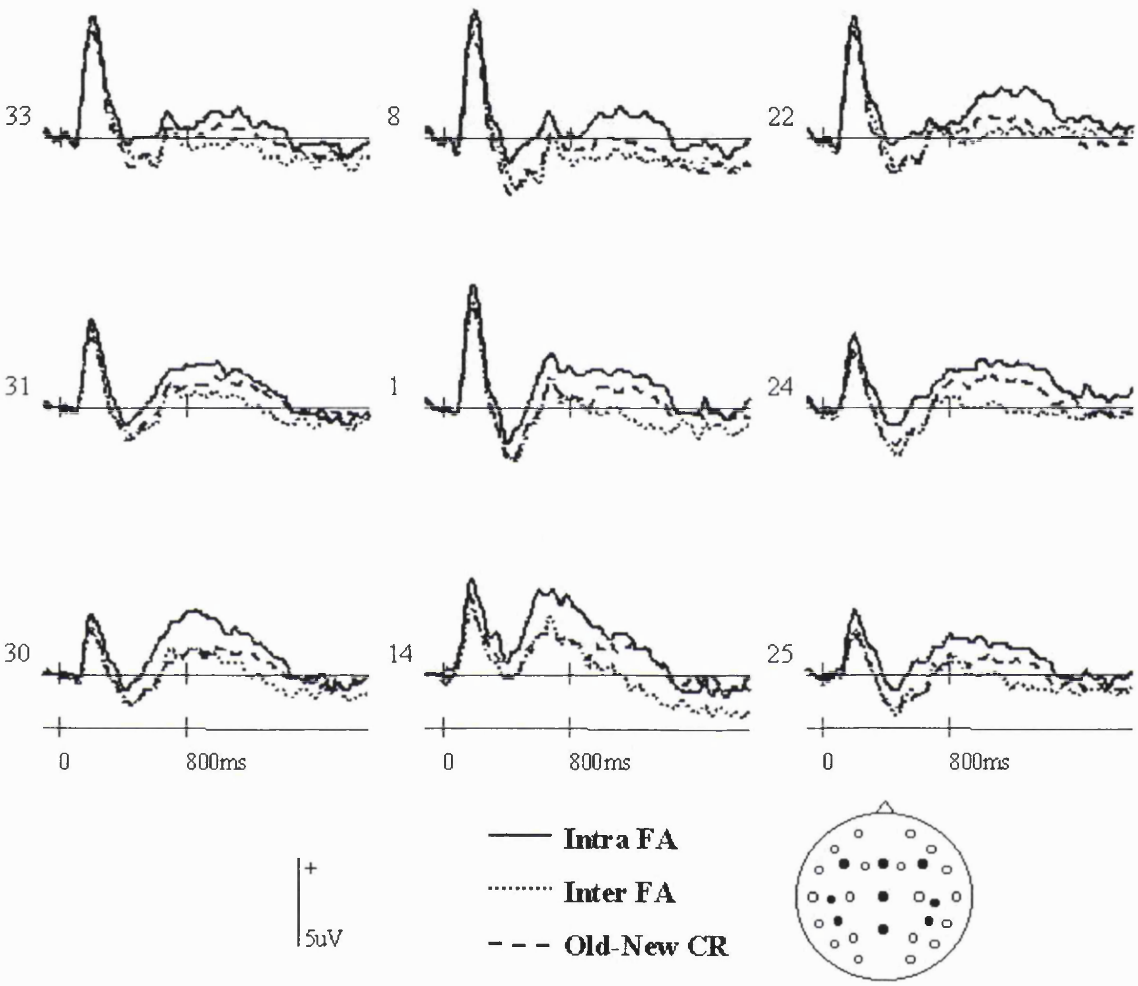

Figure 6.4. Grand average waveforms (N=12) for Intra FA, Inter FA, and Old-New CR in Experiment 2. The locations of the sites are indicated as the number of the electrodes in the montage.

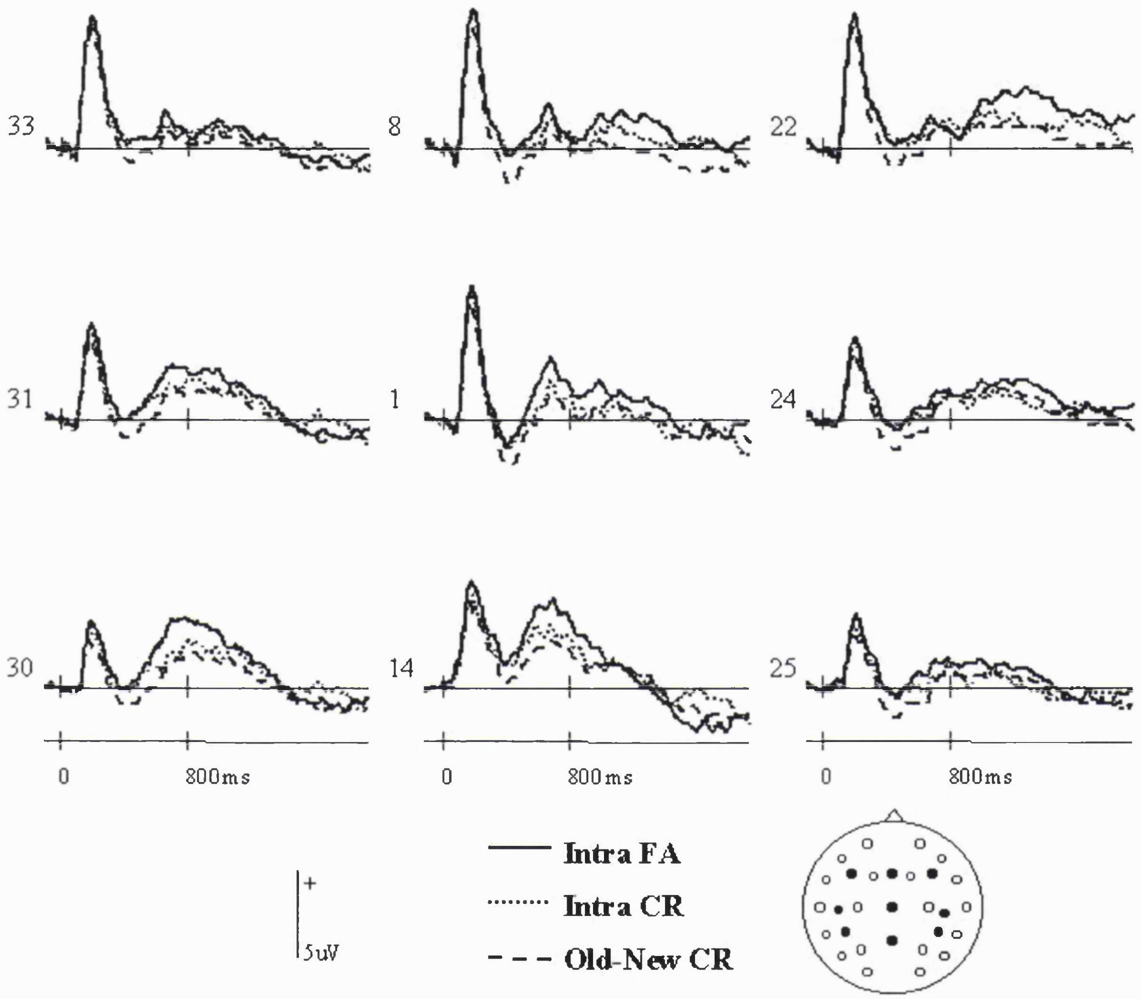

Figure 6.5. Grand average waveforms (N=15) for Intra FA, Intra CR, and Old-New CR in Experiment 2. The locations of the sites are indicated as the number of the electrodes in the montage.

6.3.2.1.1 Analyses of lateral sites

Table 6.4 shows the results of the overall ANOVAs for the four time regions based on the data from all 18 subjects (Inter FA excluded). As can be seen from the table, there were significant effects involving Response Category in all four time regions. Similar results were obtained from the ANOVAs in which false alarms to Inter pairs and correct rejections to Intra pairs were included, based on the data from the 12 and 15 subjects who contributed enough Inter FA and Intra CR trials respectively. In light of these significant effects, subsidiary ANOVAs for pairwise comparisons between response categories were performed. Because there were no differences between the ERPs elicited by Old-New CR and Inter CR items in any of the four time regions, the waveforms to these two response categories were collapsed in these subsidiary analyses to form the category of Correct Rejections (CR). Mean amplitudes associated with the ERP effects for Hits, Intra FAs, Inter FAs, and Intra CRs, in comparison to CRs are shown at anterior, central, and posterior sites across each of the four latency regions in figure 6.6. The results of these ANOVAs are listed in table 6.5 and elucidated below. Only results based on all 18 subjects are reported unless an ANOVA based on data from the aforementioned subsets of subjects revealed a different pattern of results.

Table 6.4. Results of overall ANOVAs of the magnitude analyses over each time region in Experiment 2.[a,b]

	300-600 ms	600-900 ms	900-1400 ms	1400-1900 ms
RC	$F_{2.7,46.7}$=8.28***	$F_{2.6,44.5}$=6.47**	-	-
RC x AP	-	$F_{3.1,52.2}$=3.56*	-	$F_{3.2,53.8}$=3.02*
RC x ST	$F_{2.8,46.9}$=5.69**	$F_{2.8,46.8}$=11.04***	-	-
RC x HM x AP	-	$F_{3.6,61.9}$=4.41***	$F_{3.5,59}$=4.86**	-
RC x AP x ST	-	-	$F_{6,102.3}$=2.35*	$F_{5.6,95}$=2.26*

[a.] Only significant effects involving the factor of response category are reported.
[b.] RC=response category, HM=hemisphere, AP=anterior-posterior location, ST=electrode site.
*** p<.001; ** p<.01; * p<.05

Hit vs. CR. As shown in table 6.5, the ANOVAs comparing the ERPs associated with Hit and CR trials revealed a significant effect of Response Category in the 300-600 ms and the 600-900 ms time regions, reflecting the fact that the ERPs associated with Hits were

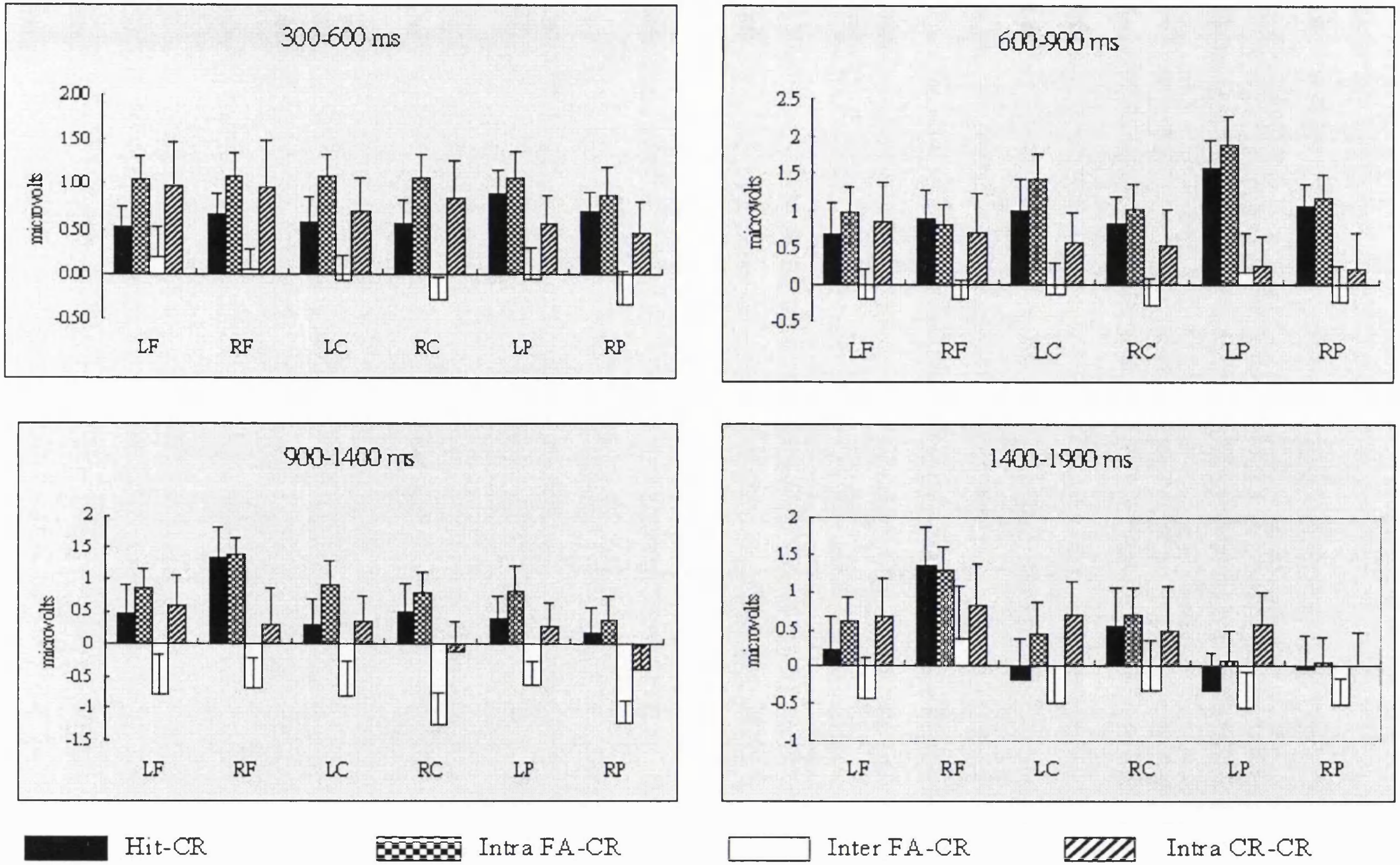

Figure 6.6. Mean amplitudes (with standard errors) associated with the ERP effects for Hits (N=18), Intra FAs (N=18), Inter FAs (N=12), and Intra CRs (N=15), in comparison to CRs at anterior, central, and posterior sites across the four time regions in Experiment 2.

more positive than the ERPs associated with CRs. The two-way interaction between Response Category and Location was significant in the 600-900 ms and the 1400-1900 ms time regions. The three-way interaction between Response Category, Hemisphere, and Location was significant in the 300-600, 600-900, and 900-1400 ms time regions. These interactions reflected variations in the scalp distribution of the positive-going effect for Hits across the scalp and the time regions as shown in figures 6.3 and 6.6. At parietal sites, the positive-going effect to Hits onset around 300 ms, was larger over the left than the right hemisphere, and decayed by around 1000 ms. The Hit vs. CR effect had a different pattern over frontal sites. The effect onset around 800 ms lasted until the end of the recording epoch, and was larger over the right hemisphere than the left.

Table 6.5. Results of subsidiary ANOVAs of the magnitude analyses over each latency region in Experiment 2. [a,b]

	Hit vs. CR	Intra FA vs. CR	Inter FA[c] vs. CR	Intra FA vs. Inter FA[c]	Intra FA Vs. Intra CR[d]	Intra CR[d] vs. CR
300-600 ms						
RC	$F_{1,17}$=10.16**	$F_{1,17}$=19.02***	-	$F_{1,11}$=13.7***	-	$F_{1,14}$=4.68*
RC x HM x AP	$F_{1.7,28.8}$=4.28*	-	-	-	-	-
600-900 ms						
RC	$F_{1,17}$=8.84**	$F_{1,17}$=16.99***	-	$F_{1,11}$=9.77**	-	-
RC x AP	$F_{1.3,22.1}$=5.18*	$F_{1.2,20.3}$=5.36*	-	-	$F_{1.1,14.9}$=6.1*	-
RC x HM x AP	$F_{1.8,31.3}$=9.57***	$F_{1.9,33.1}$=4.78**	-	-	-	-
900-1400 ms						
RC	-	$F_{1,17}$=9.79**	$F_{1,11}$=5.48*	$F_{1,11}$=28.99***	-	-
RC x HM x AP	$F_{1.9,32.7}$=8.2***	$F_{1.9,33.1}$=6.1**	-	-	-	-
1400-1900 ms						
RC	-	$F_{1,17}$=4.33*	-	-	-	-
RC x AP	$F_{1.2,19.9}$=5.99*	-	-	-	-	-

a. Only significant effects involving the factor of response category are reported.
b. RC=response category, HM=hemisphere, AP=anterior-posterior location, ST=electrode site
*** p<.001; ** p<.01; * p<.05
c. Comparisons were based on data from 12 subjects who contributed sufficient Inter FA trials.
d. Comparison was based on data from 15 subjects who contributed sufficient Intra CR trials.

Intra FA vs. CR. The results of the comparisons between Intra FA and CR were very similar to those revealed in the Hit vs. CR contrast. As shown in table 6.5, the effect of

Response Category was significant across the four time regions, reflecting that the waveforms to Intra FA were more positive going than the waveforms to CR. The two-way interaction between Response Category and Location was significant in the 600-900 ms time region, and approached significance in the 1400-1900 ms time region [$F(1.3,21.4)=3.67$, $p=.06$]. The three-way interaction between Response Category, Location, and Hemisphere was significant in the 600-900 ms, and 900-1400 ms time regions. As can be seen from figures 6.3 and 6.6, these interactions were due to the positive-going effect for Intra FA in comparison to CR being larger at left than right parietal sites during the 600-1400 ms time regions. Figure 6.6 also shows that the Intra FA vs. CR effect was larger at right than left frontal sites between 900 and 1900 ms.

Hit vs. Intra FA. As can be seen from figures 6.3 and 6.6, the waveforms associated with these two classes of response categories were highly similar. There were no significant effects involving Response Categories observed in any of the four time regions.

Inter FA vs. CR. As can be seen from figure 6.4, the results of the comparison between Inter FA and CR trials were very different from those of the comparisons between Hit and CR (see figure 6.3). A significant effect for Response Category was observed in the time region of 900-1400 ms only. This effect reflected the fact that the waveforms elicited by Inter FAs in this region were more negative-going than those elicited by CRs.

Intra FA vs. Inter FA. In this contrast, the main effect of response category was significant during the 300-600, 600-900, and 900-1400 ms time regions, reflecting the greater positivity of the ERPs to Intra FAs.

Intra FA vs. Intra CR. The two-way interaction between Response Category and Location was significant in the 600-900 ms time region. Follow-up analysis showed that the difference between these two response categories was significant at left parietal sites [$F(1,14)=6.79$, $p<.05$] but not at other sites, reflecting the positivity associated with Intra FA relative to Intra CR, as can be seen in Figure 6.5.

Intra CR vs. CR. In this contrast, the main effect of response category was significant during the 300-600 ms time region, reflecting the greater positivity of the ERPs to Intra CRs.

6.3.2.1.2 Analyses of Midfrontal Sites

The waveforms from the midfrontal sites (19,8,9) are shown in figure 6.7. The ANOVAs based on data from all 18 subjects showed that the ERPs associated with Hits and Intra FAs did not differ from each other ($p=.09$) but were both more positive compared to the ERPs associated with CRs [$F(1,17)=10.22$, $p<.01$ and $F(1,17)=23.38$, $p<.001$ respectively]. It was also shown, based on data from the 12 subjects who contributed sufficient false alarms to Inter pairs, that the ERPs associated with Hits and Intra FAs were more positive than the ERPs associated with Inter FAs [$F(1,11)=11.23$, $p<.01$ and $F(1,11)=24.46$, $p<.001$ respectively]. The waveforms associated with Inter FAs did not differ from those associated with CRs ($p=.85$). To examine whether this positivity for Hits and Intra FAs compared to CRs were specifically in association with Old responses, pairwise comparison between Miss and CRs, as well as Intra CRs and CRs were also conducted. It was shown, based on data from 14 and 15 subjects who contributed sufficient Miss and Intra CR trials, that the ERPs associated with both Miss and Intra CRs were both more positive than CRs [$F(1,13)=5.24$, $p<.05$ and $F(1,14)=4.3$, $p=.05$].

6.3.2.3 ERP Results – Topographical Analyses

The scalp topographies of the old/new effects for Old pairs and the 'false recognition' effects for Intra pairs, as shown in figure 6.8, were compared across the four time regions. Prior to analysis, the data were rescaled in order to avoid the confounding between any differences in the magnitude the two effects and the differences in scalp distribution. Both effects onset in the 300-600 ms time region, during which the positivity was widespread over the central scalp. The effects shifted to the left parietal scalp in the 600-900 ms time region and to right frontal sites in the 900-1400 and 1400-1900 ms time

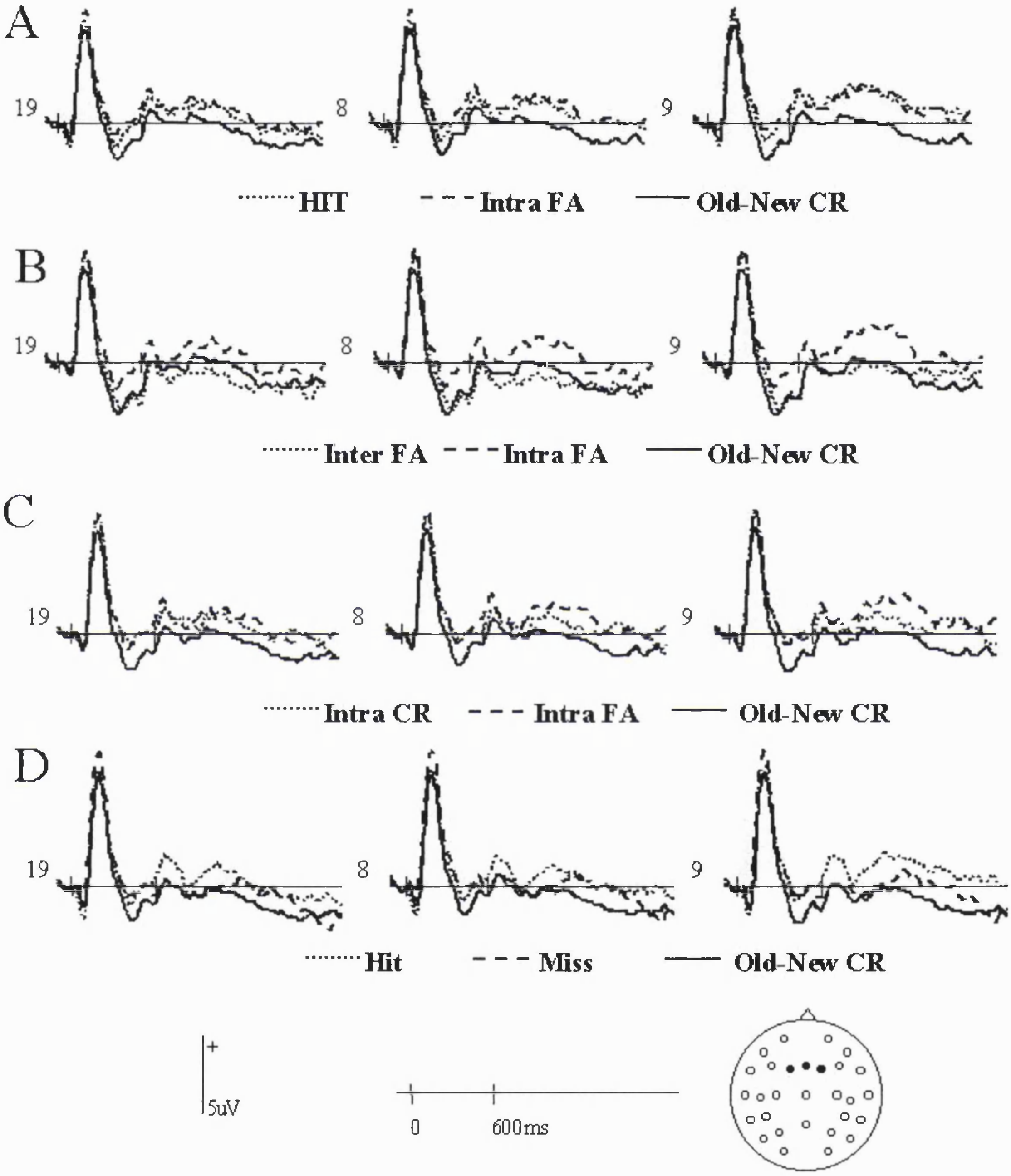

Figure 6.7. ERP waveforms associated with different response categories at midfrontal sites in Experiment 2. A: waveforms for Hit, Intra FA, Old-New CR (N=18); B: waveforms for Inter FA, Intra FA, Old-New CR (N=12); C: waveforms for Intra CR, Intra FA, Old-New CR (N=15); D: waveforms for Hit, Miss, Old-New CR(N=14). The locations of the sites are indicated as the number of the electrodes in the montage.

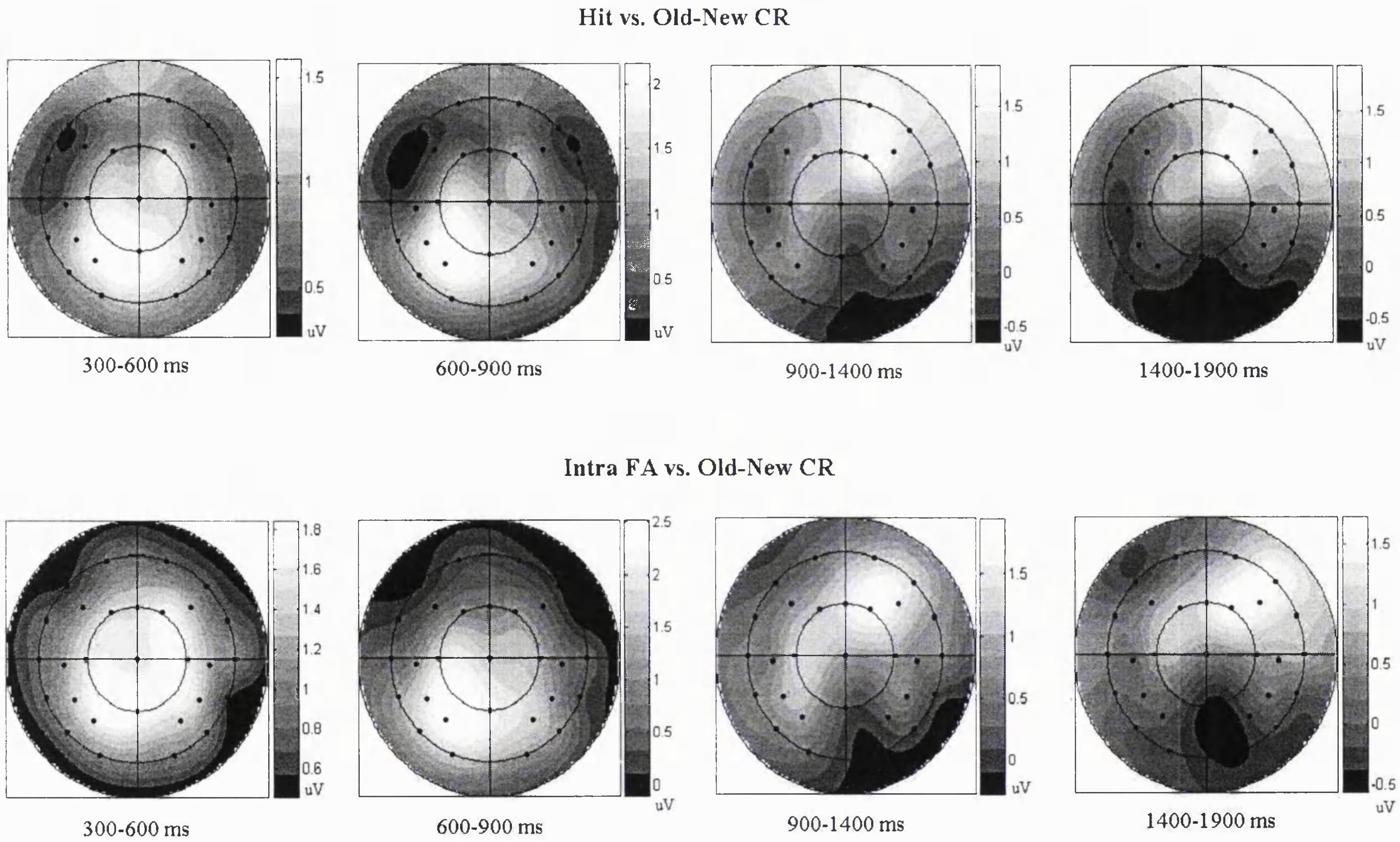

Figure 6.8. Voltage spline maps showing the topographies of the old/new effect for Old pairs (differences between Hit and Old-New CR) and the false recognition effect for Intra pairs (differences between Intra FA and Old-New CR) across four latency regions in Experiment 2.

regions. The topographies of these two effects were very similar across the four EEG recording epochs. ANOVAs showed that the topographical distributions of the Old/New effect for Old pairs and the false recognition effect for Intra pairs were statistically indistinguishable. The difference between the two effects was not significant and did not interact with time region or electrode site (all $Fs<1$). However, the interaction between time region and electrode sites was significant [$F(5.3,90.8)=4.62$, $p=0.001$], indicating that the distributions of both effects changed with time, as would be expected given the pattern shown in figures 6.3 and 6.6.

6.3.2.4 Summary of ERP results

ERPs associated with correctly classified Old pairs were more positive than those associated with correct rejections. In the time region of 300-600 ms, this positivity was widespread over the central scalp. Between 600ms and 900 ms, the positive-going effect was larger over the left hemisphere at parietal sites. From 900 ms to the end of the recording epoch, the positive effect shifted to frontal sites and was larger over the right than the left hemisphere. Statistically indistinguishable effects, in terms of both amplitude and topography, were elicited by Intra FAs relative to CRs, but were absent for Inter FAs.

6.3.3 Discussion

The ERP data suggest that different mechanisms were involved in the source judgement errors for confusable and non-confusable source-item pairings. ERPs associated with Intra FAs and Hits were indistinguishable, and differed from those associated with Inter FAs. Notably, a left parietal effect was observed for Hits and Intra FAs, but not for Inter FAs. The presence and absence of the left parietal effect for Hits and Inter FAs respectively is in line with the findings of Wilding and Rugg (1996), who suggested that this effect is sensitive to the accuracy of source judgments. However, the observation of a left parietal effect for Intra FAs reveals the involvement of recollection in source judgment errors when source-item pairings are highly confusable. Following the assumption that Intra FAs resulted from the influence of gist memories for study lists, the ERP findings support the notion that some judgement errors can result from the retrieval of the partial or inexact source information contained in gist memories.

The above findings suggest that the left parietal effect is not necessarily sensitive to the accuracy of source memory. Whether or not the effect is found for source errors depends on the mechanism underlying these errors. When information that is imperfectly diagnostic of different sources is recollected, the left parietal effect can be associated with source attribution errors. However, the effect will be absent if source errors are not accompanied by recollection of non-diagnostic information.

The ERP evidence for the involvement of recollection in Intra FAs resembles findings from previous ERP studies of DRM memory errors, in which the neural correlates of recollection were also observed for both true and false recognition (Duzel et al, 1997; Johnson et al., 1997; Nessler et al., 2001). Among these studies, that conducted by Nessler et al. (2001) is of particular interest in the present context. In their second experiment, subjects were presented at study with words belonging to different categories, and were required either to focus on the conceptual similarity between these words by categorizing them ('Category' group), or to focus on item-specific information by making animacy judgments ('Item' group). In a later recognition test, Nessler et al. found that the parietal ERP old/new effects associated with the true and false recognition in the Category group were indistinguishable, while the parietal effect in the Item group was smaller for false recognition than for true recognition. Moreover, the early frontal effect, held to reflect familiarity-based recognition (Curran, 2000; Rugg et al, 1998), was observed for both true and false recognition in the Category group, but only for true recognition in the Item group. Nessler et al's interpretation of their data focused on the early frontal effect associated with false recognition in the Category group. They suggested that it was the conceptual similarity between items encoded at study that led to familiarity-based false recognition. The different parietal effects associated with false recognition in the Category and Item groups suggest however that, in addition, the conceptual similarity between study items contributed to false recollection, as is also suggested by the different ERPs elicited by Intra and Inter pairs in the present study.

The gist memories formed in the present study are somewhat different from the errors produced in the DRM procedure. In the DRM procedure, it is the similarity between a group of individual items that generates the gist memory. In the present study, however, gist memory depends upon the similarity of the associations between two groups of semantically related items. The finding that the left parietal effect was associated with both Hits and Intra FAs, but not with Inter FAs suggests that the probability of recollection differs according to whether the gist memories formed at study are maintained or 'broken' at test. A similar finding was reported in an associative recognition study conducted by Donaldson and Rugg (1998). In their experiment 1, subjects studied unrelated word pairs and then discriminated test pairs composed of old words from those composed of new words. For test pairs judged old, subjects were also requested to judge whether the two words were in the same pairing as at study or in a different pairing. Donaldson and Rugg found that the left parietal effect was larger when elicited by pairs of old words whose members maintained their study pairing than it was for pairs where members were rearranged between study and test. A similar finding was found in their experiment 2 when subjects were requested to discriminate between old and new pairs without judging whether the pair was the same or rearranged. These findings suggest that what was recollected in that experiment, as was also the case here, was the relation between study words, rather than information specific to each word alone.

An alternative explanation for the left parietal effect elicited by Intra FAs in the present study is that the effect reflects recollection of each of the two studied items, rather their association. By this account, the higher false alarm rate for Intra than for Inter pairs occurred because the former were more difficult to reject with a recall-to-reject strategy (Clark, 1992; Clark & Gronlund, 1996). For several reasons, this alternative explanation is unlikely. First, if the left parietal effect for Intra FAs reflected recollection for the constituent words, similar effects should have been observed for Inter FAs. However, as is evident in figure 6.5, there is no sign of a left parietal effect in association with this response category. Second, data from the fifteen subjects who contributed sufficient Intra CR trials showed no sign of a left parietal effect associated with correct rejections to the Intra pairs, suggesting that a recall-to-reject strategy was not adopted in order to reject these items.

In addition to the left parietal old/new effect, Hits and Intra FAs also elicited a right frontal effect, suggesting that the information recollected in response to these two classes of stimuli was subjected to equivalent levels of post-retrieval monitoring and evaluation. These post-retrieval processes were however insufficient to allow rejection of the Intra pairs, perhaps because what was recollected in response to Old and Intra pairs was so similar. Crucially, as with the left parietal effect, the right frontal effect was not observed for Inter FAs, suggesting that monitoring processes were not engaged when Inter pairs were classified incorrectly. It is important to note, however, that this does not mean that the post-retrieval monitoring processes indexed by the right frontal effect are specific to recollection. As mentioned in the introduction, the left parietal and right frontal effects are dissociable (Rugg, Allan, & Birch, 2000; Wilding & Rugg, 1997b). The contingency between the effects observed in the present study likely reflects the strategy adopted by subjects to focus evaluation and monitoring processes on recollected information.

Apart from the effects discussed above, a diffusely distributed positive-going effect was associated with Hits and Intra FAs during the 300-600 ms time region. This time region corresponds to the latency region in which the early frontal effect, held to be a neural correlate of familiarity-based recognition, has been observed. For two reasons, the effect reported here cannot easily be identified with the early frontal effect. First, the scalp distribution of the present effect differs from that reported in the earlier studies (Curran, 2000; Nessler et al, 2001; Tsivilis et al., 2001), where the early effect demonstrated an anterior maximum. Second, the present effect was also observed when Intra pairs were correctly rejected (see table 6.5 and figure 6.4), yet there was no such effect for either

Inter FAs or Inter CRs. Thus the effect was not sensitive to response accuracy. Instead, it appears to have been modulated by whether or not the two members of a test pair belonged to a common study list.

The failure to observe the mid-frontal effect for Inter FAs could indicate that these errors were not familiarity-based. However, this conclusion might not hold for the following reason. First, the stimuli employed in the current experiments were word pairs rather than single items. At test, subjects were presented with word pairs whose initial words had repeatedly shown in different trials. The repetition of the initial words, together with the concurrent presentation of two words, might both introduce variability in the onset of the processes underlying familiarity-based recognition and hence the time course of the mid-frontal effect. This variability might make it difficult to observe the putative ERP index of familiarity. It is also possible that the familiarity involved in the source judgement errors observed in the present study is of a different informational form from that indexed by the early frontal effect, which thus far has been linked with item, rather than associative, memory. Another possible reason why the early frontal effect was not observed for Inter FAs was that the current experiment did not employ any test pairs in which both items were unstudied. The 'baseline' was provided by Old-New pairs, in which one member was old. It is possible that the familiarity of these old items elicited an ERP effect sufficiently large to obscure any further ERP modulation due to the familiarity of pairs containing two old items.

The only ERP effect observed specifically for Inter pairs in the present study was a negativity associated with Inter FAs in comparison to CRs during the 900-1400 ms time region. Statistical analyses did not show significant interactions between this effect and scalp region. However, visual inspection suggests that this effect was larger over central/posterior scalp regions than anterior scalp region. A similar late negativity effect associated with old items has been reported in several studies that employed memory tests requiring more than simple old/new recognition such as associative recognition or source memory test (e.g., Donaldson & Rugg, 1998; Wilding & Rugg, 1996). It has been suggested that this effect might reflect response-related rather than mnemonic factors, as its magnitude was correlated with response times (Wilding & Rugg, 1997b). Consistent with this view, Inter FA trials were associated with longer RTs than CRs.

6.4 Concluding Remarks

In conclusion, it has been demonstrated that the mechanisms underlying source judgement errors for confusable and non-confusable source-item pairing discriminations are different. When items are associated with confusable sources, partial information derived from gist memories may be recollected and utilised in subsequent source judgments, resulting in recollection-based errors. By contrast, when test items are paired with sources belonging to distinct gist representations, little episodic information is recollected, and errors are through alternative, non-recollective mechanisms.

Chapter 7. The Necessary Conditions for Gist Memory to Modulate Recollection-Based Source Judgement Errors: Experiments Three and Four

7.1 Introduction

It was shown in Experiment 2 that the involvement of recollection in source judgement errors is modulated by the partial information derived from the gist memory formed during encoding. Recollection-based errors, as indexed by the left parietal ERP old/new effect, were observed for Intra pairs that corresponded to the gist memories for study pairs sharing similar source-item relations, but were not observed for Inter pairs that contained initial and second words belonging to different gist memories. An interesting and important question that followed was in what way the gist memories of study lists are formed, and what are the necessary conditions for the partial information derived from the gist to induce recollection-based source judgement errors?

7.2 Experiment Three

Examining the formation of the study lists employed in Experiment 2, the recollection-based source judgement errors for Intra pairs might have resulted from three characteristics of the study pairs used to generate Intra pairs: (1) the semantic relation between the initial words, (2) the semantic relation between the second words, and (3) the spatial/temporal proximity shared by the study pairs. These three aspects of characteristics were not shared by study pairs that were re-paired to generate Inter pairs. It was argued in Experiments 1 and 2 that the semantic relations between the initial words and between the second words of the study pairs encouraged the formation of gist memory, from which recollection of partial information was elicited in response to Intra pairs. However, it was not clear whether the semantic relation between the initial words and that between the second words played the same or different roles in the formation of gist memory. Nor was it clear whether both were required to modulate the involvement of recollection in source judgement errors. Additionally, Intra pairs were generated by re-pairing study pairs belonging to the same list, which were presented concurrently at study. The spatial/temporal proximity shared by the study pairs alone might have been a sufficient condition for Intra pairs to elicit false recollection whether or not gist memories were formed for study pairs. It was not clear whether such spatial/temporal proximity between the study pairs was a necessary condition for the formation of gist memory from which false recollection was derived.

Experiment 3 aimed to disentangle the influences of these three factors on the formation of gist memory, and investigate how they interact to modulate the involvement of recollection in source judgement errors. This goal was achieved by manipulating the semantic relations between the constituent members of different study pairs and the spatial/temporal proximity shared by these study pairs to generate different types of rearranged test pairs. How the aforementioned three factors interact to influence the formation of gist memory was evaluated by examining the false alarm rates to the various kinds of rearranged pairs. The involvement of recollection in source judgement errors was examined with the Remember/Know procedure.

7.2.1 Method

7.2.1.1 Subjects

Two groups of 18 subjects, resulting in a total of 36 subjects, participated in this experiment. Each subject was paid for £6. Subjects were alternately allocated to either the 'related' or the 'unrelated' condition (for details of these two conditions see the following section). The 18 subjects of the 'related' group consisted of 9 males and 9 females, as did the 18 subjects of the 'unrelated' group.

7.2.1.2 Overview of the Experiment

Each subject engaged in four study-test cycles, with four study lists and one test list in each cycle. The constructions of the study and test lists are illustrated in figures 7.1 to 7.3. The semantic relation between the initial words of study pairs and the spatial/temporal proximity shared by the study pairs were manipulated as two within-subjects factors. As can be seen from figure 7.1, two pairs of associated words served as the initial words of the study pairs in each list. For instance, the initial words of study pairs in list 1 were 'kid' and 'parent', which are associated words, as well as 'pearl' and 'jewel', which are also associated words. With this characteristic, the initial words of two same-list study pairs that were re-paired to generate 'intra-list' rearranged pairs could be either semantically associated (e.g., kid and parent) or unassociated (e.g., kid and jewel).

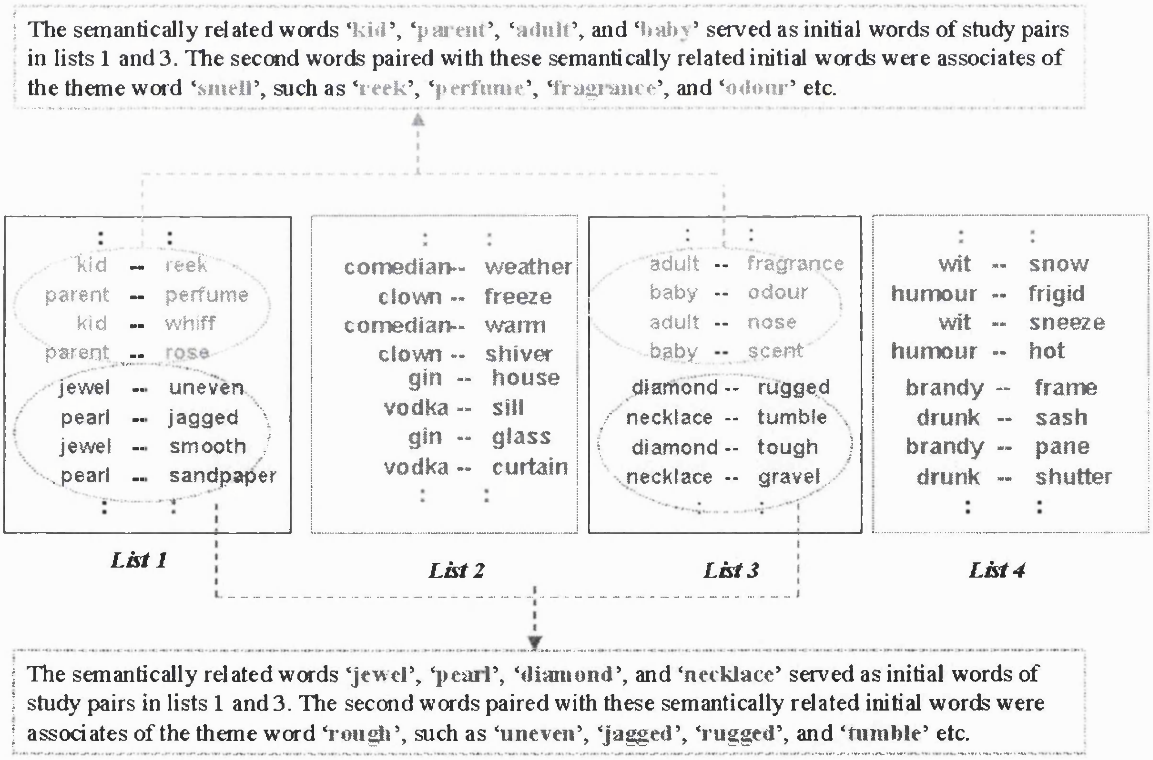

Figure 7.1. Illustration of the formation of four study lists in one study-test block in the 'related' condition of Experiment 3. Note that study lists 1 and 3 are yoked in the sense that there were semantic relations between the constituent members of the study pairs belonging to these two lists, and so were lists 2 and 4.

The semantic relations between the initial words of study pairs belonging to different lists were also manipulated. The two pairs of initial words in the first study list were each semantically associated with one of the two pairs of initial words in the third study list (e.g., 'kid' and 'parent' in list 1 are associated with 'adult' and 'baby' in list 3; 'pearl' and 'jewel' in list 1 are associated with 'diamond' and 'necklace' in list 3), and so were the initial words of the second and fourth study lists (e.g., 'comedian' and 'clown' in list 2 are semantically associated with 'wit' and 'humour' in list 4). With this characteristic, the initial words of two different-list study pairs that were re-paired to generate 'inter-list' rearranged pairs could also be either semantically associated (e.g., kid and adult) or unassociated (e.g., kid and diamond).

The semantic relation between the second words of study pairs, whose initial words were semantically associated with each other, was manipulated as a between-subjects factor across the 'related' and 'unrelated' conditions. In the 'related' condition, the second words of study pairs sharing associated initial words were semantically related with each other (see figure 7.1). Take study lists 1 and 3 in figure 7.1 as an example. For study pairs whose initial words were 'kids', 'parent', 'adult', and 'baby', their second words were associates of the theme word 'smell', such as 'reek', 'perfume', 'fragrance', 'nose' and so on. For study pairs whose initial words were 'jewel', 'pearl', 'necklace', and 'diamond', their second words were associates of the theme word 'rough', such as 'rugged', 'uneven', 'jagged', 'tumble' and so on. In the 'unrelated' condition, by contrast, there was no such semantic relation between the second words of word pairs whose initial words were associated (see figure 7.2).

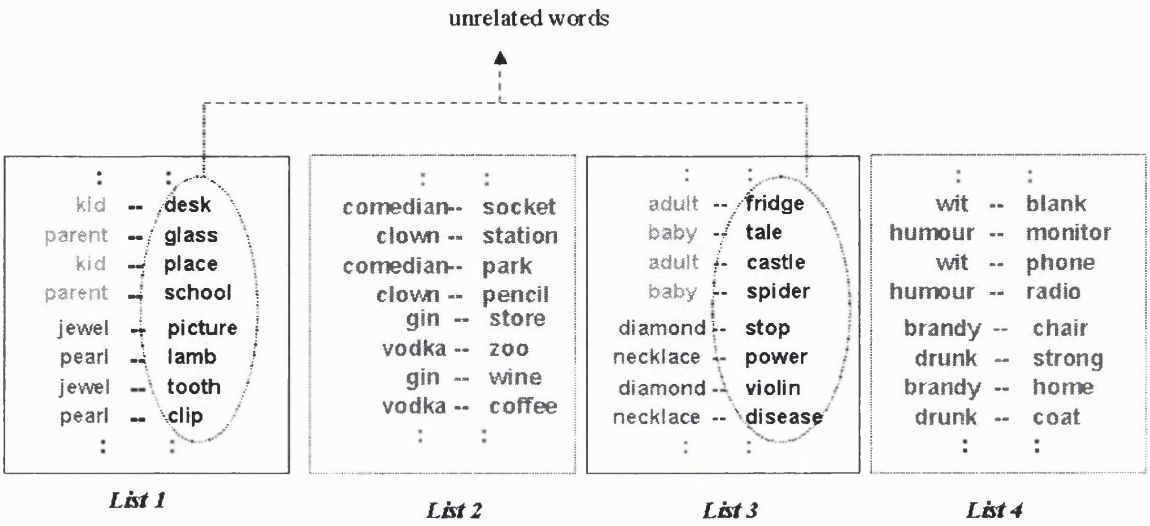

Figure 7.2. Illustration of the formation of four study lists in one study-test block in the 'unrelated' condition of Experiment 3. Note that the manipulation on the semantic relation between the initial words of the study pairs was the same as that in the 'related' condition. However, the second words of study pairs in the 'unrelated' condition were unrelated words.

At test, subjects were presented with Old pairs, Old-New pairs and four types of rearranged pairs (see figure 7.3 for illustration). Old pairs were word pairs that had been presented at study in the same pairing. Old-New pairs were constructed by pairing studied initial words with new words that were not presented at study and were not related to any studied initial words or second words. The four types of rearranged pairs were 'Associated Intra pairs', 'Unassociated Intra pairs', 'Associated Inter pairs', and 'Unassociated Inter pairs', which denoted the method the rearranged items were generated. 'Intra' and 'Inter' pairs, either with the label of 'Associated' or 'Unassociated', were rearranged items whose initial words had been exchanged by re-pairing word pairs originally studied on the same list or on two different lists respectively. 'Associated' and 'Unassociated' pairs, either with the label of 'Intra' or 'Inter', were generated by re-pairing two study pairs whose initial words were associated and unassociated respectively. Hence, these rearranged pairs were the four combinations of two variables: the spatial-temporal proximity (intra vs. inter) of the study pairs and the semantic association (associated vs. unassociated) of the initial words of the study pairs, from which rearranged pairs were generated.

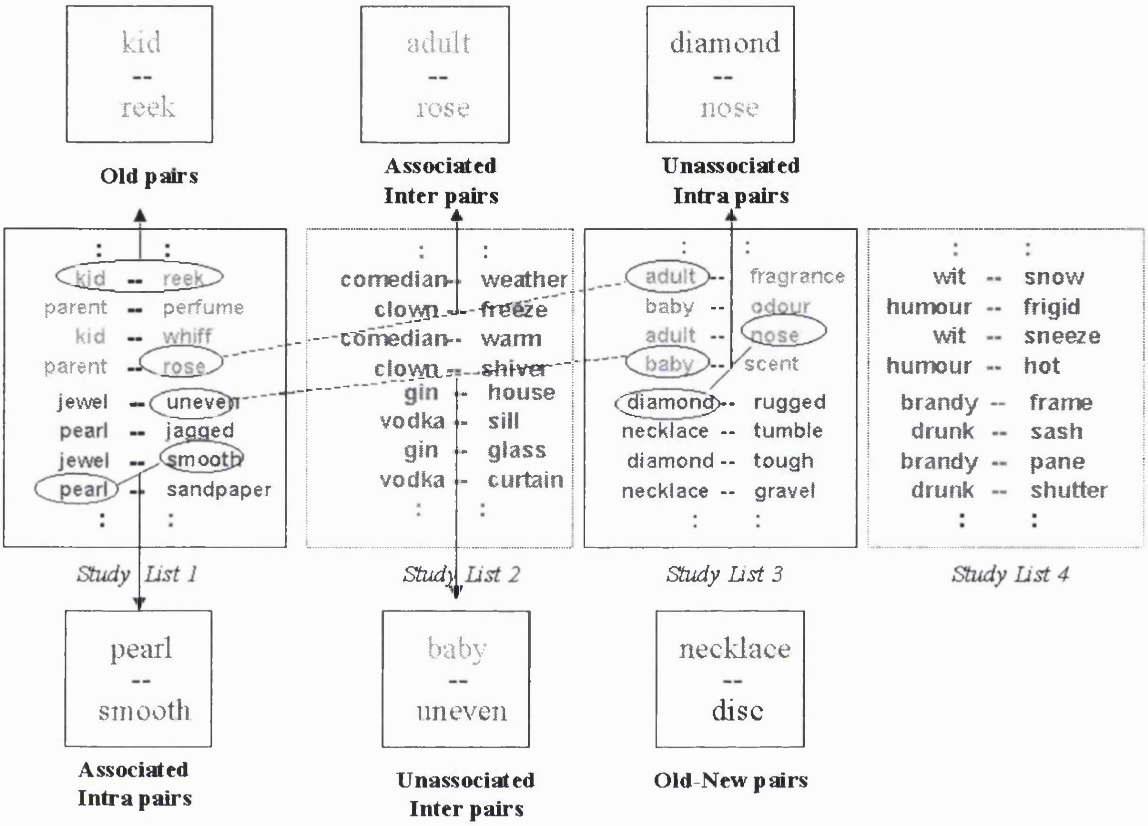

Figure 7.3. Illustration of the formation of six types of test pairs from two yoked study lists (in this case lists 1 and 3) in the 'related' condition of Experiment 3. Note that these six types of test pairs were also generated in the same way from the other two yoked study lists (i.e., lists 2 and 4). Also note that the test pairs in the 'unrelated' condition were generated in the same way as shown here, except that the second words of study pairs in the 'unrelated' condition were not semantically related with each other.

7.2.1.3 Stimuli

Study lists for the 'related' group. Sixteen sets of words were assigned to four study-test cycles to generate four lists of sixteen word pairs for each study phase. Each set comprised one group of four associated words, which served as the initial items of study pairs, and another group of sixteen semantically related words, which served as the second items of study pairs. The associated word groups that served as initial items were selected from the word lists developed by McEvoy, Nelson, and Komatsu (1999), whereas the semantically related words that served as second items were selected from the word lists developed by Stadler, Roediger, and McDermott (1999). Each of the four associated words was paired with four of the related words to construct sixteen study pairs. These sixteen study pairs were assigned to the two odd-numbered lists (the first and third lists) with eight pairs in each list. It was arranged that the word pairs sharing the same initial words were always assigned to the same list. These eight word pairs constituted half of the study pairs of each study list. The other eight pairs of each of these two lists were generated by the same method with another word set assigned to the same study-test cycle. Study pairs of the even-numbered lists (the second and fourth) were generated in the same way with the other two word sets assigned to the same study-test cycle. Within each study-test cycle, the first and the third lists were 'yoked' in the sense that the initial words of these two lists were semantically associated. The second and fourth lists were also yoked for the same reason. The allocation of the word sets to the study-test cycles was counterbalanced across subjects, so was the presentation order of the four study lists in each cycle. In each study list, four study pairs that had different initial words were assigned as the first and the last two items and served as fillers, whereas the presentation order of the other twelve word pairs was randomly assigned for each subject.

Study lists for the 'unrelated' group. The study lists in the 'unrelated' condition were generated in the same way as those in the 'related' condition, with the exception that the sixteen groups of semantically related words that served as second items of study pairs were replaced by groups of words that were not strongly related with each other. The unrelated words were selected from the Francis and Kucera corpus (1982), and their mean frequency was matched with that of the related words.

Test list. There was one test list in each study-test cycle, containing sixty-eight word pairs. Four pairs were fillers while the remaining pairs belonged to one of six categories (see figure 7.3 for illustration). (1) From each study list, four pairs that had different initial words were assigned as 'Old' pairs and maintained their studying pairings. (2) Two pairs from each list whose initial words were semantically associated were rearranged to form 'Associated Intra' pairs. (3) Two pairs from each list whose initial words were not semantically associated were rearranged to form 'Unassociated Intra' pairs. (4) Two pairs from each list were rearranged with two other pairs from the yoked list (i.e. lists one and three, lists two and four). These rearranged pairs were 'Associated Inter' pairs as the initial words of the two study pairs to be exchanged were semantically associated. (5) Two pairs from each list were rearranged with two other pairs from the yoked list. These rearranged pairs were 'Unassociated Inter' pairs as the initial words of the two study pairs to be exchanged were not semantically associated. (6) The sixteen initial words employed on the four study lists were each paired with one new word each to generate sixteen 'Old-New' pairs. The new words were selected from the Francis and Kucera corpus (1982), and their mean frequency was matched with that of the old words. The assignment of the study pairs to these different types of test pairs was counterbalanced across subjects.

7.2.1.4 Procedure

The procedure employed in this experiment, including the instruction for the Remember/Know judgement, was the same as the procedure of Experiment 1 described in Chapter 6.

7.2.2 Results

7.2.2.1 Old/New Recognition

Table 7.1 displays the proportion of 'Old' and 'New' responses to the six classes of test item, together with their associated response times. Values listed in this table were based on data from all subjects across 'related' and 'unrelated' groups. Performances of old/new recognition for subjects of these two groups are listed separately in table 7.2.

A priori tests on the data across 'related' and 'unrelated' groups revealed that the hit rate to Old pairs was significantly higher than the false alarm rates for Associated Intra pairs

(t_{35}=5.05, p<.001) and Associated Inter pairs (t_{35}=6.82, p<.001). In addition, Associated Intra pairs were more likely to be identified as 'old' than Associated Inter pairs (t_{35}=3.12, p<.01) and Unassociated Intra pairs (t_{35}=4.64, p<.001). There were also more 'Old' responses to Associated Inter pairs than to Unassociated Inter pairs (t_{35}=2.32, p<.05). The false alarm rates for Unassociated Inter pairs was higher than that for Old-New pairs (t_{35}=9.21, p<.001). Thus, Associated Intra pairs elicited the highest false alarm rate, followed by Associated Inter pairs, and then Unassociated Intra and Unassociated Inter pairs.

Table 7.1. Mean proportion of responses (SD) and mean reaction times (SD) for each response category of all subjects across the 'related' and 'unrelated' groups in Experiment 3.

Stimuli Type	Response Category	Proportion (SD)	RT(SD)
Old Pair	Hits	.57 (.13)	1370 (292)
	Miss		1384 (324)
Associated Intra Pair	False alarm	.47 (.16)	1415 (331)
	Correct rejection		1391 (324)
Unassociated Intra Pair	False alarm	.36 (.19)	1449 (313)
	Correct rejection		1389 (341)
Associated Inter Pair	False alarm	.42 (.16)	1421 (325)
	Correct rejection		1399 (339)
Unassociated Inter Pair	False alarm	.36 (.21)	1418 (306)
	Correct rejection		1387 (350)
Old-New Pair	False alarm	.15 (.13)	1447 (339)
	Correct rejection		1289 (294)

To evaluate how the semantic relation between the second words of study pairs modulated the old/new recognition performance, a mixed-design ANOVA was conducted with the different types of stimuli as the within-subjects factor, and the 'related' vs. 'unrelated' group as the between-subjects factor. This between-subjects factor is hereafter denoted as 'Second-word Relation'. The proportion of old responses to Old-New pairs was higher in the 'unrelated' group than in the 'related' group (t_{34}=2.6, p<.05), suggesting that response bias in these two between-subjects conditions was different. To

Table 7.2. Mean proportion of responses (SD) and mean reaction times (SD) for each response category of subjects in the 'related' and 'unrelated' groups of Experiment 3.

		Related Group		**Unrelated Group**	
Stimuli Type	**Response Category**	**Proportion (SD)**	**RT(SD)**	**Proportion (SD)**	**RT(SD)**
Old Pair	Hits	.58 (.15)	1400 (327)	.57 (.10)	1340 (259)
	Miss		1391 (362)		1376 (292)
Associated Intra Pair	False alarm	.46 (.16)	1432 (363)	.49 (.17)	1398 (306)
	Correct rejection		1381 (371)		1401 (278)
Unassociated Intra Pair	False alarm	.34 (.21)	1475 (340)	.38 (.17)	1424 (293)
	Correct rejection		1372 (376)		1405 (313)
Associated Inter Pair	False alarm	.42 (.18)	1415 (344)	.41 (.15)	1429 (315)
	Correct rejection		1399 (364)		1400 (322)
Unassociated Inter Pair	False alarm	.34 (.22)	1450 (339)	.39 (.21)	1386 (275)
	Correct rejection		1356 (382)		1417 (324)
Old-New Pair	False alarm	.10 (.11)	1492 (388)	.20 (.13)	1401 (286)
	Correct rejection		1259 (307)		1318 (287)

incorporate the different response bias into account, the ANOVA was conducted with the difference scores between the proportion of old responses to Old-New pairs and those to the other five types of test pairs as the dependent variable (see figure 7.4). The ANOVA showed that the main effect of stimulus type was significant [$F(2.65,89.95)=25.71$, $p<.001$], reflecting the different numbers of old responses to these five classes of test items. The main effect of 'Second-word Relation' was significant [$F(1,34)=5.57$, $p<.05$], reflecting the fact that more 'Old' responses were made to test pairs in the 'related' group than in the 'unrelated' group when the false alarm rate to Old-New pairs was subtracted from the hit rate and the false alarm rates to the rearranged pairs. However, the interaction between stimulus type and Second-word Relation was not significant ($p=.54$), suggesting that whether or not the second words of study pairs used to generate rearranged pairs was semantically related did not have different effects on the hit rate to Old pairs and the false alarm rates to the rearranged pairs.

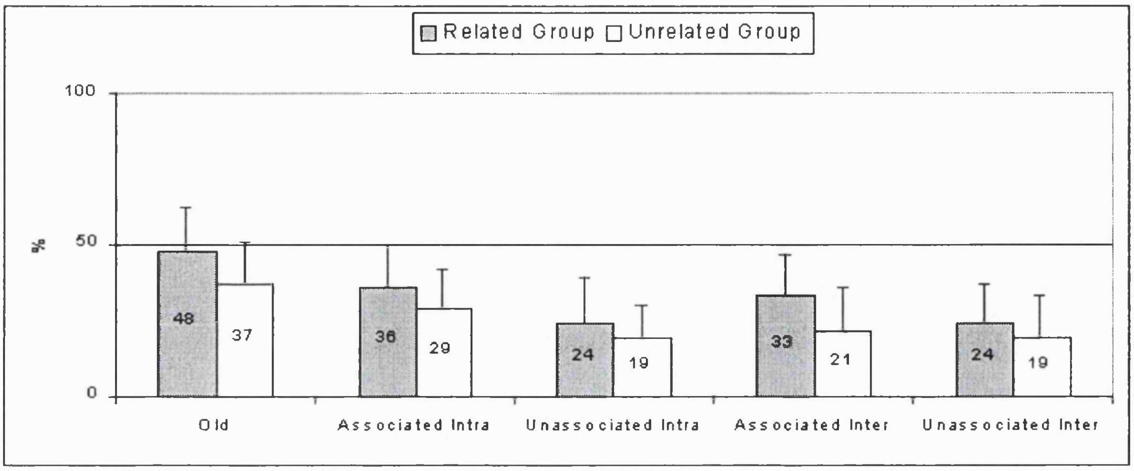

Figure 7.4. The difference scores between the proportion of old responses to Old-New pairs and those to the other five types of test pairs in Experiment 3.

Another set of analyses was conducted to investigate how the false alarm rates for the four types of rearranged pairs were modulated by the semantic association between the initial words and the spatial/temporal proximity shared by the study pairs used to generate these rearranged pairs. The four types of rearranged pairs were viewed as the combinations of two within-subjects factors: whether or not the initial words of study pairs used to generate the rearranged pairs were semantically associated (i.e., Associated pairs vs. Unassociated pairs), and whether or not these study pairs belonged to the same list (i.e., Intra pairs vs. Inter pairs). These two factors are hereafter denoted as 'Association' and 'Proximity' respectively. The ANOVA showed that the main effect of Association was significant [$F(1,34)=15.52$, $p<.001$], whereas the main effect of Proximity approached significance [$F(1,34)=3.68$, $p=.06$]. Neither of these two within-subjects factors interacted with the between-subjects factor 'Second-word Relation'. However, the interaction between Association and Proximity was significant [$F(1,34)=5.52$, $p<.05$]. As can be seen from Figure 7.5, the follow-up analyses showed that the simple main effect of Proximity was significant [$F(1,34)=9.78$, $p<.01$] when the initial words of the study pairs used to generate rearranged pairs were semantically associated, but was not significant ($F<1$) when these initial words were not semantically associated.

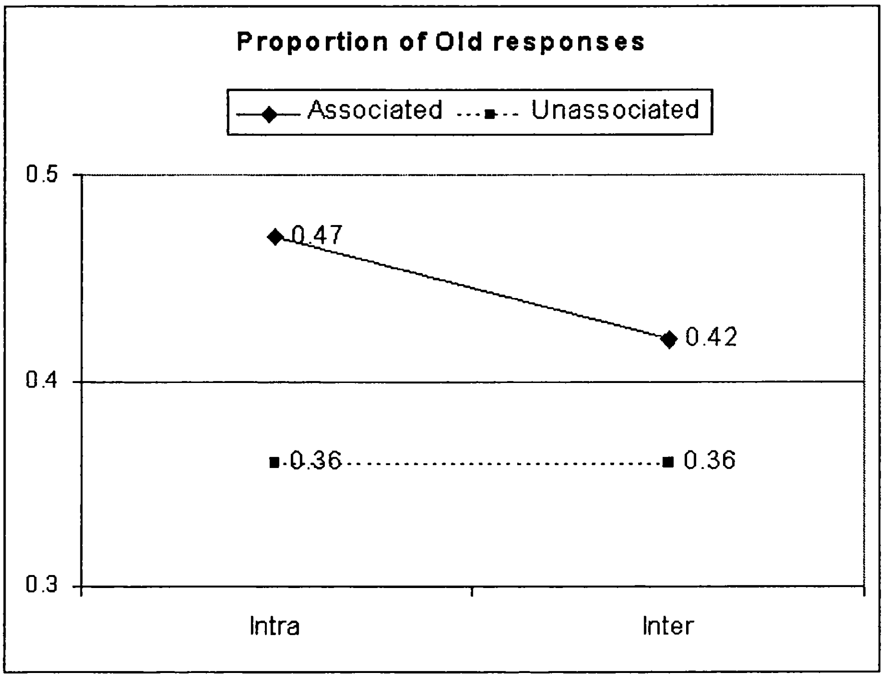

Figure 7.5. Illustration of the interaction effect between the factors of 'Association' and 'Proximity' on the proportion of old responses to the four types of rearranged pairs in Experiment 3.

A repeated measures ANOVA was also conducted on the response time data associated with old/new responses to the six types of test pairs, with Second-word Relation employed as a between-subjects factor. The main effect of response type (old vs. new) was not significant (p=.09). The main effect of stimulus type was significant [F(3.85, 127.2)=5.33, p=.001], and so was its interaction with response type [F(4.25, 140.13)=5.2, p<.01]. Neither the main effect of Second-word Relation, nor its interaction with stimulus type or response type was significant. A separate one-way ANOVA was conducted on the response times associated with 'Old' responses to the six types of stimuli, and exhibited a significant main effect [F(3.9, 132.66)=2.38, p=.05]. Newman-Keuls post hoc tests revealed that the response times associate with hit trials were significantly shorter than those associated with false alarms to the other five types of test pairs.

7.2.2.2 Remember/Know Judgement

Table 7.3 displays the proportion of 'Remember' response, the raw and corrected proportion of 'Know' responses to the six classes of test item, together with their associated response times. Values listed in this table were based on data from all subjects across 'related' and 'unrelated' groups. Performances of Remember/Know judgements for subjects of these two groups are separately listed in table 7.4.

Similar to Experiment 1, two sets of analyses were conducted on the data of Remember/Know judgements to the six types of test stimuli. In the first set, the raw proportion of 'R' responses and corrected proportion of 'K' responses were employed as dependent variables. In the second set of analyses, the ratio between the proportion of 'R' response and the proportion of 'Old' response ('Remember/Old' ratio) were employed as the dependent variable.

Raw Proportion of 'Remember' Response. A priori tests on the data across 'related' and 'unrelated' groups revealed that the raw proportion of 'R' responses was significantly higher for Old pairs than for Associated Intra pairs (t_{35}=3.68, p=.001) and Associated Inter pairs (t_{35}=6.63, p<.001). In addition, Associated Intra pairs attracted more 'R' responses than Associated Inter pairs (t_{35}=4.17, p<.001) and Unassociated Intra pairs (t_{35}=4.92, p<.001). There were also more 'R' responses to Associated Inter pairs than to Unassociated Inter pairs (t_{35}=2.07, p<.05). The number of 'R' responses for Unassociated Inter pairs was larger than that for Old-New pairs (t_{35} = 5.08, p<.001). Thus, Associated Intra pairs elicited the largest number of 'R' responses, followed by Associated Inter pairs, and then Unassociated Intra and Unassociated Inter pairs.

Raw Proportion of 'Remember' Response. A priori tests on the data across 'related' and 'unrelated' groups revealed that the raw proportion of 'R' responses was significantly higher for Old pairs than for Associated Intra pairs (t_{35}=3.68, p=.001) and Associated Inter pairs (t_{35} = 6.63, p<.001). In addition, Associated Intra pairs attracted more 'R'

Table 7.3. Mean proportion of Remember responses (SD), mean proportion of Know responses (SD), mean corrected proportion of Know responses (SD), mean ratio of Remember/Old (SD), and mean reaction times (SD) to each stimulus type of subjects across the 'related' and 'unrelated groups of Experiment 3.

Stimuli Type	R/K Response	Proportion (SD)	R/Old ratio (SD)	RT(ms)
Old Pair	*Remember*	.31 (.15)	.54 (.21)	1345 (294)
	Know (raw)	.26 (.11)		1413 (320)
	Know (corrected)	.37 (.15)		
Associated Intra Pair	*Remember*	.23 (.14)	.48 (.25)	1412 (369)
	Know (raw)	.24 (.11)		1443 (329)
	Know (corrected)	.32 (.15)		
Unassociated Intra Pair	*Remember*	.14 (.12)	.35 (.30)	1394 (332)
	Know (raw)	.22 (.14)		1385 (304)
	Know (corrected)	.26 (.17)		
Associated Inter Pair	*Remember*	.18 (.13)	.41 (.27)	1400 (349)
	Know (raw)	.24 (.12)		1410 (322)
	Know (corrected)	.29 (.16)		
Unassociated Inter Pair	*Remember*	.14 (.15)	.35 (.32)	1378 (304)
	Know (raw)	.22 (.14)		1395 (309)
	Know (corrected)	.27 (.18)		
Old-New Pair	*Remember*	.05 (.08)	.27 (.33)	1436 (388)
	Know (raw)	.10 (.08)		1452 (335)
	Know (corrected)	.11 (.09)		

Table 7.4. Mean proportion of Remember responses (SD), mean proportion of Know responses (SD), mean corrected proportion of Know responses (SD), mean ratio of Remember/Old (SD), and mean reaction times (SD) to each stimulus type of subjects in the 'related' and 'unrelated groups of Experiment 3.

		Related Group			Unrelated Group		
Stimuli Type	R/K Response	Proportion	R/Old ratio	RT(ms)	Proportion	R/Old ratio	RT(ms)
Old Pair	*Remember*	.28 (.14)	.48 (.18)	1369 (345)	.34 (.16)	.59 (.23)	1321 (242)
	Know (raw)	.29 (.09)		1427 (337)	.22 (.13)		1399 (311)
	Know (corrected)	.42 (.14)			.32 (.15)		
Associated Intra Pair	*Remember*	.21 (.17)	.43 (.30)	1460 (435)	.25 (.11)	.52 (.20)	1369 (306)
	Know (raw)	.25 (.12)		1438 (333	.24 (.11)		1448 (335)
	Know (corrected)	.31 (.14)			.33 (.17)		
Unassociated Intra Pair	*Remember*	.12 (.11)	.32 (.35)	1414 (389)	.16 (.12)	.38 (.26)	1379 (295)
	Know (raw)	.22 (.16)		1355 (275)	.23 (.13)		1411 (331)
	Know (corrected)	.26 (.19)			.27 (.15)		
Associated Inter Pair	*Remember*	.18 (.15)	.36 (.26)	1376 (379)	.19 (.12)	.46 (.28)	1419 (333)
	Know (raw)	.25 (.11)		1393 (326)	.22 (.14)		1428 (327)
	Know (corrected)	.31 (.15)			.27 (.17)		
Unassociated Inter Pair	*Remember*	.09 (.11)	.26 (.28)	1479 (363)	.18 (.18)	.45 (.33)	1297 (228)
	Know (raw)	.24 (.16)		1385 (333)	.20 (.11)		1406 (291)
	Know (corrected)	.28 (.21)			.26 (.16)		
Old-New Pair	*Remember*	.03 (.06)	.26 (.36)	1399 (462)	.07 (.09)	.27 (.30)	1467 (336)
	Know (raw)	.07 (.07)		1511 (373)	.13 (.08)		1397 (297)
	Know (corrected)	.07 (.08)			.14 (.08)		

responses than Associated Inter pairs (t_{35}=4.17, p<.001) and Unassociated Intra pairs (t_{35}=4.92, p<.001). There were also more 'R' responses to Associated Inter pairs than to Unassociated Inter pairs (t_{35}=2.07, p<.05). The number of 'R' responses for Unassociated Inter pairs was larger than that for Old-New pairs (t_{35}=5.08, p<.001). Thus, Associated Intra pairs elicited the largest number of 'R' responses, followed by Associated Inter pairs, and then Unassociated Intra and Unassociated Inter pairs.

The raw proportion of 'R' responses to Old-New pairs was not different between the 'related' and 'unrelated' groups (p=.18), suggesting that the response bias in making 'R' judgements was not different across these two between-subjects conditions, and hence it was not necessary to introduce a correction for base rates. With the raw proportion of 'R' responses as the dependent variable, a mixed ANOVA was conducted with stimulus type as the within-subjects factor, and Second-word Relation (i.e., 'related' group vs. 'unrelated' group) as the between-subjects factor. The ANOVA showed that the main effect of stimulus type was significant [F(3.02,102.5)=38.45, p<.001], reflecting the different numbers of 'R' responses to the six classes of test items. The main effect of Second-word Relation and its interaction with stimulus type were not significant (p=.19 and p=.51 respectively).

In the analysis that focused on the raw proportion of 'R' responses to the four types of rearranged pairs, the main effects of Association (i.e. Associated vs. Unassociated rearranged pairs) and Proximity (i.e. Intra vs. Inter rearranged pairs) were significant [F(1,34)=16.5, p<.001 and F(1,34)=7.18, p=.01 respectively], so was the interaction between these two within-subjects factors [F(1,34)=6.35, p<.001]. Follow-up analyses showed that, as can be seen in figure 7.6, the simple main effect of Proximity was significant [F(1,34)=17.27, p<.001] when the initial words of the study pairs used to generate the rearranged pairs were semantically associated, but was not significant when these initial words were not semantically associated (F<1). Neither of these within-subjects effects interacted with the between-subjects factor Second-word Relation.

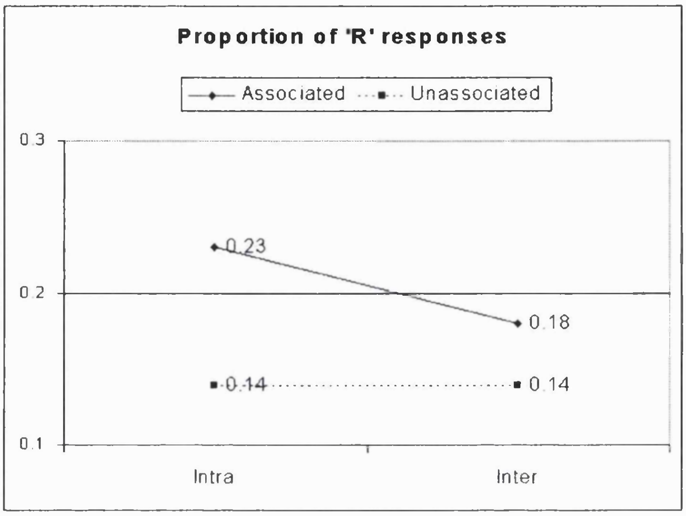

Figure 7.6. Illustration of the interaction effect between the factors of 'Association' and 'Proximity' on the proportion of 'R' responses to the four types of rearranged pairs in Experiment 3.

Corrected Proportion of 'Know' Response. A priori tests on data across 'related' and 'unrelated' groups revealed that the corrected proportion of 'K' responses was significantly higher for Old pairs than for Associated Intra pairs (t_{35}=2.3, p<.05) and Associated Inter pairs (t_{35}=2.96, p<.01). In addition, Associated Intra pairs attracted more 'K' responses than Unassociated Intra pairs (t_{35}=2.65, p<.05). However, there was no significant difference between Associated Intra pairs and Associated Inter pairs (p=.17). The proportion of 'K' responses for Unassociated Inter pairs was larger than that for Old-New pairs (t_{35}=7.3, p<.001). Thus Old pairs attracted the highest proportion of 'K' responses, followed by Associated Intra and Associated Inter pairs, which were not different from each other.

The Old-New pairs was associated with a higher proportion of 'K' responses in the 'unrelated' condition then in the 'related' condition (t_{34}=2.68, p=.01). This different response bias was incorporated into account by employing the difference scores between the proportion of 'K' responses to Old-New pairs and those to the other five types of test pairs (see figure 7.7) as the dependent variable. Independent variables employed in this mixed-design ANOVA were the between-subjects factor Second-word Relation, and the within-subjects factor stimulus type. The ANOVA showed that the main effect of stimulus type was significant [$F(3.32,112.88)=7.33$, $p<.001$], reflecting the different proportions of 'K' responses to the five kinds of test pairs. The main effect of Second-word Relation was significant [$F(1,34)=10.52$, $p<.01$], indicating that a larger number of 'K' responses were elicited when there was a semantic relation between the second words of the study pairs than when there was not such semantic relation. The interaction between stimulus type and Second-word Relation was, however, not significant ($p=.10$).

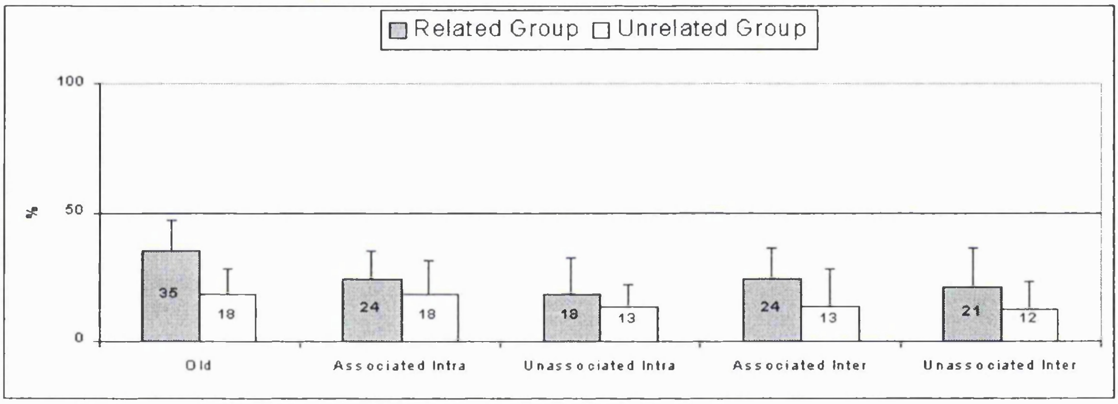

Figure 7.7. The difference scores between the corrected proportion of 'Know' responses to Old-New pairs and those to the other five types of test pairs in Experiment 3.

In the analysis that focused on the corrected proportion of 'K' responses to the four types of rearranged pairs, the main effect of Association (i.e. Associated vs. Unassociated rearranged pairs) was significant [$F(1,34)=3.97$, $p=.05$]. The main effect of Proximity (i.e. Intra vs. Inter rearranged pairs) was not significant, and nor was its interaction with Association ($p=.45$ & $p=.14$ respectively).

Remember/Old Ratio. A priori tests on data across 'related' and 'unrelated' groups showed that the difference between the Remember/Old Ratios for Old pairs and Associated Intra pairs approached significance ($t_{35}=1.92$, $p=.06$). Associated Intra pairs were associated with a higher Remember/Old ratio than Unassociated Intra pairs and

Associated Inter pairs (t_{35}=3.78, p<.001 and t_{35}=2.85, p<.01 respectively). Thus a larger proportion of Old responses to Associated Intra pairs were assigned a 'Remember' response than in the cases of Associated Inter and Unassociated Intra items. The mixed ANOVA that addressed the four types of rearranged pairs showed that the main effect of Association (i.e., Associated vs. Unassociated rearranged pairs) was significant [$F(1,34)=9.72$, $p<.01$]. The main effect of Proximity (i.e., Intra vs. Inter rearranged pairs) was not significant (p=.07), nor was its interaction with Association (p=.08). The between-subjects factor, Second-word Relation, was not significant (p=.22).

7.2.3 Discussion

This experiment sought to examine how recollection-based source judgement errors for rearranged pairs observed in Experiment 2 (i.e., false alarms to Intra pairs) were modulated by the semantic relations and the spatial/temporal proximity between the constituent members of study pairs from which the rearranged pairs were generated. The four types of rearranged pairs, generated by manipulating the semantic relations and the spatial/temporal proximity between the study pairs, attracted different numbers of false alarms and proportions of Remember responses. Before discussing the implications of the different false alarm rates for these four types of rearranged pairs, it is worth noting that the hit rate was significantly higher than the false alarm rate for Associated Intra pairs, and Unassociated Inter pairs attracted a higher false alarm rate than Old-New pairs. The finding that Old pairs were more likely than Associated Intra pairs to be identified as 'old' suggests that some information specific to studied pairs, and not available from the gist memory, was encoded and stored to support later retrieval. This notion is supported by the different responses times and proportions of 'R' responses associated with hit trials and false alarms to Associated Intra pairs. On the other hand, the higher false alarm rate for Unassociated Inter pairs than for Old-New pairs suggests that rearranged pairs could be incorrectly identified merely because of the repetition of their components, although the combination of the components was different at study and at test.

The four kinds of rearranged stimuli gave rise to different false alarm rates. The false alarm rates for Unassociated Intra and Unassociated Inter pairs did not differ, and were both significantly lower than the false alarm rates for Associated Intra and Associated Inter pairs. The false alarm rate for Unassociated Inter pairs can be viewed as the baseline for making false alarms to rearranged items in the absence of the contribution of partial information derived from gist memories. Therefore, the similar false alarm rates for Unassociated Intra and Unassociated Inter pairs suggest that the spatial/temporal proximity between the initial and second words of study pairs alone is not sufficient to modulate source judgement errors. By contrast, the higher false alarm rates for Associated Intra and Associated Inter pairs as opposed to Unassociated Inter pairs suggest that source judgement errors are modulated by the semantic association between the initial words to be discriminated. Presumably, the semantic association between the initial words encouraged the formation of a gist memory for study pairs whose initial words were associated. Partial information about the initial words, which were viewed as 'sources' in the current experiment, retrieved from these gist memories allowed the rejection of rearranged pairs that contained initial words incongruent with a gist memory. However, the same partial information biased subjects to accept Associated Intra and Associated Inter pairs, whose replaced initial words were congruent with the gist.

The different false alarm rates for Associated and Unassociated rearranged pairs suggest that the formation of the gist memories for study pairs relies primarily on the semantic association between the initial words. Nevertheless, the contribution of the semantic association between the initial words to the formation of gist memory is modulated by the spatial/temporal proximity shared by the study pairs, as shown by the higher false alarm rate for Associated Intra pairs than for Associated Inter pairs. Thus, the effect of the semantic association between the initial words on source judgement errors was amplified by the spatial/temporal proximity shared by the study pairs as opposed to when the study pairs, which were used to generate rearranged pairs, belonged to different lists. Another way to interpret the interaction between semantic association between initial words and spatial/temporal proximity between study pairs is that the former factor is the necessary condition for the formation of the gist memory. The formation of gist memory is modulated by the spatial/temporal proximity between the sources only when these sources are semantically associated.

In addition to the semantic association between the initial words and the spatial/temporal proximity shared by the study pairs, another issue addressed in this study was whether source judgement errors would be modulated by the semantic relation between the second words of study pairs used to generate rearranged pairs. Old-New pairs were more likely to be incorrectly identified as studied items in the 'unrelated' group as opposed to those in the 'related' group. This finding suggests that the semantic relation between the second words changed the baseline, or response bias, to make old responses. A possible reason for this change in baseline is that when the second words are associates of some specific theme words, the semantic relation can be utilised to exclude Old-New pairs, whose second words were distinctively different from the studied second words. By contrast, when there is no semantic relation involved in the studied second words, this advantage no longer exists and therefore the difficulty of rejecting Old-New pairs is increased. Nevertheless, the crucial finding is that the semantic relation between the second words did not modulate the effects of the semantic association between the initial words and the spatial/temporal proximity shared by the study pairs on source judgment errors. It is therefore suggested that the formation of the gist memories for study pairs mainly relies on the semantic association between the initial words of the study pairs.

The involvement of recollection in memory judgements was examined by evaluating the recollective experience, self-reported by subjects in the Remember/Know procedure, associated with the various kinds of test pairs. Old pairs attracted a larger number of 'R' responses than Associated Intra pairs, suggesting that at least some proportion of recognised studied items are identified on the basis of recollection that cannot be derived from the gist memory. On the other hand, there were more 'R' responses to Unassociated Inter pairs than to Old/New pairs, indicating that recollective experience can be elicited by rearranged items that do not correspond to the gist memory.

The issue of how the semantic association between the initial words and the spatial/temporal proximity shared by the study pairs modulate the involvement of recollection in source judgement errors was addressed by comparing the proportion of 'R' responses to the four types of rearranged pairs. Both the semantic association between the initial words and the spatial/temporal proximity shared by the study pairs had significant effects on the proportion of 'R' responses to rearranged pairs, suggesting that both factors played a role in eliciting recollective experiences. The interaction between these two factors reveals that neither the semantic association nor the spatial/temporal proximity alone was sufficient to modulate the occurrence of recollection-based errors. The finding that the proportion of 'R' responses to Associated Inter and Unassociated Inter pairs was not significantly different suggests that the semantic association between the initial words did not modulate recollection-based source judgement errors when the two initial words belonged to two separate study lists. On the other hand, the similar proportions of 'R' responses to Unassociated Intra and Unassociated Inter pairs shows that the spatial/temporal proximity between the study pairs alone cannot modulate the involvement of recollection in source judgement errors. Taken together, it appears that both semantic association between the initial words and the spatial/temporal proximity between the study pairs are necessary to modulate recollection-based source judgement errors.

The proportion of 'R' responses to the four types of rearranged pairs did not differ between the 'related' and 'unrelated' groups. This finding indicates that the semantic relation between the second words had no effects on modulating the recollective experience associated with source judgement errors. It was also found that the Second-word Relation (i.e., 'related' group vs. 'unrelated' group) factor did not interact with the semantic association between the initial words and the spatial/temporal proximity shared by the study pairs. Together with the finding that more 'K' responses were elicited in the 'related' than in the 'unrelated' group, this outcome implies that it is familiarity-based judgements that is modulated by the semantic relation between the second words.

In summary, the three characteristics of the study pairs (i.e., the semantic association between the initial words of study pairs, the semantic relation between the second words of study pairs, and the spatial/temporal proximity shared by the study pairs) contribute to the formation of gist memory with different weights. The semantic association between the initial words alone is sufficient to induce the formation of gist memory and bias subjects to incorrectly endorse rearranged pairs whose initial words belong to the same gist. The spatial/temporal proximity between the study pairs alone is not sufficient to induced gist-based source judgement errors. However, this factor amplifies the contribution of the semantic association between the initial words on the formation of gist memories. The semantic relation between the second words also contributes to the formation of gist memory. However, the contribution from the second words is independent from those from the initial words. Regarding the recollective experience, both the semantic relation between the initial words and the spatial/temporal proximity between the study pairs were required to modulate the involvement of recollection in source judgement errors for rearranged pairs generated from these study pairs. In contrast to the initial words' influence on recollection-based source judgement errors, the semantic relation between the second words only affects the involvement of familiarity, but not recollection, in source judgement errors.

7.3 Experiment Four

Experiment 3 demonstrated that the semantic association between sources (i.e., the initial words of the study pairs) has the major role in the formation of gist memories for study pairs. The current experiment further investigated the contribution of the semantic association between sources to the gist memory by examining the ERPs associated with false alarms to rearranged pairs whose original and replaced initial words were semantically associated or unassociated. Specifically, the aim was to examine how the ERP effects associated with gist-based source judgement errors, as manifested in the left parietal and right frontal effects observed in Experiment 2, would be modulated by the semantic association between the sources to be discriminated. The spatial/temporal proximity between the sources to be discriminated was kept constant, so that any observed ERP effects could be attributed to the semantic association between the sources without the confounding effect from the spatial/temporal proximity between the sources.

Study lists employed in the current experiment were constructed in a similar way as those employed in Experiment 3 (see figure 7.8). There were four different initial words in each list. Among these four initial words were two pairs of associated words. However, in contrast to the study lists employed in Experiment 3, the semantic association between the initial words of study pairs belonging to different study lists was not manipulated, such that initial words of different lists were always unassociated. At test, subjects were required to discriminate Old pairs from Old-New pairs and two kinds of rearranged pairs. Both types of rearranged pairs were generated by re-pairing word pairs originally studied on the same list. For one type of rearranged pairs, the Associated Intra pairs, their original and replaced initial words were semantically associated. For the other type of rearranged pairs, the Unassociated Intra pairs, there was no semantic association between their original and replaced initial words. With this arrangement, the spatial/temporal proximity and the semantic relation between the second words of the study pairs used to generate the two classes of rearranged pairs were kept constant. Associated Intra and Unassociated Intra pairs therefore differed only in that the former were generated by re-pairing study pairs whose initial words were semantically related, whereas the latter were generated by re-pairing study pairs whose initial words were unrelated. If indeed it is the semantic association between the initial words that plays the major role in eliciting recollection-based source judgement errors, different ERP effects should be observed for false alarms to Associated Intra and Unassociated Intra pairs. It was expected that false alarms to Associated Intra pairs, as with the Intra pairs in Experiment 2, would be associated with the left parietal old/new effect. On the other hand, if spatial/temporal proximity between the initial words alone is not sufficient to elicit recollection-based errors, no recollection should be involved in false alarms to Unassociated Intra pairs, and thus the left parietal effect should be absent for this class of memory error.

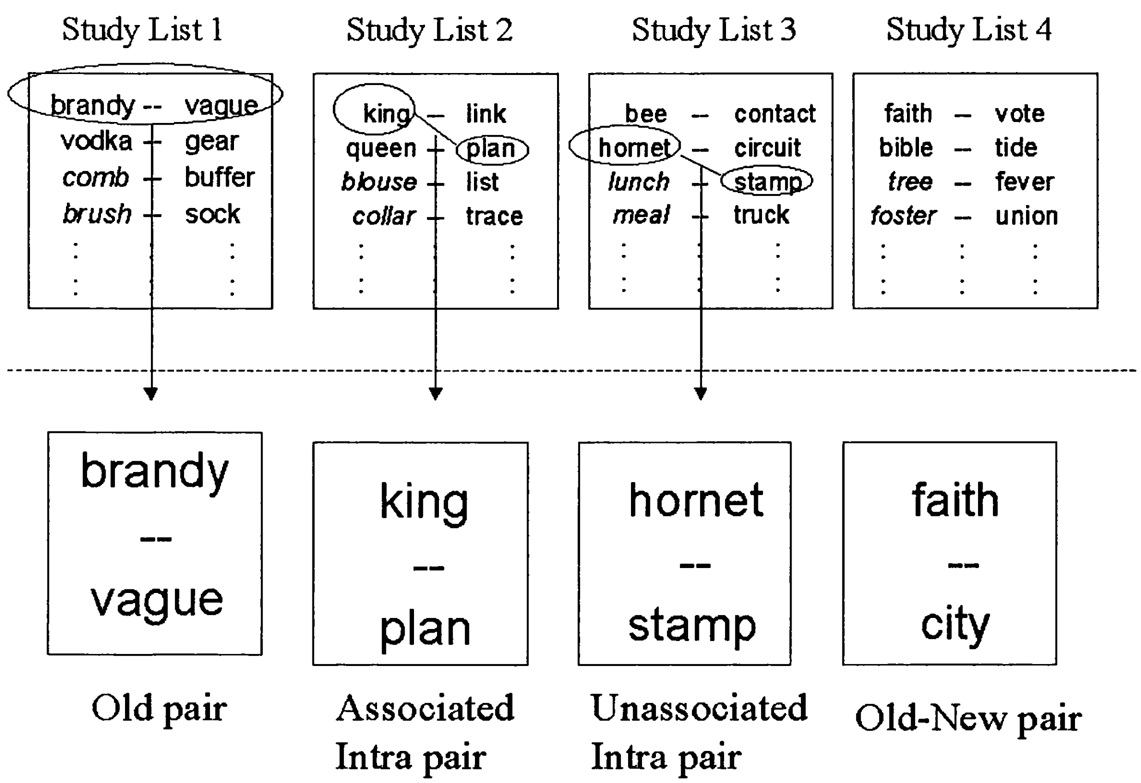

Figure 7.8. Illustration of the formation of four study lists and the four types of test pairs generated from these lists in Experiment 4.

The current experiment also indirectly examined the conclusion of Experiment 3 that the semantic relation between the second words does not affect the occurrence of recollection-based source judgement errors. In contrast to the study lists employed in Experiment 2, the second words of study pairs sharing associated initial words were not semantically related with each other. If the semantic relation between the second words affects only familiarity-based but not recollection-based source judgement errors, the recollection-related ERP effects associated with false alarms to Associated Intra pairs should be similar to those associated with Intra FAs in Experiment 2. However, different patterns of ERPs associated with false alarms to Associated Intra pairs and Intra pairs would be observed if the semantic relation between the second words has effects on recollection-based errors.

7.3.1 Method

7.3.1.1 Subjects

A total of 26 right-handed healthy volunteers participated in the experiment. Each subject was paid at the rate of £7.50 per hour. Data from 2 subjects were discarded due to equipment failure. Data from another 6 subjects were discarded because they did not contribute sufficient valid ERP trials. Among the remaining 18 subjects, 9 subjects were female.

7.3.1.2 Stimuli and Design

Words from three sources were used to generate the word pairs: (1) Forty associated word pairs chosen from the Birkbeck Word Association Norms (Moss & Older, 1996), see appendix 1. (2) Twenty unrelated word groups with 16 words in each group. These 320 words are selected from 16 related word lists developed by Stadler et al. (1999) and were used as second words in previous experiments. However, in the current experiment, words from all lists are pooled together and randomly assigned to 20 unrelated word groups, with the arrangement that words from the same original list are not assigned to the same group. (3) Eighty words selected from the Francis and Kucera corpus (1982), with their mean frequency matched with that of the twenty unrelated word groups.

Study list. There were 20 study lists with 16 pairs in each list. The study lists were created by dividing the 40 associated word pairs and the 20 unrelated word groups into 20 units, with 20 associated word pairs and one unrelated word group in each unit. Each unit was used to generate the 16 word pairs of one study list. Each word of the four associated word pairs was assigned to four pairs as their initial word, while each word of the unrelated word group was assigned to one study pair as their second word (see figure 7.8 for illustration). By this arrangement, every four of the 16 study pairs in one study list shared one initial word. The four initial words in each study list can be divided into two associated pairs. The second words of the study pairs belonging to the same list were selected from different related word lists developed by Stadler et al., and were not highly related with each other.

Test list. There was one test list in each study-test cycle. The construction of each test list was based on the 4 study lists presented in the study phase of the cycle. Each test list contained 66 test pairs. Two of these pairs were fillers, while the remaining 64 pairs belonged to one of four categories (see figure 7.8 for illustration). (1) From each of the four study lists, four study pairs with different initial words were assigned as 'Old' pairs and maintained their studying pairings (2) Four other pairs of each study list, whose initial words were different from each other, were presented at test with rearranged pairing. Each two of the four study pairs whose initial words were semantically associated exchanged their initial words to form 'Associated Intra' pairs. (3) Another four pairs of each study list, whose initial words were different from each other, were rearranged at to form 'Unassociated Intra' pairs. Each two of the four study pairs whose initial words were not semantically associated exchanged their initial words. (4) Four unstudied words were paired with the four first words of each study list to form 'Old-New' pairs. Across the whole experiment, there were 80 Old pairs, 80 Associated Intra pairs, 80 Unassociated Intra pairs, 80 Old-New pairs, and 10 fillers. The assignment of each study pair to the different types of test pair was counterbalanced across subjects.

7.3.1.3 Procedure

The procedure employed in this experiment was the same as the procedure of Experiment 2 described in Chapter 6. ERPs were recorded during the test phase. The ERP recording procedure was the same as that described in Chapter 5.

7.3.2 Results

7.3.2.1 Behavioural Results

Table 7.5 displays the proportion of 'old' and 'new' responses to the four classes of test item, together with their associated response times. A priori t-tests showed that the hit rate to Old pairs was significantly higher than the false alarm rate for Associated Intra pairs (t_{17}=3.44, p<.01). In addition, Associated Intra pairs were more likely to be identified as 'old' than Unassociated Intra pairs (t_{17}=2.61, p<.05), and there were more old responses to Unassociated Intra pairs than to Old-New pairs (t_{17}=9.32, p<.01). Thus, Associated Intra pairs elicited the highest false alarm rate, followed by Unassociated Intra pairs and then Old-New pairs.

Table 7.5. Mean proportion of responses (SD) and mean reaction times (SD) for each response category of Experiment 4.

Stimuli Type	Response Category	Proportion (SD)	RT(SD)
Old Pair	Hits	.64 (.08)	1429 (217)
	Miss		1496 (236)
Associated Intra Pair	False alarm	.52 (.14)	1473 (251)
	Correct rejection		1553 (265)
Unassociated Intra Pair	False alarm	.46 (.17)	1487 (226)
	Correct rejection		1542 (268)
Old-New Pair	False alarm	.24 (.14)	1404 (201)
	Correct rejection		1440 (212)

The response times for false alarms to Associated Intra and Unassociated Intra pairs were longer than the response time for hits. A one-way ANOVA on these response times to Old, Associated Intra, and Unassociated Intra pairs (Old-New pairs were not included as two subjects did not make any old responses to this type of stimuli) revealed a significant main effect for the three categories of test pairs [F(1.7, 28.93)=4.39, p<.05]. Newman-Keuls post hoc tests confirmed that the response times for false alarms to Associated Intra and Unassociated Intra pairs were not significantly different, and were both longer than the response time for hits to Old pairs.

7.3.2.2 ERP Results – Amplitude Analyses

Averaged ERPs were formed for four response categories based on data from all the 18 subjects: hits to old pairs, false alarms to Associated Intra pairs, correct rejections to Unassociated Intra pairs, and correct rejections to Old-New pairs (hereafter abbreviated to Hit, Associated Intra FA, Unassociated Intra CR, and Old-New CR respectively), with the mean trial numbers (range in brackets) of 38 (27-54), 30(18-41), 32 (16-68), and 44 (24-64) respectively. Four subjects contributed fewer than 16 false alarms to Unassociated Intra pairs (hereafter abbreviated to Unassociated Intra FA), and these subjects' data were excluded from analyses involving this response category. The mean trial numbers of the 14 subjects contributing ERPs for Hit, Associated Intra FA, Unassociated Intra FA, Unassociated Intra CR, and Old-New CR were 36 (27-48), 32 (20-41), 30 (17-44), 28 (16-37), and 43 (27-58) respectively. Another three subjects contributed fewer than 16 correct rejections to Associated Intra pairs (hereafter abbreviated to Associated Intra CR), and data from these subjects were excluded from analyses involving this response category. The mean trial numbers of the 15 subjects contributing ERPs for Hit, Associated Intra FA, Associated Intra CR, Unassociated Intra CR, and Old-New CR were 39 (27-54), 30 (18-41), 31 (16-57), 34 (19-68), 46 (27-64).

Grand average ERP waveforms overlaid by condition are shown in figures 7.9-7.11. As can be seen from the figures, in each case the waveforms diverge from approximate 300 ms after stimulus onset. Notably, the waveforms associated with Hits are more positive-going than the waveforms associated with Old-New CR. This positive shift is initially larger over the left than the right hemisphere at parietal sites, but is larger over the right than the left hemisphere at frontal sites later on in the recording epoch. It can also be seen that a positive shift is associated with Associated Intra FA in comparison to Old-New CR at parietal sites. However, the positivity-going effect for Associated Intra pairs is less sustained than that for with Old pairs, and is absent at frontal sites in the later part of the recording epoch. As can be seen from figures 7.10 and 7.11, the positive shift associated with Old and Associated Intra pairs was not observed for Unassociated Intra and Associated Intra CR pairs.

ERPs were quantified by measuring the mean amplitudes of four time regions: 300-600, 600-900, 900-1400, and 1400-1900 ms as in Experiment 2. An overall ANOVA was first conducted for each time region on the data from 18 electrode sites. These sites were located over 6 scalp regions: left frontal (electrodes 48,33,19), right frontal (electrodes 38,22,9), left central (electrodes 47,31,17), right central (electrodes 39,24,11), left parietal (electrodes 46,30,29), and right parietal (electrodes 40,25,26). Factors entered into the global ANOVA were Response Category (Hit, Associated Intra FA, Unassociated Intra CR, Old-New CR for all 18 subjects; Hit, Associated Intra FA, Unassociated Intra FA, Unassociated Intra CR, Old-New CR for 14 subjects; Hit, Associated Intra FA, Associated Intra CR, Unassociated Intra CR, Old-New CR for 15 subjects), Hemisphere (left, right), Location (anterior, central, posterior), and Site. Subsidiary ANOVAs for pairwise comparison between response categories were conducted when there were significant effects involving response categories in the overall ANOVA.

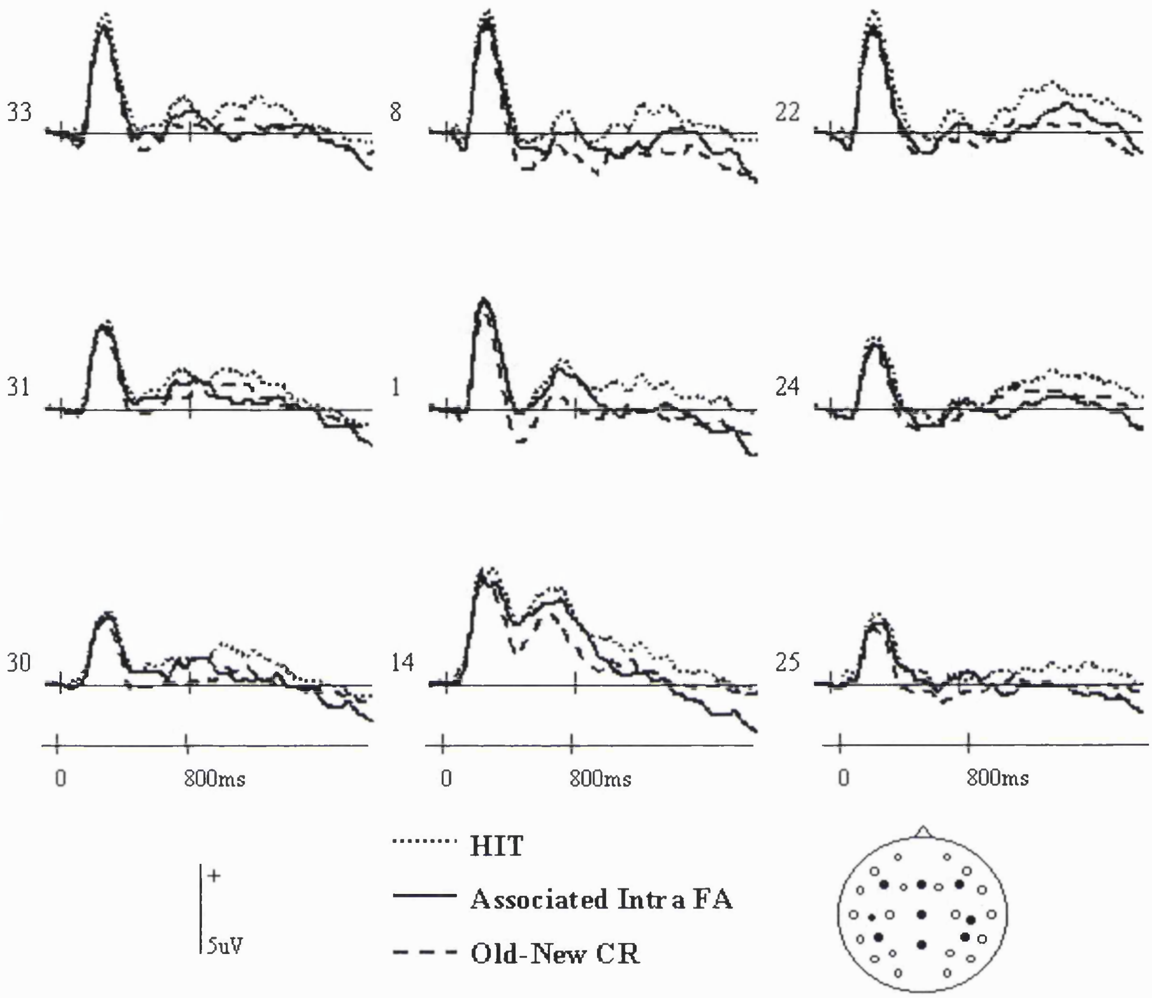

Figure 7.9. Grand average waveforms (N=18) for Hit, Associated Intra FA, and Old-New CR trials in Experiment 4. The locations of the sites are indicated as the number of the electrodes in the montage.

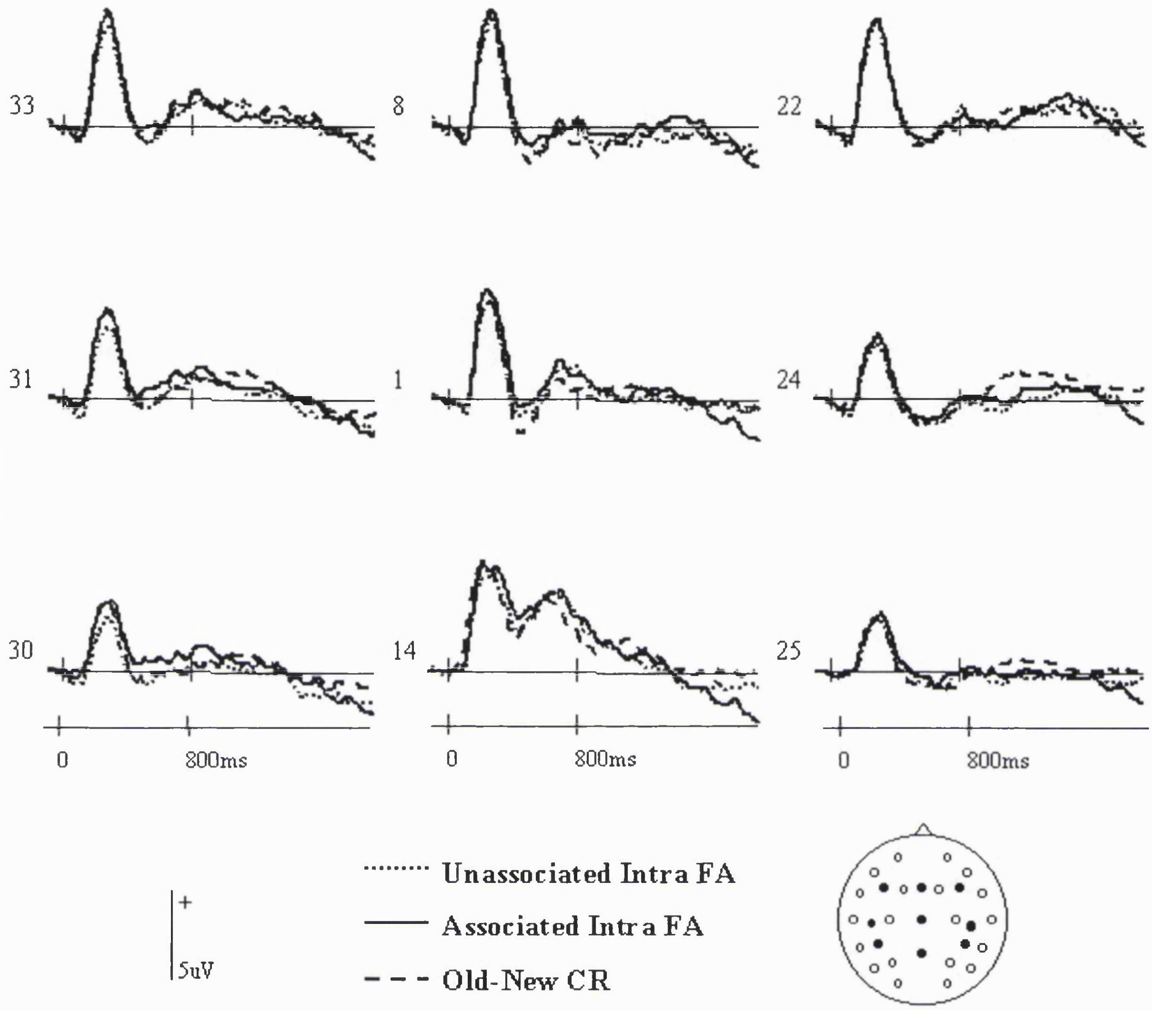

Figure 7.10. Grand average waveforms (N=14) for Associated Intra FA, Unassociated Intra FA, and Old-New CR trials in Experiment 4. The locations of the sites are indicated as the number of the electrodes in the montage.

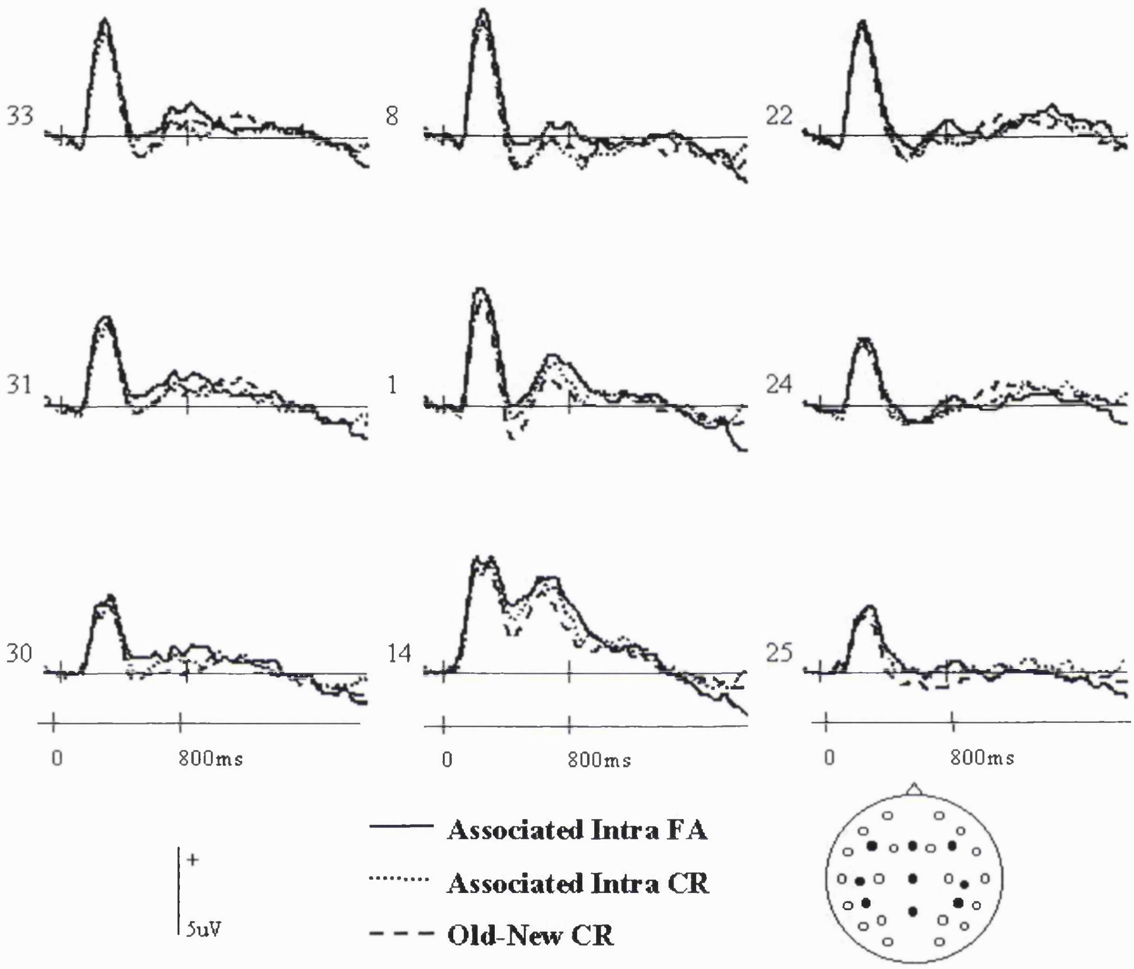

Figure 7.11. Grand average waveforms (N=14) for Associated Intra FA, Associated Intra CR, and Old-New CR trials in Experiment 4. The locations of the sites are indicated as the number of the electrodes in the montage.

Table 7.6 shows the results of the overall ANOVAs for the four time regions based on the data from all the 18 subjects (Unassociated Intra FA excluded). As can be seen from the table, there were significant effects involving Response Category in all four time regions. Similar results were obtained from the ANOVAs in which Unassociated Intra FAs and Associated Intra CRs were included, based on the data from the 14 and 15 subjects who contributed enough Unassociated Intra FA and Associated Intra CR trials. In light of these significant effects, subsidiary ANOVAs for pairwise comparisons between response categories were performed. Because there were no differences between the ERPs elicited by Old-New CR and Unassociated Intra CR items in any of the four time regions, the waveforms to these two response categories were collapsed in these subsidiary analyses to form the category of Correct Rejections (CR). Mean amplitudes associated with the ERP effects between different response categories and Correct Rejections are shown at anterior, central, and posterior sites across each of the four latency regions in figure 7.12. The results of these ANOVAs are listed in table 7.7 and elucidated below. Only results based on all 18 subjects are reported unless an ANOVA based on data from the aforementioned subsets of subjects revealed a different pattern of results.

Table 7.6. Results of overall ANOVAs of the magnitude analyses over each time region in Experiment 4.[a,b]

	300-600 ms	600-900 ms	900-1400 ms	1400-1900 ms
RC	F(2.3,38.3)=6.77***	F(2.6,44.5)=6.47**	F(2,33.2)=4.77*	-
RC x ST	-	-	F(3,50.7)=2.94*	-
RC x HM x AP	-	F(3.8,64.8)=3.16*	F(3.5,59.3)=4.08**	F(3.6,61.2)=2.38*
RC x AP x ST	-	-	F(6,102.3)=2.35*	-

[a] Only significant effects involving the factor of response category are reported.
[b] RC=response category, HM=hemisphere, AP=anterior-posterior location, ST=electrode site.
*** p<.001; ** p<.01; * p<.05

Hit vs. CR. As shown in table 7.7, the ANOVAs comparing the ERPs associated with Hit and CR trials revealed a significant effect of Response Category in all the four time regions, reflecting the fact that the ERPs associated with Hits were more positive than the ERPs associated with CRs. In the 600-900 ms time region, the two-way interaction between Response Category and Site, as well as the three-way interaction between

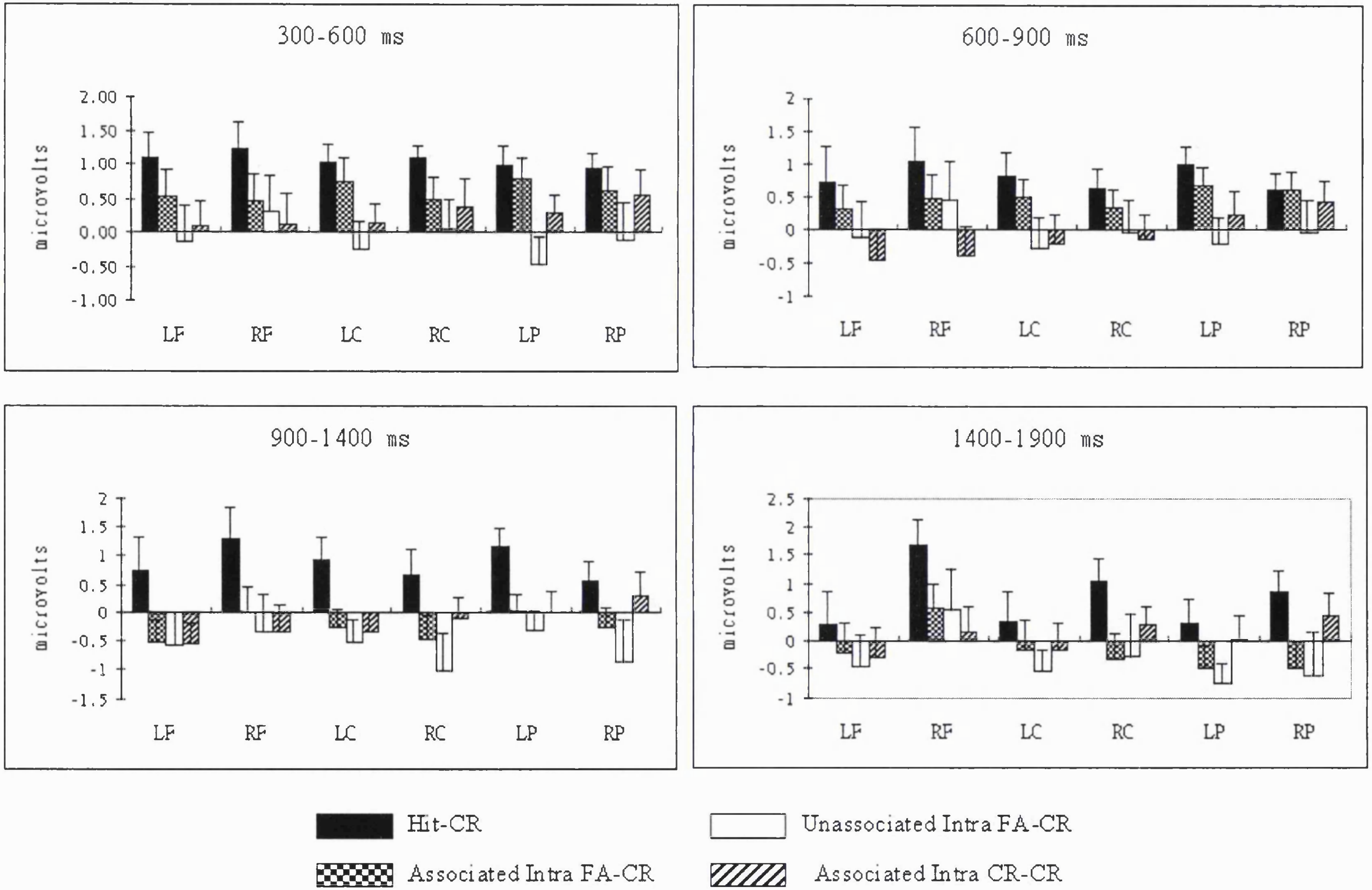

Figure 7.12. Mean amplitudes (with standard errors) associated with the ERP effects for Hits (N=18), Associated Intra FAs (N=18), Unassociated Intra FAs (N=14), and Associated Intra CRs (N=15), in comparison to CRs at anterior, central, and posterior sites across the four time regions in Experiment 4.

Table 7.7. Results of subsidiary ANOVAs of the magnitude analyses over each latency region in Experiment 4. [a,b]

	Hit vs. CR	Associated Intra FA vs. CR	Hit vs. Associated Intra FA
300-600 ms			
RC	F(1,17)=24.39 ***	F(1,17)=4.6*	-
600-900 ms			
RC	F(1,17)=7.24*	F(1,17)=4.6*	-
RCx ST	F(1.2,20.3)=4.95*	-	-
RcxHMxAP	F(1.6,26.9)=8.54**	-	-
900-1400 ms			
RC	F(1,17)=8*	-	F(1,17)=18.63***
RCxST	F(1.1,19.2)=6.12*	-	-
RcxHMxAP	F(1.6,27.1)=7.22**	F(1.5,26.3)=3.87*	-
1400-1900 ms			
RC	F(1,17)=4.23*	-	F(1,17)=11.46***
RCxHM	F(1,17)=5.74*	-	F(1,17)=6.33*
RcxHMxAP	(F(2,33.2)=3.07, p=.06)	-	-

[a] Only significant effects involving the factor of response category are reported.
[b] RC=response category, HM=hemisphere, AP=anterior-posterior location, ST=electrode site
*** p<.001; ** p<.01; * p<.05

Response Category, Hemisphere, and Location, were both significant. Follow-up analyses showed that the difference between Hit and CR was not significant over the anterior scalp sites (p=.10) but was significant over left and right parietal regions [F(1,17)=13.92, p<.01 and F(1,17)=5.78, p<.03]. As can be seen from figures 7.9 and 7.12, this effect at parietal sites was larger over the left hemisphere than the right hemisphere. The same two interaction effects were also significant in the 900-1400 ms time region. Follow-up analyses revealed that the difference between Hit and CR was significant over left parietal and right frontal scalp regions [F(1,17)=13.79, p<.01 and F(1,17)=4.96, p<.05 respectively], but was not significant over right parietal and left frontal scalp regions (p=.11 and p=.20 respectively). In the 1400-1900 ms time region the two-way interaction between Response Category and Hemisphere was significant. Follow-up analyses showed that the effect of Response Category was significant over the right hemisphere [F(1,17)=12.34, p<.01] but not over the left hemisphere (p=.52). The three-way interaction between Response Category, Hemisphere, and Location approached significance [F(2,33.2)=3.07, p=.06], reflecting that the effect of Response Category over the right hemisphere was larger over frontal scalp regions than parietal regions. The interactions revealed above reflected variations in the scalp distribution of the positive-going effect for Hits across the scalp and the time regions as shown in figures 7.9 and 7.12. At parietal sites, the positive-going effect to Hits onset around 300 ms, was larger over the left than the right hemisphere, and decayed by around 1000 ms. The Hit vs. CR effect had a different pattern over frontal sites. The effect onset around 800 ms lasted until the end of the recording epoch, and was larger over the right hemisphere than the left.

Associated Intra FA. vs. CR. As shown in table 7.7, the ANOVAs comparing the waveforms associated with Associated Intra FA and CR revealed a significant main effect of Response Category in the time regions of 300-600 ms and 600-900 ms. Although Response Category did not interact with Hemisphere or Location in the 600-900 ms, analyses on data from different scalp regions showed that the effect of Response Category was significant at left parietal sites [F(1,17)=6.25, p<.02], approached significance at right parietal sites [F(1,17)=4.43, p=.05], and was not significant over central or frontal scalp regions (p=.3 and p=.11 respectively). The three-way interaction between Response Category, Hemisphere, and Location was significant in the 1400-1900 ms time region. However, no significant effect involving Response Category was found in analyses on data from different scalp region during this time region. There were no significant effects involving the factor of Response Category in the 1400-1900 ms time region. Therefore, similar to the comparison between Hit and CR, the waveforms associated with Associated Intra FA were more positive-going than those associated with CR in the 600-900 ms time region at parietal sites, with a tendency to be larger over left than right hemisphere (see figures 7.9 and 7.12). However, this effect was less sustained than the old/new effect for Old pairs, as there was no difference significant effect for Associated Intra FA in comparison to CR observed in the 900-1400 time region.

Moreover, the right frontal effect exhibited by recognised Old pairs in the 1400-1900 ms time region was not observed in false alarms to Associated Intra pairs.

Hit vs. Associated Intra FA. As can be seen from table 7.7, the comparisons between Hits and Associated Intra FA showed that the main effect of response category was significant in the 900-1400 ms and 1400-1900 ms time regions, due to the fact that the waveforms associated with Hit were more positive-going than those associated with Associated Intra FAs. The two-way interaction between Response Category and Hemisphere was significant in the 1400-1900 time region. Follow-up analyses showed that the effect of Response Category was significant in the right hemisphere [$F(1,17)=11.45$, $p<.01$], but not in the left hemisphere ($p=.07$).

Unassociated Intra FA vs. CR. No significant effects involving the factor of Response Category were observed in this comparison.

Associated Intra FA vs. Unassociated FA. No significant effects involving the factor of Response Category were observed in this comparison.

Associated Intra CR vs. CR. No significant effects involving the factor of Response Category were observed in this comparison.

7.3.2.3 ERP Results – Topographical Analyses

The scalp topography of the old/new effect for Old pairs across the four EEG recording epochs is shown in figure 7.13. As can be seen from the figure, the old/new effect onset in the 300-600 ms time region, during which the positivity was widespread over the central scalp. The peak of the old/new effect shifted to the left parietal scalp in the 600-900 ms time region and to right frontal sites in the 900-1400 and 1400-1900 ms time regions. An ANOVA performed on the rescaled old/new effect recorded during the 600-900 ms and 1400-1900 ms showed a significant interaction between time region and electrode sites [F(4.9,82.6)=3.3, p=.01], indicating that the distribution of the old/new effect changed with time, which is in accordance with the pattern shown in figure 7.9.

The topographies of the false recognition effect for Associated Intra pairs during the 300-600 ms and 600-900 ms time regions, as shown in figure 7.14, was very similar to the topographies of the old/new effect for Old pairs. ANOVAs showed that the topographical distributions of the old/new effect for Old pairs and the false recognition effect for Associated Intra pairs were statistically indistinguishable across the two time regions. The difference between the two effects was not significant and did not interact with time region or electrode site (all Fs<1).

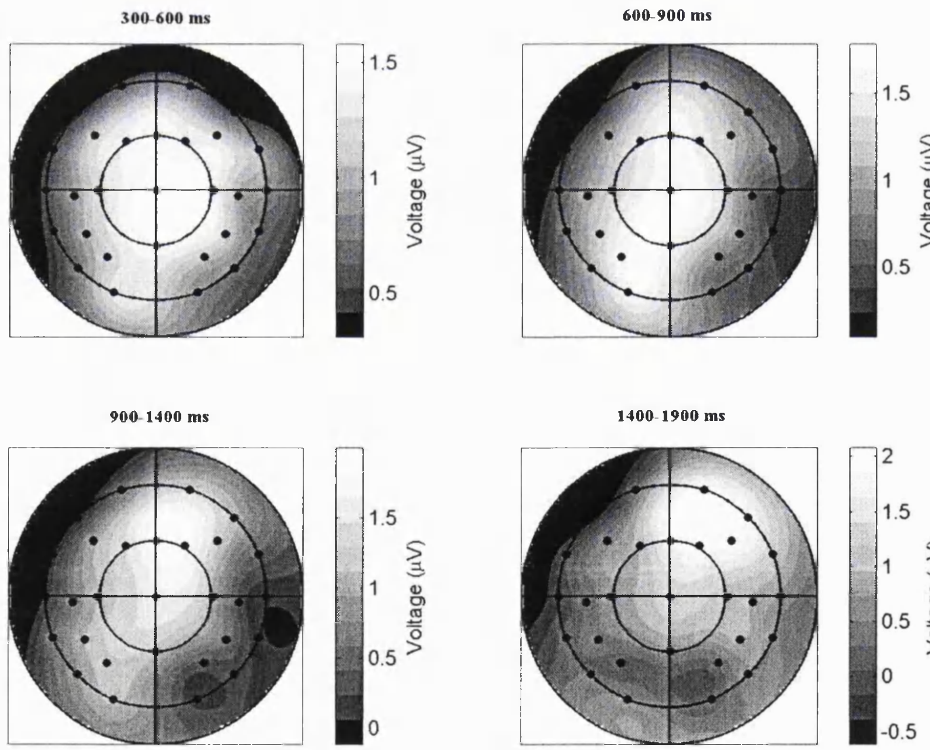

Figure 7.13. Voltage spline maps showing the topographies of the old/new effect for Old pairs (differences between Hit and Old-New CR) in Experiment 4.

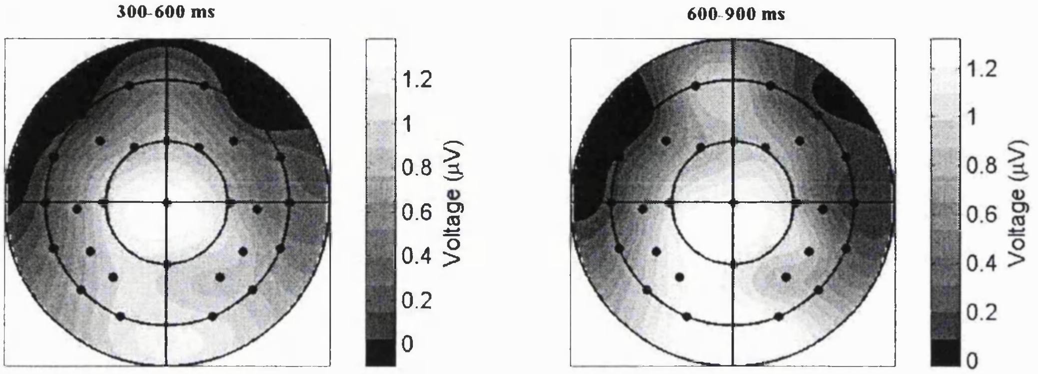

Figure 7.14. Voltage spline maps showing the topographies of the false recognition effect for Associated Intra pairs (differences between Associated Intra FA and Old-New CR) in Experiment 4.

7.3.2.4 Summary of ERP results

ERPs associated with correctly classified Old pairs were more positive than those associated with correct rejections. In the 300-600 ms time region, this positivity was widespread over the central scalp. Between 600ms and 900 ms, the positive-going effect was larger over the left hemisphere at parietal sites. From 900 ms to the end of the recording epoch, the positive effect shifted to frontal sites and was larger over the right than the left hemisphere. A left parietal effect was observed for Associated Intra FAs. The distribution of this effect was indistinguishable from the left parietal effect for Old pairs. However, the effect for Associated Intra pairs was less sustained than that for Old pairs. In addition, Associated Intra pairs failed to elicit a reliable right frontal effect. No significant ERP effect was observed for Unassociated Intra FAs.

7.3.3 Discussion

In the current experiment, the hit rate for Old pairs was higher than the false alarm rate for Associated Intra pairs, indicating that studied items are more likely to be identified as old than rearranged lure items that are consistent with the gist memories formed during encoding. On the other hand, the higher false alarm rate for Associated Intra pairs than for Unassociated Intra pairs demonstrates the contribution of the semantic association between the initial words on the formation of gist memory, from which partial information is derived to induce source judgement errors. These findings, mirroring the results of the 'unrelated' group in Experiment 3, reflect the effect of the semantic association between the initial words on the formation of the gist memory.

On the other hand, although the Associated Intra and Unassociated Intra pairs in the current experiment were generated in a similar way as the Intra and Inter pairs in Experiment 2, the patterns of behavioural responses to these rearranged pairs in the two experiments were not exactly the same. In Experiment 2, the false alarm rate for Intra pairs was the same as the hit rate for Old pairs, and was much higher than the false alarm rate for Inter pairs. It was also found that the response times associated with false alarms to Intra pairs was the same as those associated with hit trails, and both were shorter than the response times associated with false alarms to Inter pairs. These findings, in accordance with the different patterns of ERPs elicited by Intra and Inter items, indicate that different processes are involved in processing these two kinds of rearranged stimuli. In the current experiment, although Associated Intra pairs attracted more false alarms than Unassociated Intra pairs, the difference between these two types of false alarm rates (M=.06, S.E.=.02) is much smaller than that between the false alarm rates for Intra and Inter pairs (M=.39, S.E.=.04) observed in Experiment 2, as revealed in a cross-experiment comparison (t_{34}=7.49, $p<.001$). In addition, the response times associated with the false alarms to Associated Intra and Unassociated Intra items in the current experiment did not differ from each other, and both were longer than the response time associated with hit trials. The different behavioural results for the two experiments are further illustrated by the different patterns of correlation between the proportions of old responses to the different types of test pairs in each experiment. As can be seen from table 7.8, the false alarm rate for Intra pairs in Experiment 2 is significantly correlated with the hit rate. By contrast, in the current experiment, the false alarm rate for Associated Intra pairs is not correlated with the hit rate but rather with the false alarm rate for Unassociated Intra and Old-New pairs, as can be seen from table 7.9. This finding, together with the similar RTs associated with false alarms to Associated Intra and Unassociated Intra pairs in the current experiment, suggest that the source judgment errors for Associated Intra pairs may not be based on the same mechanism as that for the Intra pairs in Experiment 2.

Table 7.8. The correlation between the proportions of old responses to different stimulus types in Experiment 2 (*: p<.05; n.s.: nonsignificant).

	Intra	Inter	Old-New
Hit	.49*	-.36 (n.s.)	-.34 (n.s.)
Intra		.20 (n.s.)	.08 (n.s.)
Inter			.78*

Table 7.9. The correlation between the proportions of old responses to different stimulus types in Experiment 4 (*:p<.05; n.s.: nonsignificant).

	Associated Intra	Unassociated Intra	Old-New
Hit	.14 (n.s.)	-.07 (n.s.)	.09 (n.s.)
Associated Intra		.84*	.78*
Unassociated Intra			.80*

Turing to the ERP results of the current experiment, the left parietal and the right frontal effects were observed for correctly identified Old pairs, reflecting the involvement of recollection and post-retrieval monitoring/evaluation processes in the source judgement task employed in the current experiment. The left parietal effect was also observed for the false alarms to Associated Intra pairs, with its topographical distribution indistinguishable from that of the left parietal effect for Old pairs in the 600-900 ms time region. It is therefore suggested, consistent with the conclusion drawn in Experiment 2, that recollection is involved in the source judgement errors for rearranged items that corresponded to the gist memories formed at study. Nevertheless, the left parietal effect for the Associated Intra pairs was less sustained than that for Old pairs. While the left parietal effect was observed for Old pairs in the time region of 600-1400 ms, it was only observed for Associated Intra pairs in the 600-900 ms time latency. The different durations of the left parietal effect for Old and Associated Intra pairs contrast markedly with the indistinguishable left parietal effect for Old and Intra pairs in Experiment 2.

Why was the left parietal effect for Associated Intra pairs of shorter duration than the left parietal effect for Old pairs? One possible answer to this question lies on the observation that there was a negative-going wave associated with false alarms to Associated Intra pairs over posterior scalp regions in the late recording epoch. As can be seen from figure 7.9, the waveforms associated with false alarms to Associated Intra pairs were more negative-going than those associated with hit and correct rejection trials. This negative-going effect started at around 900 ms after stimulus onset and was distributed over posterior electrode sites. The left parietal effect for the Associated Intra pairs might therefore had been of the same duration as the parietal effect for Old pairs, but was cancelled, or 'dragged off' by the posterior negative wave during the 900-1400 ms time region, which was not observed in hit trials. It should be noted, however, that the negativity for false alarms to Associated Intra pairs in comparison to hits to Old pairs and correct rejections to Old-New pairs was not statistically significant. This non-significant result hampered the interpretation that the duration of the parietal effect for Associated Intra pairs was shortened because of the overlapping posterior negative wave.

Another interpretation for why the left parietal effect was indistinguishable for Old and Intra pairs in Experiment 2 but of different durations for Old and Associated Intra pairs in the current experiment might be derived from the aforementioned different behavioural result patterns for Intra pairs and Associated Intra pairs. The false alarm rates for Inter pairs in Experiment 2 and for Unassociated Intra pairs in the current experiment can be viewed as the proportion of source judgement errors based on non-recollection-based factors, which also contribute to the false alarms to Intra and Associated Intra pairs. The small but reliable difference in false alarm rates for Associated Intra and Unassociated

Intra pairs, as opposed to the large different false alarm rates for Intra and Inter pairs in Experiment 2, raises the possibility that a large proportion of the false alarms to Associated Intra pairs were actually not recollection-based. The large proportion of non-recollection-based false alarms to Associated Intra pairs might therefore lead to a diluted left parietal effect, whose pattern is different from that for Old pairs. Nevertheless, this interpretation has difficulties in explaining why it is the duration rather than the amplitude of the left parietal effect that differs for Old and Associated Intra pairs. If it was the different proportions of recollection-based responses underlying hits to Old pairs and false alarms to Associated Intra pairs that caused the different patterns of the left parietal effect for these two classes of items, the effect is more likely to be different in amplitudes rather than duration.

A more appealing interpretation for the different durations of the left parietal effect for Old and Associated Intra pairs lies in the finding that the Associated Intra false alarm rate was correlated with the Unassociated Intra false alarm rate but not with the hit rate. This finding implies that although recollection is involved in both hits to Old pairs and false alarms to Associated Intra pairs, the quality and/or quantity of recollection in these two response categories was not equivalent. That is, while recollection was involved in false alarms to Associated Intra pairs, it might not play a dominant role. Instead, some non-recollection-based factors common to Associated Intra pairs and Unassociated Intra pairs made a larger contribution than recollection to Associated Intra false alarms. The different duration of the left parietal effect for Old and Associated Intra pairs may reflect the different quality or amount of recollection for these two classes of items.

It has been suggested that the amplitude of the left parietal effect may reflect the quality or amount of information that is recollected (Donaldson & Rugg, 1998; Wilding, 2000; Wilding & Rugg, 1996). Nessler et al. (2001) also found that the parietal effect was of a smaller amplitude for lure items than for studied items in the 'Item' group, and suggested that less recollection was elicited by lure items than by studied items. The findings of these studies were however related to the different amplitudes rather than duration of the left parietal effect elicited by recognised items, and may not be applied to the duration differences observed in the current experiment. Nevertheless, the duration of the left parietal effect may index the quality or amount of recollection in dimensions different from those indexed by the amplitude of the effect. In one ERP study employing the DRM procedure, Miller and colleagues (Miller, Baratta, Wynveen, & Rosenfeld, 2001) reported that the latency, but not the amplitude or topographic distribution, of the P300 component was different for correctly and incorrectly recognised true targets and lure items. They reported that the peak latency of P300 was earlier for incorrectly identified semantically related lure items than for correctly identified studied items. Assuming that the peak latency of P300 is related to stimulus evaluation or categorisation (Donchin & Coles, 1988), Miller et al. argued that the shorter P300 latency for lure than for studied items indicates that the evaluation or categorisation processes take less time for the former than for the latter items. They further suggested that some item-specific information is associated with studied but not with lure items. The latency of P300 was longer for studied items than for lure items because it took a longer time to evaluate or categorise the item-specific information that was available for the former but not the latter items. In a similar vein, the different duration of the left parietal effect for Old and Associated Intra pairs may reflect that some aspects of information were recollected for the former but not the latter items. Specific information about the source-item pairing might be recollected more slowly than the partial information derived from the gist memory (c.f. Johnson et al., 1994; McElree et al., 1999), and is only available for Old but not for Associated Intra pairs. The larger number of 'R' responses to Old pairs than to Associated Intra pairs in Experiment 3 provides converging evidence for the notion that recognised Old pairs are accompanied by some recollected information that is absent for incorrectly identified Associated Intra pairs.

The incorrectly identified Associated Intra pairs failed to elicit a reliable right frontal effect, which contrasts remarkably with the finding of a right frontal effect for the incorrectly identified Intra pairs in Experiment 2 and the correctly recognised Old pairs in the current experiment. The presence and absence of the right frontal effect for Old pairs and Associated pairs, both associated with the left parietal effect (although with different latencies), demonstrate that the two effects are dissociable and the right frontal effect is not obligatory to recollection (Rugg, Allan, & Birch, 2000; Wilding & Rugg, 1997b). The right frontal effect has been thought to reflect monitoring/evaluation processes operating in a strategic manner (Allan et al., 2001; Ranganath & Paller, 2000; Wilding, 1999). The presence and absence of the right frontal effect for Old and Associated Intra pairs might shed some light on understanding the conditions that engage post-retrieval monitoring processes. If the duration of the left parietal effect does indeed reflect the quality or amount of recollection, the present findings suggest that there is a 'threshold' for amount or quality of recollection required to initiate post-retrieval monitoring processes. These processes, as indexed by the right frontal effect, are engaged for Old pairs as sufficient or salient information about the studied pairs was recollected. By contrast, although recollection was involved in false alarms to Associated Intra pairs, the quality or amount of the recollected information was not sufficient to elicit post-retrieval monitoring processes. Certainly this proposal holds only when the duration of the left parietal effect indeed reflect the quality or amount of information that is recollected. Nevertheless, at least, the present finding indicates that the engagement of the post-retrieval processes is modulated by some aspect of recollection, which is associated with the duration of the left parietal effect.

As noted in the introduction, the conclusion of Experiment 3 that the semantic relation between the second words does not affect recollection-based source judgement errors can be examined by comparing the ERPs effects for Associated Intra pairs in the current experiment and those for Intra pairs in Experiment 2. Both types of rearranged stimuli were generated in a similar way – the study pairs used to generate these two classes of rearranged stimuli had semantically associated initial words – and were expected to attract similar responses. If indeed the semantic relation between the second words does not modulate the occurrence of recollection-based source judgement errors, similar ERP effects for these two classes of rearranged pairs should be equivalent. Nevertheless it is evident in both behavioral data and ERP data that the two classes of pairs were processed differently. It appears, from the ERP results, that 'full-blown' recollection-driven source judgment errors occurred only when both members of rearranged pairs were semantically related to other studied items. This notion is inconsistent with the finding of Experiment 3 that the semantic relation between the second words had no effects on the 'Remember' responses of the Remember/Know judgements.

Why were there inconsistent results between the ERP effects and Remember/Know judgements? One plausible explanation is that subjects did not follow the instruction to make Remember/Know judgements exclusively on the basis of their memories for the word pairs. Instead, they did not differentiate the recollective experience elicited by the pairing between the two word members from those elicited by the words per se. It is therefore possible that the 'R' responses observed in Experiment 3 does not actually reflect the recollective experience associated with the pairing between the initial and second words. Another possibility is that the left parietal effect and the Remember/Know judgement are different in their sensitivity to recollection. The influence of the semantic relation between the second words on recollection might not be sufficient to elicit different proportion of 'R' responses, but is sufficient to modulate the occurrence or magnitude of the left parietal effect. This difference in sensitivity might result from the fact that the 'Remember/Know' procedure indexes recollection in a binary fashion, whereas the left parietal effect might index recollection in a graded fashion (e.g. Wilding, 2000).

Chapter 8. The Subsequent Memory Effect for Gist-Based Memory Errors: Experiment Five

8.1 Introduction

It was demonstrated in Experiment 2 that recollection is involved in false alarms to Intra pairs, that is, pairs which are generated by re-pairing two study pairs and are consistent with the gist memories of word pairs presented at study. In contrast to the indistinguishable ERP effects associated with Old and Intra pairs observed in Experiment 2, the left parietal effect for incorrectly identified Associated Intra pairs in Experiment 4 was less sustained than that for correctly recognised Old pairs. This finding suggests that 'full-blown' recollection-driven memory errors occur only when both members of rearranged pairs are semantically related to other studied items. The formation of gist memory, which supports later recollection-based memory errors, relies on both the semantic relations between the initial words, and the semantic relations between the second words of word pairs presented at study. On the other hand, whether an Intra pair is correctly rejected or incorrectly classified at test might be related to whether specific information about the original study pairs is encoded at study. It is therefore of interest to investigate the relation between the brain activity elicited by word pairs during encoding and the accuracy of the subsequent memory test for these word pairs.

Previous studies of 'subsequent memory effects' focused mainly on the neural correlates of successful encoding for recalling or recognising studied items on the subsequent test. ERPs elicited by study items are compared according to whether these items are subsequently remembered (recalled or recognised) or forgotten (not recalled or missed) at test. Only a few studies have been conducted to examine the neural correlates of encoding for items that subsequently attract memory errors, and most of these studies focused on source memory errors. The results of these studies are inconsistent. It was reported that the ERPs recorded during encoding were not predictive of the accuracy of subsequent source memory test when the source discrimination concerned the gender of voices (Senkfor & Van Petten, 1998) or temporal order (Friedmand & Trott 2000) of the words. By contrast, Gonsalves and Paller (2000) reported that the ERPs elicited by items during encoding were predictive of whether these items would attract reality-monitoring errors on the subsequent test. The ERPs elicited by study words were more positive at parietal and occipital sites when these study words were, on a subsequent exclusion task, incorrectly claimed to have been presented with a corresponding picture than when they were correctly rejected. Assuming that the posterior ERPs in response to words were modulated by the vividness of visual imagery (Farah, Peronnet, Weisberg & Monheit, 1990), Gonsalves and Paller argued that the subsequent memory effect for reality-monitoring errors was related to the vividness of the visual imagery elicited by the study words. The more vivid the visual imagery generated in response to a study word, the more likely subjects would be to incorrectly claim that the picture of the object corresponding to the word had been presented at study.

One possible reason why the subsequent memory effect for source memory errors was observed by Gonsalves and Paller (2000) but not by others (Friedman & Trott, 2000; Van Petten & Senkfor, 1998) is that Gonsalves and Paller employed a reality monitoring task, in which vivid perceptual experience acquired during encoding is critical for the subsequent source memory test. Study items from internal and external sources are associated with different degrees of vividness of perceptual experience that can be reflected by the ERPs elicited by these items during encoding (Farah et al, 1990). In a similar vein, the ERPs elicited by internally presented study items (e.g., imagined pictures) also differ according to whether these items are accompanied by characteristics that are usually associated with externally presented study items (e.g., vivid perceptual experience elicited by perceived objects). Given that it is the vivid perceptual experience associated with internally presented items that promotes reality monitoring errors, the different ERPs elicited by internal presented study items associated with and without vivid perceptual experience are therefore predictive of the performance of the subsequent reality-monitoring test.

It has been suggested that the subsequent memory effects do not reflect a unitary process but rather a collection of task-dependent processes (Wagner et al, 1999). The subsequent memory effect for memory errors in which the vividness of perceptual experience does not play a major role, such as gist-based false recognition, might be different from the subsequent memory effect for reality monitoring errors observed by Gonsalves and Paller (2000). However, there have been no studies conducted to investigate the subsequent memory effect for gist-based false recognition. This is due to a limitation of the DRM procedure, in that the incorrectly identified item (the critical lure) is not present at study, such that no brain activity associated with that item can be recorded at encoding. The experimental procedure employed in this thesis provides an opportunity to examine the subsequent memory effect for gist-based memory errors. Different from the DRM procedure, the lures that attract gist-based false recognition in the current study are Intra pairs, which are created by re-pairing two word pairs that have been shown at study. Therefore, ERPs elicited by these study pairs during encoding can be recorded and contrasted according to whether Intra lures generated from these pairs are correctly or incorrectly classified on the subsequent test.

To investigate the subsequent memory effect for gist-based memory errors, the current experiment employed the same experimental design as that described for Experiment 2, with the exception that study pairs were presented one at a time rather than simultaneously with other pairs of the same study list. This modification allowed the ERPs elicited by study pairs to be recorded and then compared according to the responses attracted by these pairs belonged to on the subsequent memory test. Two kinds of subsequent memory effect were examined in this experiment. The first one concerns the neural correlates of successful encoding for identifying intact Old pairs on the subsequent test, whereas the second one concerns the neural correlates of successful encoding for rejecting Intra lures that are consistent with the gist memory formed during encoding.

8.2 Method

8.2.1 Subjects

A total of 21 right-handed healthy volunteers participated in the experiment. Each subject was paid at the rate of £7.50 per hour. Of the 21 subjects, 14 were female. Not all the 21 subjects contributed their data to both the study phase and test phase ERP analyses, as some subjects did not contribute sufficient (>16) valid ERP trials on some conditions involved in the analyses. The numbers of subjects involved in the various ERP analyses are reported in the result section.

8.2.2 Stimuli and Design

There were four study-test cycles, with four study lists and one test list in each cycle. The constructions of the study and test lists were the same as those in Experiment 2, except that the numbers of Old, Intra, Inter, and Old-New pairs in each test list were different. There were 16 word pairs in each study list, with the first and the last pairs serving as fillers. Each test list contained seventy-four word pairs. Two pairs were fillers while the remaining pairs belonged to one of four categories: (1) Six pairs from each of the study lists were assigned as Old pairs and maintained their pairings. (2) Another four pairs from each study list were re-paired with items from the same list to form Intra pairs. (3) Four other pairs from each study list were re-paired with other words from one of the other three study lists to form Inter pairs. (4) The eight initial words employed on the four study lists were paired with two new words each to generate Old-New pairs. Therefore, each test list in a study-test cycle contained 24 Old pairs, 16 Intra pairs, 16 Inter pairs and 16 Old-New pairs in total. The number of the Old pairs was larger than that to the other pair types to ensure that an adequate number of study pairs, which were 'forgotten' on the subsequent test (i.e., Miss), were available to form ERPs.

8.2.3 Procedure

The procedure employed in this experiment was the same as that employed in Experiment 2 except for the format in which study pairs were presented during encoding phase. Instead of presenting a whole list of 16 study pairs concurrently as in Experiment 2, the four study lists in each study-test cycle were presented consecutively, with one study pair at a time. There was a short break of 30 seconds between each study list. Each study trial started with the presentation of the first fixation character '@' for 500 ms, followed by the presentation of the study pair. The word pair was presented on the centre of the monitor with the initial word above and the second word below the second fixation character ('- -'). After 1000 ms, the words disappeared and the second fixation point remained on the screen for another 1500 ms. The first fixation character then returned to signal the beginning of the next trial. Subjects were instructed to memorise word pairs silently. It was emphasised that the relationship between the two words of each pair was important for the following test. The procedure of the test phase was the same as that employed in Experiment 2.

ERPs were recorded during the study phase and the test phase. The setting of the ERP recording was the same as that reported in Chapter 5.

8.3. Behavioural Results

Table 8.1 displays the proportion of 'Old' and 'New' responses to the four classes of test item, together with their associated response times. The values in the column of 'N=21' are averaged data from all the 21 subjects, whereas the values in the column of 'N=19' are averaged data from the 19 subjects who contributed sufficient hits to Old pairs and false alarms to Intra pairs at test for ERP analyses. The statistical analyses of behavioural data reported below were conducted on the data from the subset of 19 subjects. However, the same results were obtained when data from all the 21 subjects were included.

Table 8.1. Mean proportion of responses (SD) and mean reaction times (SD) for each response category in Experiment 5.

Stimuli Type	Response Category	Proportion (SD)		RT(SD)	
		N=21	N=19	N=21	N=19
Old Pair	Hits	.73 (.11)	.71 (.11)	1534 (310)	1567 (306)
	Miss			1672 (423)	1706 (417)
Intra Pair	False alarm	.56 (.15)	.54 (.14)	1629 (390)	1672 (382)
	Correct rejection			1663 (404)	1696 (398)
Inter Pair	False alarm	.24 (.16)	.24 (.17)	1696 (545)	1734 (547)
	Correct rejection			1592 (378)	1622 (380)
Old-New Pair	False alarm	.11 (.13)	.10 (.13)	1612 (394)	1639 (386)
	Correct rejection			1433 (358)	1455 (367)

A priori tests revealed that the hit rate to old pairs was significantly higher than the false alarm rate for Intra pairs (t_{18}=5.1, p<.001). In addition, Intra pairs were more likely to be identified as 'old' than Inter pairs and Old-New pairs (t_{18}=9.62, p<.001 and t_{18}=14.8, p<.001 respectively). There were also more old responses to Inter pairs than to Old-New pairs (t_{18}=6.9, p<.01). Thus, Intra pairs elicited the highest false alarm rate, followed by Inter pairs and then Old-New pairs.

The response times for false alarms to Intra pairs were longer than the response times for hits, and were shorter than the response times for false alarms to Inter pairs. A one-way ANOVA on the response times associated with old responses to Old, Intra, and Inter pairs (Inter pairs were excluded because three subjects did not contribute this class of trials) revealed a significant main effect for the three categories of test pairs [F(1.18, 21.19)=4.92, p<.05]. Newman-Keuls post hoc tests revealed that the response times on hit trials were significantly shorter than those associated with false alarms to Intra and Inter pairs. However, the response times for Intra and Inter false alarms did not differ from each other (p=.32)

8.4 ERP Results

Two separate sets of analyses were conducted to examine the ERPs recorded during the study and test phases. To avoid the confusion caused by the complex ERP categories associated with the many different stimulus types and response categories, the following nomenclature is used to label the different categories of ERPs recorded during the study and test phases.

For ERPs recorded during the study phase:

Hit(s) :	the ERPs elicited by study pairs which were presented as Old pairs at test and were correctly classified as 'old'.
Miss(s):	the ERPs elicited by study pairs which were presented as Old pairs at test and were incorrectly classified as 'new'.
Intra FA(s):	the ERPs elicited by study pairs whose second words were constituents of Intra pairs at test, and the Intra pairs were incorrectly classified as 'old'.
Intra CR(s):	the ERPs elicited by study pairs whose second words were constituents of Intra pairs, and the Intra pairs were correctly classified as 'new'.

Note that the selection of study pairs that served as Intra FA(s) and Intra CR(s) trials were based on the second words of study pairs rather than the initial words. This is because the initial words were repeatedly presented in different study pairs and hence were unlikely to be used to define which study pairs a rearranged pair was generated from.

For ERPs recorded during the test phase:

Hit(t):	the ERPs elicited by Old pairs which were correctly identified as 'old'.
Miss(t):	the ERPs elicited by Old pairs which were incorrectly identified as 'new'.
Intra FA(t):	the ERPs elicited by Intra pairs which were incorrectly classified as 'old'.
Intra CR(t):	the ERPs elicited by Intra pairs which were correctly classified as 'new'.
Old-New CR:	the ERPs elicited by Old-New pairs which were correctly classified as 'new'.

8.4.1 ERPs at Study

The averaged waveforms associated with Hit(s), Miss(s), Intra FA(s), and Intra CR(s) are shown in figures 8.1 and 8.2. As can be seen from these figures, the waveforms diverge from around 900 ms after stimulus onset, with the waveforms associated with Hit(s) and Intra CR(s) trials more positive-going than those associated with Miss(s) and Intra FA(s) trials. The positive shift associated with HIT(s) in comparison to Miss(s) is larger over the anterior than the posterior sites. In contrast, the positive shift of Intra CR(s) in comparison to Intra FA(s) is observed in both anterior and posterior sites, and is larger over the left hemisphere than the right hemisphere.

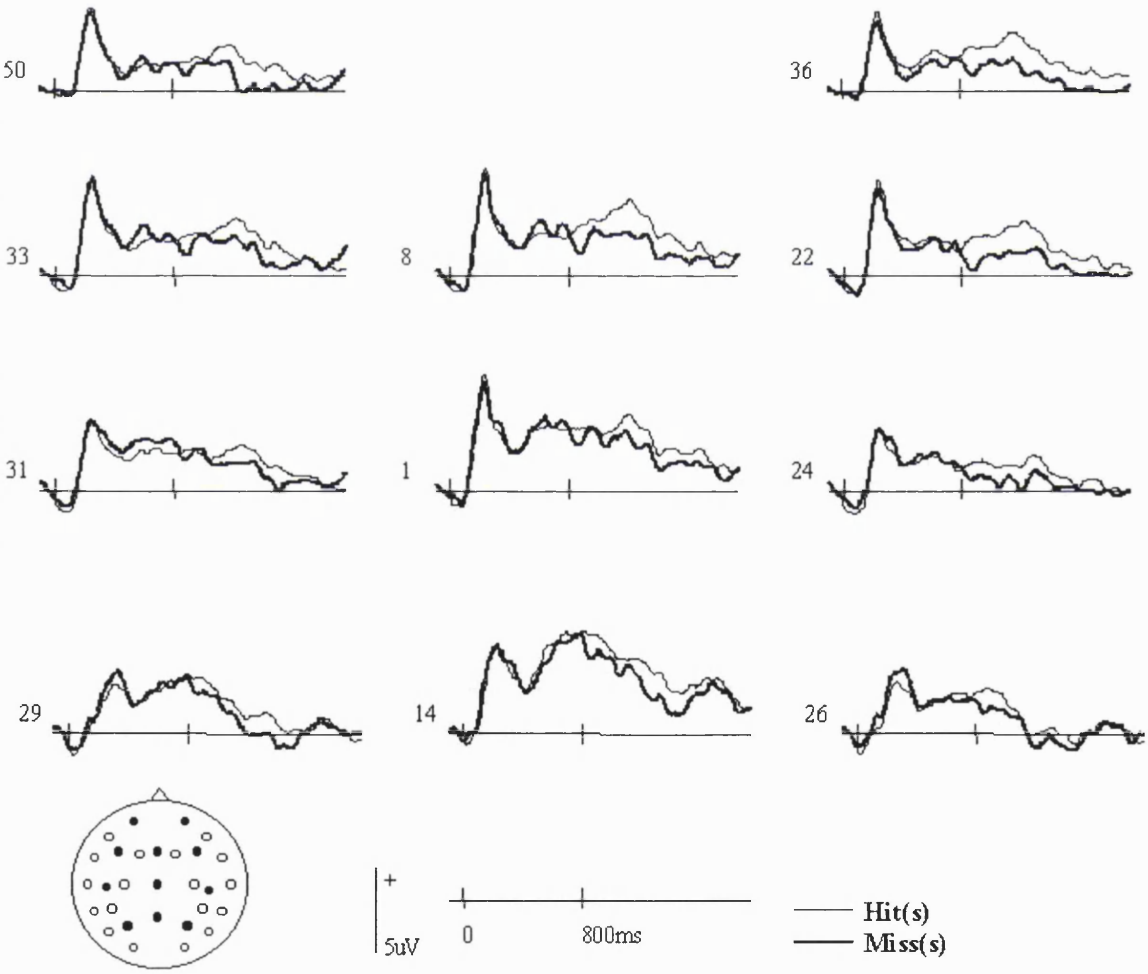

Figure 8.1. Grand average waveforms (N=16) for Subsequent Hit trials [Hit(s)] and Subsequent Miss trials [Miss(s)] recorded during the study phase of Experiment 5.

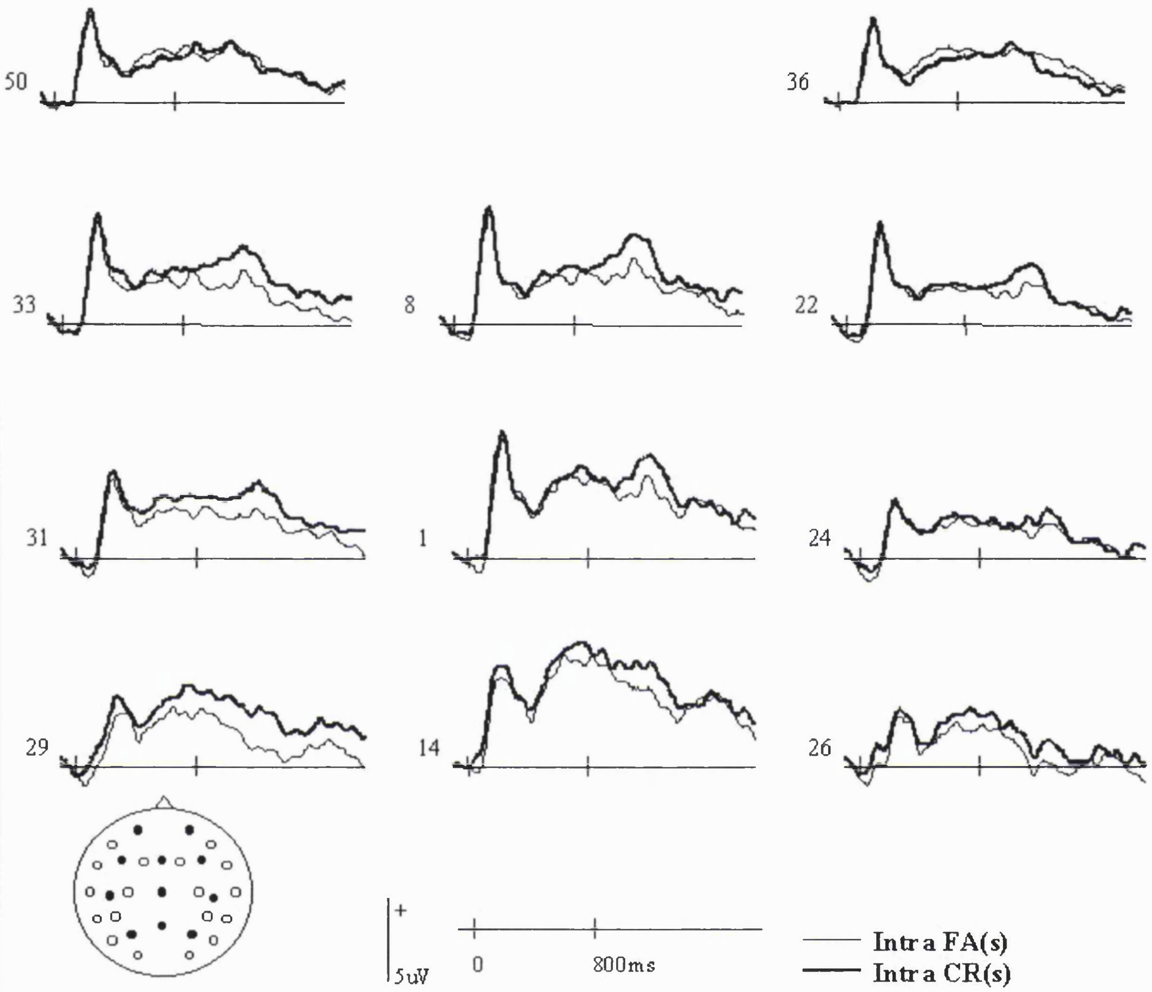

Figure 8.2. Grand average waveforms (N=16) for Subsequent Intra CR trials [Intra CR (s)] and Subsequent Intra FA trials [Intra FA(s)] recorded during the study phase of Experiment 5.

8.4.1.1 Study Phase Amplitude Analyses

ERPs were quantified by measuring mean amplitudes in the 1000-1400 ms latency region. This region, which was chosen by visual inspection, shows maximal differences between the waveforms. Repeated measures ANOVAs, incorporating the Greenhouse-Geisser procedure for violations of sphericity, were conducted in this latency region on the data from 18 electrode sites. These electrode sites were distributed over 6 scalp regions: left frontal (electrodes 48,33,19), right frontal (electrodes 9,22,38), left central (electrodes 47,31,17), right central (electrodes 11,24,39), left parietal (electrodes 46,30,29), and right parietal (electrodes 26,25,40). Factors entered into the ANOVAs were 'Subsequent Response Category' [pair-wise comparisons of Hit(s) vs. Miss(s) and Intra CR(s) vs. Intra FA(s)], Hemisphere (left, right), Location (anterior, central, and posterior), and Site (superior, medial, and inferior). Additional ANOVAs were also conducted on data from different latency regions and electrode sites when potential differences between ERPs of different subsequent response categories were observed.

Hit(s) vs. Miss(s). This comparison was based on data from 16 subjects who contributed sufficient (>16) Hit(s) and Miss(s) ERP trials. The mean trial numbers (range in brackets) of the 16 subjects contributing to Hit(s) and Miss(s) were 59 (24-97) and 23 (16-43) respectively. The ANOVA comparing the ERPs associated with Hit(s) and Miss(s) revealed that the main effect of 'Subsequent Response Category' was not significant ($p=.07$). However, the three-way interaction between Subsequent Response Category, Hemisphere and Location was significant [$F(1.5,22.1)=10.66$, $p<.001$]. This interaction reflected variations in the scalp distribution of the positive-going effect for Hit(s) in comparison to Miss(s) as shown in figure 8.1. Follow-up analyses revealed that the difference between Hit(s) and Miss(s) was significant at anterior sites [$F(1,15)=5.53$, $p<.05$] but not at central and posterior sites ($p=.09$ and $p=.16$ respectively). The positive-going effect of Hit(s) at the anterior sites was symmetrically distributed over the two hemispheres, as the interaction between Subsequent Response Category and Hemisphere at the anterior sites was not significant ($p=.29$). The same effect was also significant in the prefrontal scalp regions, as reflected in the results of a separate ANOVA conducted on the data from electrode sites 49,50,37,and 36 (see figure 8.3) [$F(1,15)=13.24$, $p<.01$ for the main effect of Subsequent Response Category, and $p=.34$ for the interaction between Subsequent Response Category and Hemisphere].

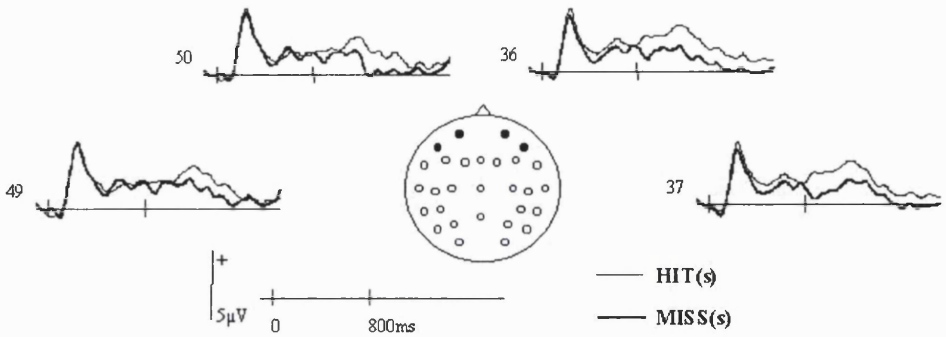

Figure 8.3. The waveforms associated with subsequent hit and subsequent miss trials over the prefrontal scalp area. (N=16) recorded during the study phase of Experiment 5.

In addition to the lateral sites reported above, ERPs associated with Hit(s) and Miss(s) trials from midline electrodes sites (see figure 8.1) were also analysed in a separate ANOVA. It was revealed that the difference between the ERPs associated with these two response categories over the midline electrodes sites was not significant (p=.12).

Intra CR(s) vs. Intra FA(s). This comparison was based on data from another 16 subjects who contributed sufficient Intra FA(s) and Intra CR(s) trials. The mean trial numbers (range in brackets) of the 16 subjects contributing to the two classes of 'Subsequent Response Categories' were 28 (16-46) and 30 (17-45) respectively. The ANOVA comparing the ERPs associated with Intra FA(s) and Intra CR(s) revealed that the main effect of 'Subsequent Response Category' was significant [$F(1,15)=4.51$, $p=.05$]. The two-way interaction between Subsequent Response Category and Hemisphere approached significance [$F(1,15)=3.99$, $p=.06$]. Follow-up analyses revealed that the difference between Intra CR(s) and Intra FA(s) was significant over the left hemisphere [$F(1,15)=6.7$, $p<.05$] but not over the right hemisphere ($p=.24$). The positive-going effect of Intra FA(s) over the left hemisphere was equally distributed at anterior, central and posterior areas (see the left hemisphere sites in figure 8.2), as the interaction between Subsequent Response Category and Location over the left hemisphere was not significant ($p=.58$). A separate ANOVA was conducted on data from midline electrodes sites and gave rise to a nonsignificant effect of Subsequent Response Category ($p=.11$).

8.4.1.2 Study Phase Topographical Analyses

A topographical analysis was conducted to test whether the distributions of the two subsequent memory effects, i.e., the difference between Hit(s) and Miss(s) and the difference between Intra CR(s) and Intra FA(s), were topographically different. This analysis was based on normalised data of 14 subjects who contributed sufficient ERP trials to the four subsequent response categories. Figures 8.4 and 8.5 show the scalp distributions of these two subsequent memory effects during the 1000-1400 ms time region. Statistical analyses showed that the interaction between Subsequent Memory Effect and recording electrode sites was significant [$F(4.3,55.7)=2.49$, $p=.05$], suggesting that the scalp distributions of these two effects was different.

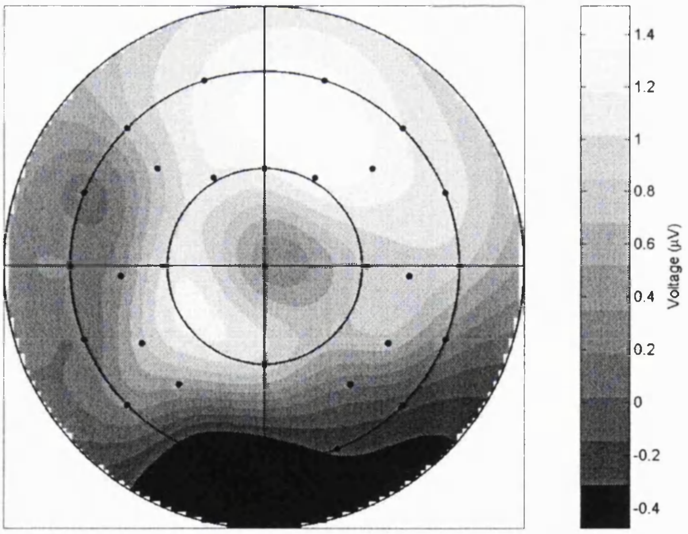

Figure 8.4. Voltage spline maps showing the topographies of the subsequent effect for Old pairs [differences between Hit(s) and Miss(s)] during the 1000-1400 ms time region in the study phase of Experiment 5.

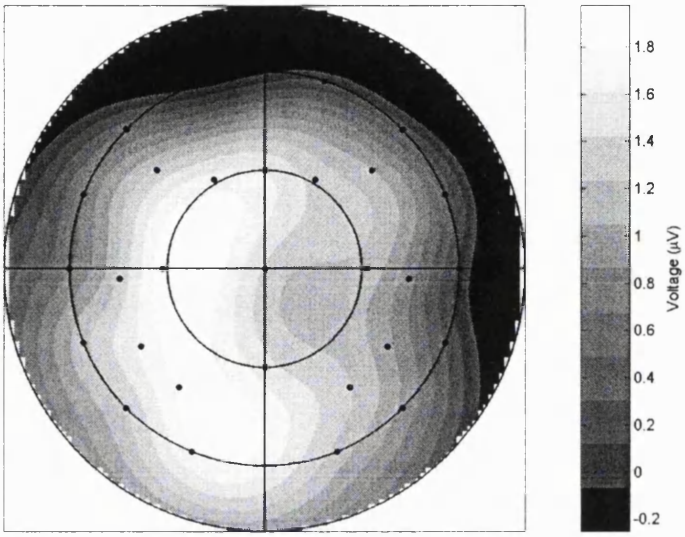

Figure 8.5. Voltage spline maps showing the topographies of the subsequent effect for Intra pairs [differences between Intra CR(s) and Intra FA(s)] during the 1000-1400 ms time region in the study phase of Experiment 5.

8.4.1.3 Summary of Study Phase ERP Results

For the study pairs that later served as Old pairs at test, the ERPs were more positive when these pairs were subsequently correctly identified than when they were incorrectly rejected. This positive-going effect, with maximal magnitude during 1000-1400 ms after stimulus onset, was located over anterior scalp. In addition to this 'Subsequent Memory Effect' for identifying Old pairs, it was also found that The ERPs recorded during encoding were also predictive of the subsequent performance for the Intra pairs. For the study pairs containing second words that subsequently appeared in these pairs, the ERPs were more positive when the Intra pair was correctly rejected than when it was incorrectly identified. This positive-going effect was located over the left hemisphere. The scalp distributions of the two subsequent memory effects appeared to be different.

8.4.2 ERPs at Test

Averaged ERPs were formed for Hit(t), Intra FA(t), and Old-New CR based on data from 19 subjects who contributed sufficient valid ERP trials in these three response categories. The mean trial numbers (range in brackets) of the 19 subjects to these three response categories were 60 (32-84), 30(17-44), and 50 (24-70) respectively. One of the 19 subjects contributed fewer than 16 false alarms to Intra pairs, and the data of this subject were excluded from analyses involving the response category of Intra CR(t). The mean trial numbers of the remaining 18 subjects contributing ERPs for Hit(t), Intra FA(t), Intra CR(t), and Old-New CR were 61 (32-84), 30 (17-44), 27 (16-43), and 52 (29-70) respectively.

Grand average ERP waveforms overlaid by condition are shown in figures 8.6 and 8.7. As can be seen from figure 8.6, the waveforms diverge from around 300 ms after stimulus onset, with the waveforms associated with Hit(t) and Intra FA(t) more positive-going than those associated with Old-New CR. This positive shift of Hit(t) and Intra FA(t) was larger over the left hemisphere in the early time region, with similar amplitude at anterior and posterior scalp sites, and is larger over the right than the left hemisphere at frontal sites in the late time latency. Figure 8.7 shows that there is a negative shift associated with Intra CR(t) in comparison to Old-New CR at the posterior scalp sites starting at around 900 ms after stimulus onset.

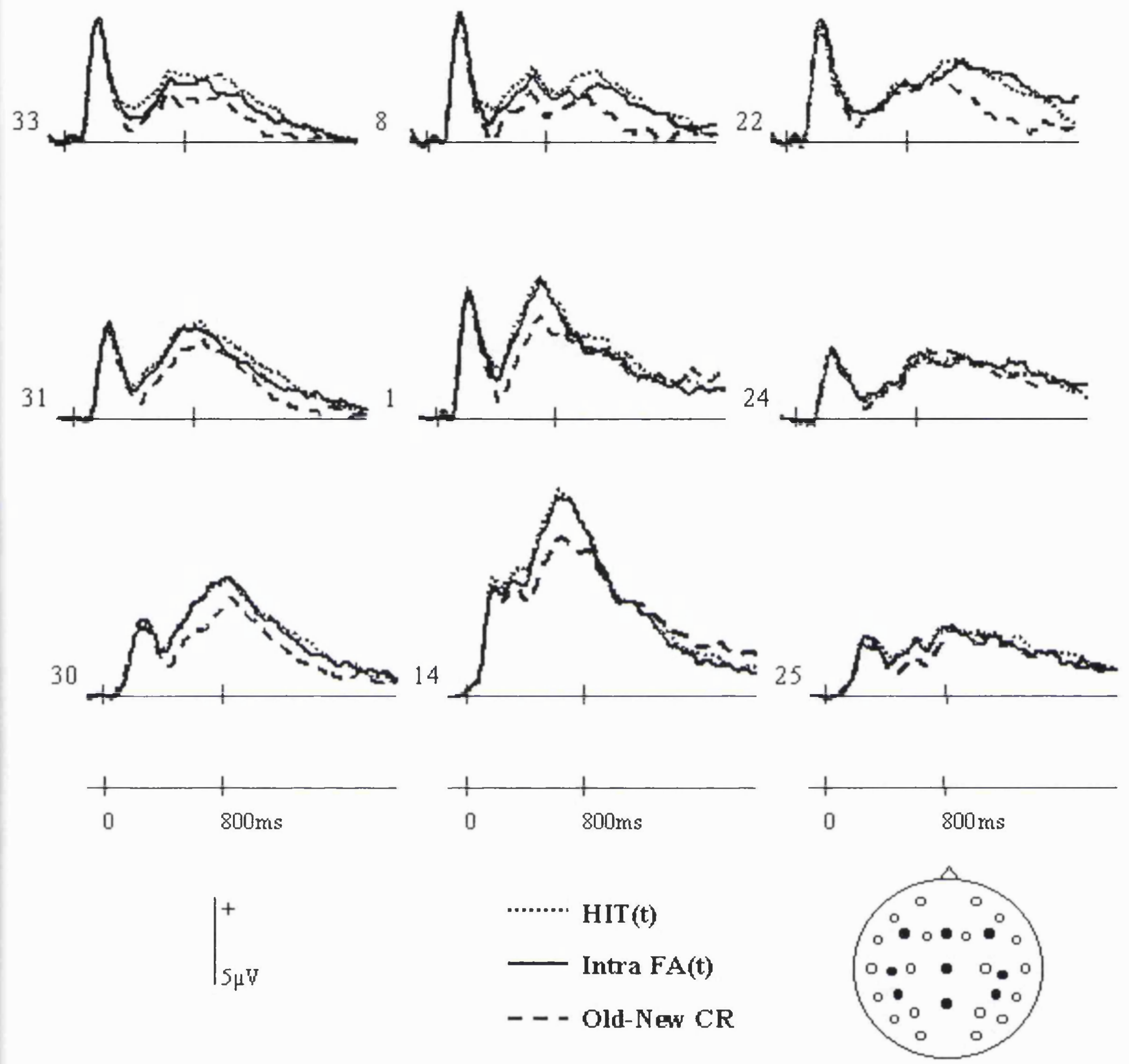

Figure 8.6. Grand average waveforms (N=19) for Hit(t), Intra FA(t), and Old-New CR trials recorded during the test phase of Experiment 5.

8.4.2.1 Test Phase Amplitude Analyses

Following the analysis method employed in Experiment 2, two sets of analyses were conducted to separately investigate the left parietal/right frontal effects, as well as the early frontal effect respectively. The time regions (300-600, 600-900, 900-1400, and 1400-1900 ms), as well as the lateral and the midfrontal sites selected for these two sets of analyses, were the same as those used in Experiment 2.

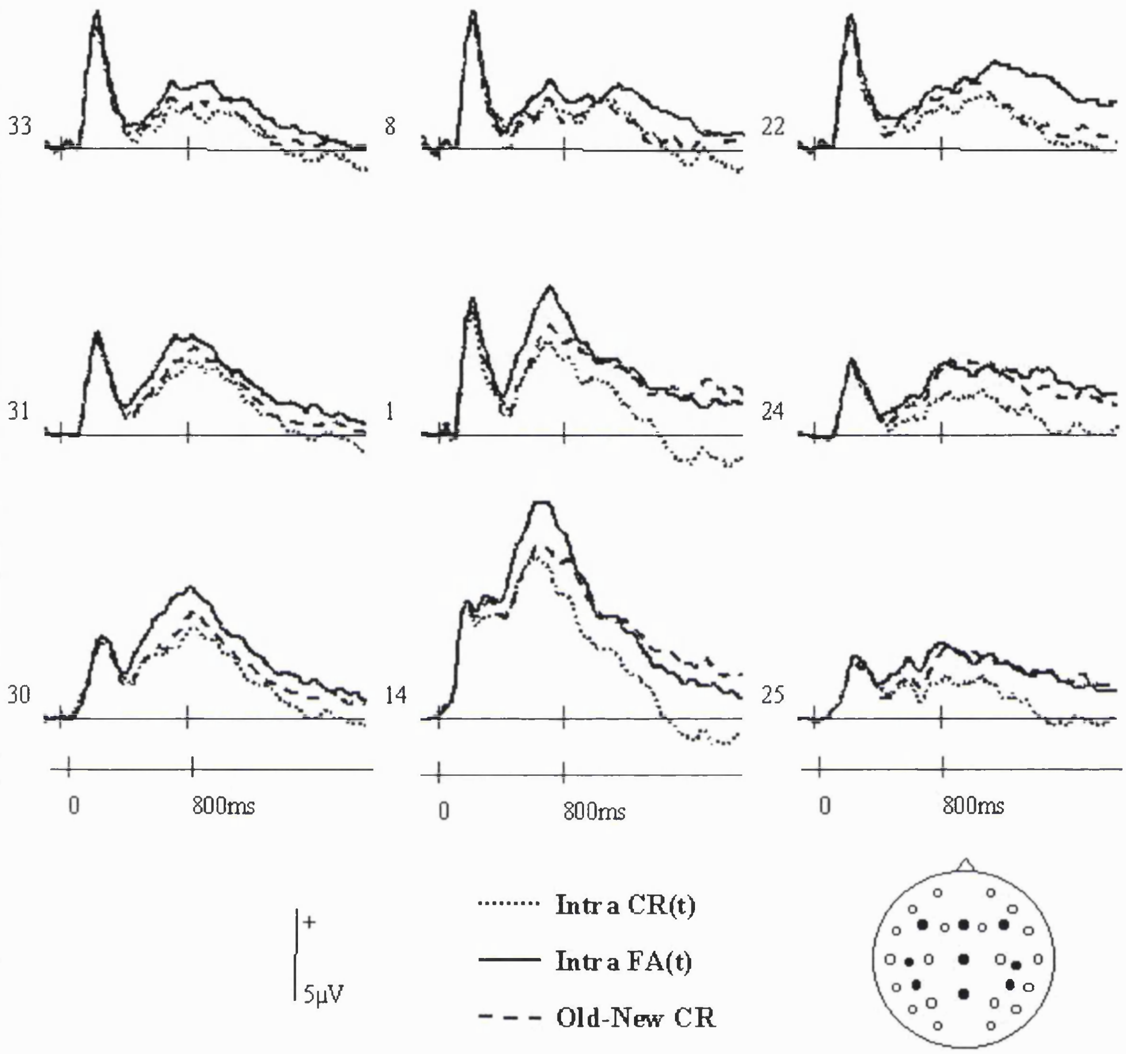

Figure 8.7. Grand average waveforms (N=18) for Intra CR(t), Intra FA(t), and Old-New CR trials recorded during the test phase of Experiment 5.

8.4.2.1.1 Analyses of Lateral Sites

Table 8.2 shows the results of overall ANOVAs for the four time regions based on the data from the 19 subjects who contributed sufficient Hit (t), Intra FA(t), and Old-New CR trials. As can be seen from the table, there were significant effects involving Response Category in all four time regions. Similar results were obtained from the ANOVAs in which correct rejections to Intra pairs were included, based on the data from the 18 subjects who contributed enough Intra CR(t) trials. In light of these significant effects, subsidiary ANOVAs for pairwise comparisons between response categories were performed. The results of these ANOVAs are listed in Table 8.3 and elucidated below. Mean amplitudes associated with the ERP effects for Hit(t), Intra FA(t), and Intra CR(t) in comparison to Old-New CR are shown at anterior, central, and posterior sites across each of the four latency regions in figure 8.8.

Table 8.2. Results of overall ANOVAs of the magnitude analyses over each latency region in the test phase of Experiment 5. [a,b]

	300-600 ms	600-900 ms	900-1400 ms	1400-1900 ms
RC		F(1.8,33)=3.99*	-	-
RC x HM	-	F(1.8,31.9)=5.2**	-	F(3.2,53.8)=3.02*
RC x AP			F(1.9,34.1)=3.22*	F(2.4,43.1)=3.39*
RC x ST	F(2.2,39.2)=4.74*	F(2.3,42)=10.07***	-	-
RC x HM x AP	-	-	F(1.7,31)=4.05*	F(2.1,37.4)=7.57**
RC x AP x ST	-	-	-	F(5.6,95)=2.26*

a. Only significant effects involving the factor of response category are reported.
b. RC=response category, HM=hemisphere, AP=anterior-posterior location, ST=electrode site.
*** p<.001; ** p<.01; * p<.05

Hit(t) vs. Old-New CR. As can be seen from figure 8.6 and table 8.3, the ERPs associated with Hit(t) was significantly more positive-going than those associated with Old-New CR during the 300-600 ms time region. The two-way interaction between Response Category and Site was significant. Follow-up analyses showed that the positive effect for Hit(t) in comparison to Old-New CR was significant at superior sites [F(1,18)=8.63, p<.01], but not at medial or inferior sites (p=.28 & p=.08 respectively). Another set of analyses conducted on midline electrode sites also showed that the ERPs associated with Hit(t) were more positive-going than the ERPs associated with Old-New CR [F(1,18)=14.88, p=.001].

Table 8.3. Results of subsidiary ANOVAs of the magnitude analyses over each latency region in the test phase of Experiment 5.[a,b]

	Hit(t) vs. Old-New CR	Intra FA(t) vs. Old-New CR	Hit(t) vs. Intra FA(t)	Intra CR(t) vs. Old-New CR[c]
300-600 ms				
RC	F(1,18)=4.52*	-	-	-
RC x ST	F(1.3,24)=11.84***	F(1.2,22)=3.92*	-	-
600-900 ms				
RC	F(1,18)=7.72**	F(1,18)=6.37*	-	-
RC x HM	F(1,18)=6.74*	F(1,18)=8.05**	-	-
RC x AP	-	F(1.3,22.8)=3.85*	-	-
RC x ST	F(1.2,21.3)=17.43***	F(1.2,21.4)=12.23***	-	-
RC x HM x AP	-	-	F(1.9,34.3)=5.03**	-
900-1400 ms				
RC	F(1,18)=5.21*	F(1,18)=4.66*	-	
RC x AP	F(1.1,20.2)=7.05**	-	-	F(1.3,22.3)=3.76*
RC x HM x AP	-	F(1.4,24.3)=4.1*	F(1.7,30.1)=7.71**	F(2.5,42.4)=4.78**
RC x AP x ST	F(3,54)=2.73*	-	-	-
1400-1900 ms				
RC	-	-	-	F(1,17)=5.09*
RC x AP	F(1.2,22.4)=6.96**	-	-	F(1.3,22.5)=4.43*
RC x HM x AP	F(1.9,33.9)=4.8*	F(1.4,24.8)=10.01**	F(1.7,30.9)=2.55**	F(1.6,27.2)=4.44*

[a.] Only significant effects involving the factor of response category are reported.
[b.] RC=response category, HM=hemisphere, AP=anterior-posterior location, ST=electrode site, *** p<.001; ** p<.01; * p<.05.
[c.] Comparisons were based on data from 18 subjects who contributed sufficient Inter CR(t) trials.

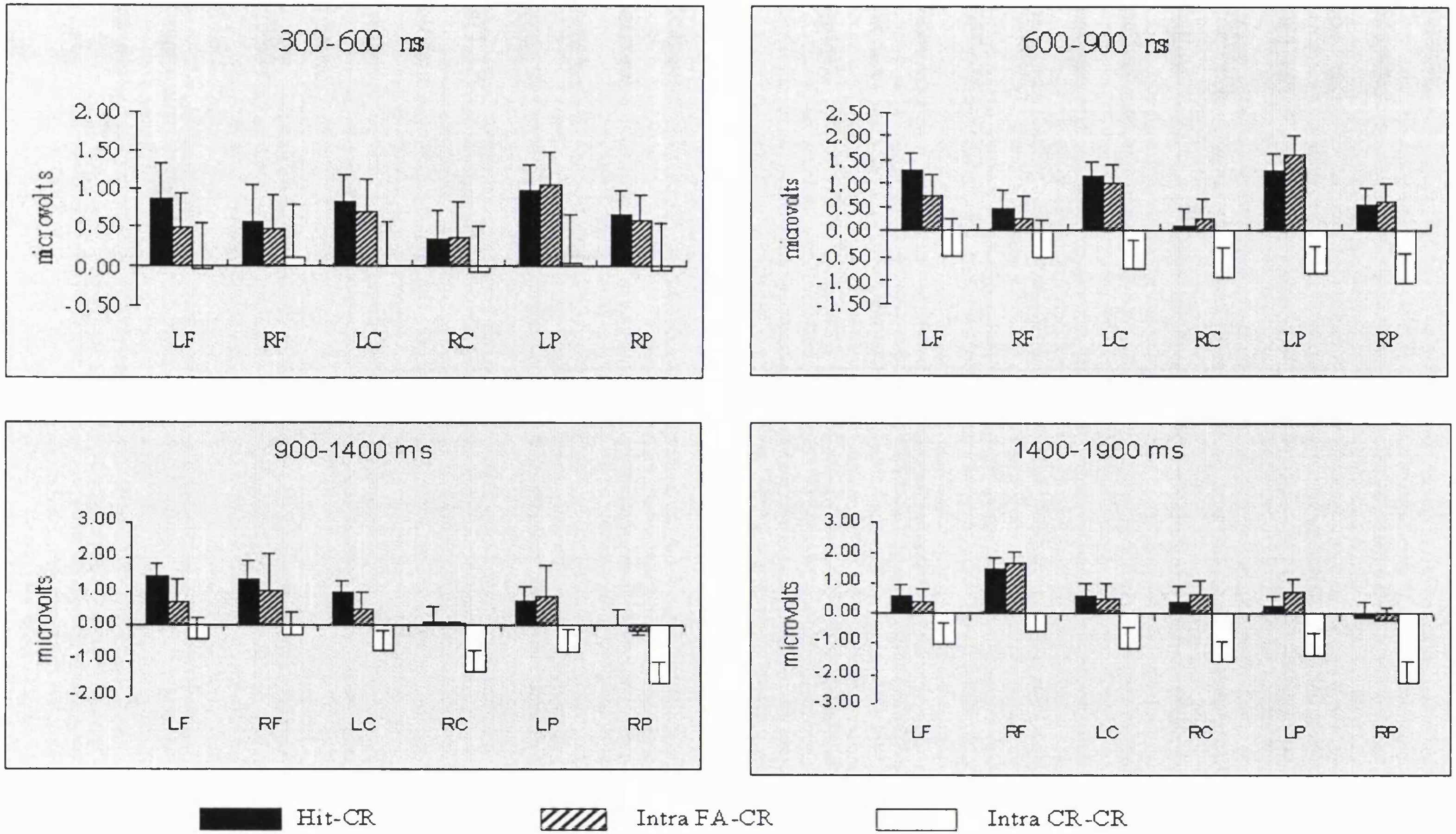

Figure 8.8. Mean amplitudes (with standard errors) associated with the ERP effects for Hit(t) (N=19), Intra FA(t) (N=19), and Intra FA(t) (N=18), in comparison to Old-New CRs at anterior, central, and posterior sites across the four time regions in Experiment 5.

In the 600-900 ms time region, the ERPs associated with Hit(t) was significantly more positive than those associated with Old-New CR. The two-way interaction between Response Category and Hemisphere was also significant. Follow-up analyses showed that the effect of Response Category was significant over the left hemisphere [$F(1,18)=13.33$, $p<.005$], but was not significant over the right hemisphere ($p=.22$). In addition, there was a significant interaction between Response Category and Site. Follow-up analyses showed that the effect of Response Category was significant at medial and superior sites [$F(1,18)=6.91$, $p<.05$ & $F(1,18)=13.09$, $p<.01$ respectively] but was not significant at inferior sites ($p=.29$). Another set of analyses conducted on midline electrode sites also showed that the ERPs associated with Hit(t) were more positive-going than the ERPs associated with Old-New CR [$F(1,18)=14.52$, $p=.001$]. Taken together, these results suggested that the positive-going effect for Hit(t) in comparison to Old-New CR was located over the left hemisphere, and was larger over medial and superior scalp regions, as can be seen from figure 8.8.

In the 900-1400 ms time region, as can be seen from table 8.3, the main effect of Response Category and its interaction with Location were significant. The interaction between Response Category and Hemisphere was not significant but approached significance [$F(1,18)=3.98$, $p=.06$]. Follow-up analyses showed that the positive-going effect for Hit(t) as opposed to Old-New CR was significant over the anterior scalp region [$F(1,18)=10.98$, $p<.005$], and the distribution of this anterior effect was bilateral as the interaction between Response Category and Hemisphere was not significant ($p=0.9$). At the central and posterior scalp regions, the main effect of Response Category was not significant ($p=.12$ and .31 respectively). However, the interaction between Response Category and Hemisphere was significant at these regions [$F(1,18)=4.54$, $p<.05$, and $F(1,18)=4.28$, $p=.05$ respectively]. Separate analyses showed that the main effect of Response Category was significant in the left central scalp region [$F(1,18)=8.58$, $p<.01$], but not in the left posterior, right central and right posterior scalp regions ($p=.08$, $p=.78$, and $p=.93$ respectively). These results suggested that the left-hemispheric distributed positive-going effect for HIT(t) in comparison to Old-New CR observed during the 600-

900 ms time region shifted to bilateral anterior regions during the 900-1400 ms time region.

In the 1400-1900 ms time region, the two-way interaction between Response Category and Location, and the three-way interaction between Response Category, Hemisphere, and Location were significant. Follow-up analyses showed that the ERPs associated with Hit(t) was significantly more positive-going than the ERPs associated with Old-New CR at right anterior scalp sites [$F(1,18)=12.72$, $p<.005$] but not at left anterior scalp sites ($p=.18$) or other areas. These results suggested that the bilateral anterior positive effect of Hit(t) in comparison to Old-New CR observed in the 900-1400 ms latency shifted to the right anterior scalp region in the 1400-1900 ms time region.

Intra FA(t) vs. Old-New CR. As can be seen from table 8.3, the only significant effect in the 300-600 ms time region was the interaction between Response Category and Site. Follow-up analyses showed that the effect of response category was significant over the superior electrode sites [$F(1,18)=4.3$, $p=.05$]. A separate ANOVA conducted on data from the midline electrode sites also revealed a significant effect of Response Category [$F(1,18)=5.45$, $p<.05$]. These results reflected the fact that the ERPs associated with Intra FA(t) were more positive-going than the ERPs associated with Old-New CR over the superior scalp region.

In the 600-900 ms time region, the main effect of Response Category was significant. The two-way interaction effects between Response Category and Location, as well as between Response Category and Hemisphere were also significant. Follow-up analyses showed that the effect of Response Category was significant over the left hemisphere [$F(1,18)=13.56$, $p<.005$] but was not significant over the right hemisphere ($p=.17$). It was also shown that the interaction between Response Category and Location was significant over the left hemisphere [$F(1.3,23.1)=3.76$, $p=.05$]. Follow-up analyses were conducted on data from left anterior, central, and posterior sites. The results showed that the difference between Intra FA(t) and Old-New CR was significant at left central and posterior sties [F(1,18)=6.16, p<.05, F(1,18)=13.59, p<.005, respectively], but was not significant at left anterior sites (p=.09). Taken together, these results reflect the fact that the ERPs associated with Intra FA(t) were more positive-going than those associated with Old-New pairs over left central and posterior regions, as shown in figure 8.8..

In the 900-1400 ms time region, the ANOVAs showed that the main effect of Response Category, and the three-way interaction effect between Response Category, Hemisphere, and Location were significant. Follow-up analyses showed that the difference between the ERPs associated with Intra FA(t) and the ERPs associated with Old-New CR was significant over the right anterior scalp sites [F(1,18)=6.14, p<.05], approached significance over the left anterior and left posterior region (p=.07, and p=.06 respectively), and was not significant over other scalp areas.

In the 1400-1900 ms time region, the three-way interaction between Response Category, Hemisphere, and Location was significant. Follow-up analyses showed that the effect of Response Category was significant over anterior scalp region [F(1,18)=7.62, p<.05] but was not significant over central or posterior scalp regions (p=.13 & p=.55 respectively). The ANOVA conducted on data from anterior sites also revealed a significant interaction effect between Response Category and Hemisphere [F(1,18)=8.42, p=.01]. Further analyses showed that the effect of Response Category was significant at right anterior sites [F(1,18)=16.87, p=.001] but not at left anterior sites (p=.45). These results reflect the fact that the ERPs associated with Intra FA(t) were more positive-going than the ERPs associated with Old-New CR at right anterior sites during the 1400-1900 ms time region.

Hit(t) vs. Intra FA(t). As can be seen from table 8.3, the ANOVAs comparing the ERPs associated with Hit(t) and Intra FA(t) revealed that the three-way interaction between Response Category, Hemisphere and Location was significant in the 600-900, 900-1400, and 1400-1900 ms time regions. These interactions reflected variations in the scalp distribution of the positive-going effect for Hit(t) trials in comparison to Intra FA(t) trials over the left frontal but not other scalp regions. Follow-up analyses showed that, during the 900-1400 ms time region, the ERPs associated with Hit(t) were significantly more positive going than Intra FA(t) over the left anterior scalp region but not at other scalp regions [$F(1,18)=4.96$, $p<.05$]. In the 600-900 and 1400-1900 ms time regions, separate analyses conducted on the six scalp regions did not show any significant effect involving the factor of Response Category.

Intra CR(t) and Old-New CR. Table 8.3 shows that, during the 900-1400 ms time region, the two-way interaction between Response Category and Location, as well as the three-way interaction between Response Category, Location, and Site were significant. Follow-up analyses showed that the effect of Response Category was significant at right central and posterior scalp regions [$F(1,17)=4.74$, $p<.05$ & $F(1,17)=7.315$, $p<.05$ respectively]. These results reflect the fact that the ERPs associated with Intra CR(t) were more negative-going than the ERPs associated with Old-New CR at right posterior scalp regions, as shown in figure 8.7. The negative-going effect for Intra FA(t) in comparison to Old-New CR was also observed in the 1400-1900 ms time region, during which the main effect of Response Category, the two-way interaction between Response Category and Location, as well as the three-way interaction between Response Category, Hemisphere, and Location were significant. Follow-up analyses showed that effect of Response Category was significant over the central and posterior scalp region [$F(1,17)=5.24$, $p<.005$, and $F(1,17)=7.79$, $p<.05$ respectively].

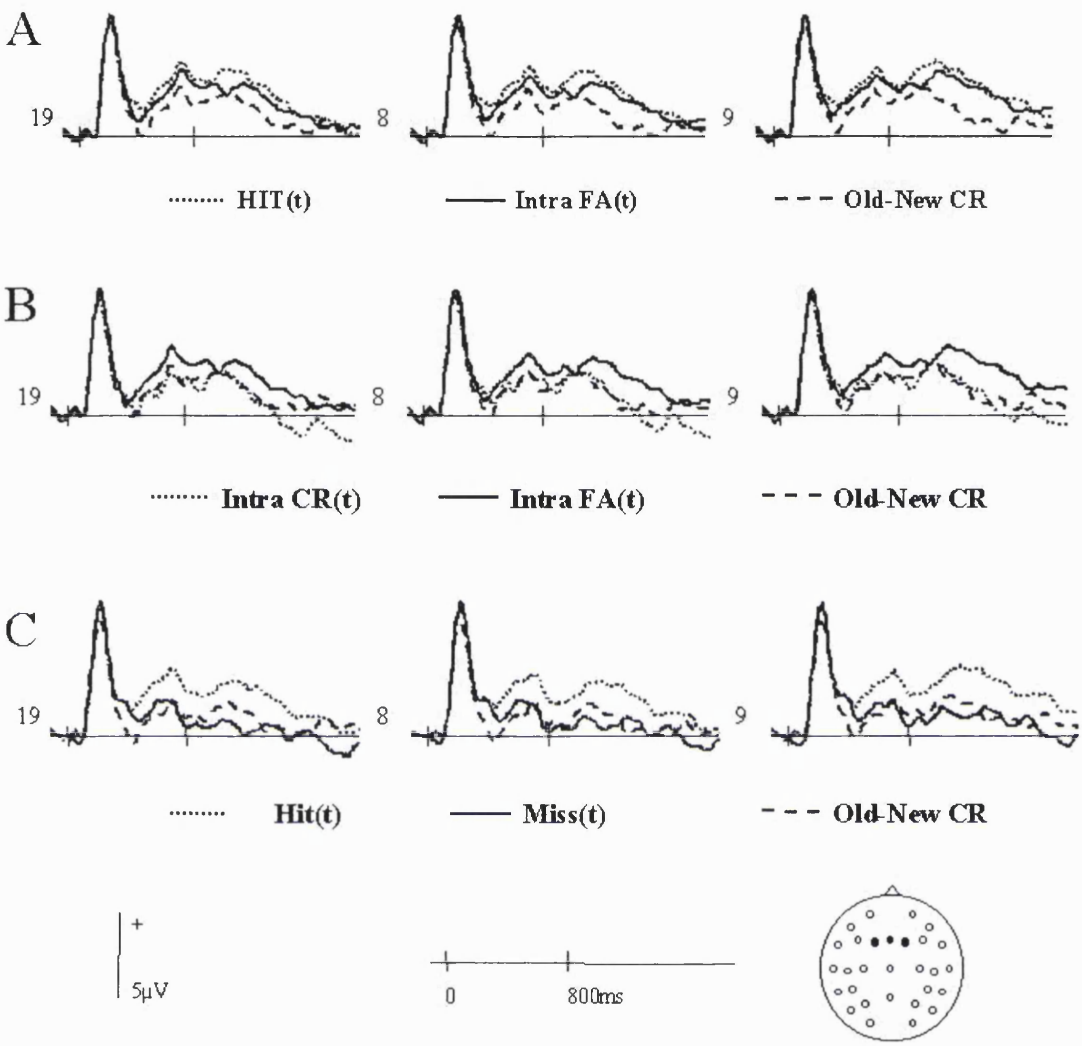

Figure 8.9. ERP waveforms associated with different response categories at midfrontal sites recorded during the test phase of Experiment 5. A: waveforms for Hit(t), Intra FA(t), Old-New CR; B: waveforms for Intra CR(t), Intra FA(t), Old-New CR; C: waveforms for Hit(t), Miss(t), Old-New CR.

8.4.2.1.2 Analyses of Midfrontal Sites

The waveforms from the midfrontal sites (19,8,9) are shown in figure 8.9. The ANOVAs based on data from all the 19 subjects showed that the ERPs associated with Hits and Intra FA(t) did not differ from each other ($p=.48$). It was also shown that the ERPs associated with Hits were more positive-going than those associated with Old-New CR at midfrontal sites [$F(1,18)=5.26$, $p<.05$]. However, the difference between the ERPs associated with Intra FA(t) and Old-New CR was not significant ($p=.12$). Pairwise comparison between Miss and Old-New CR, as well as Intra CR(t) and Old-New CR were also conducted. It was shown that, based on data from 18 and 14 subjects who contributed sufficient Miss and Intra CR(t) trials, the ERPs associated with Miss and Intra CRs were not significantly different from those associated with Old-New CR (p=.11 and p=.16 respectively).

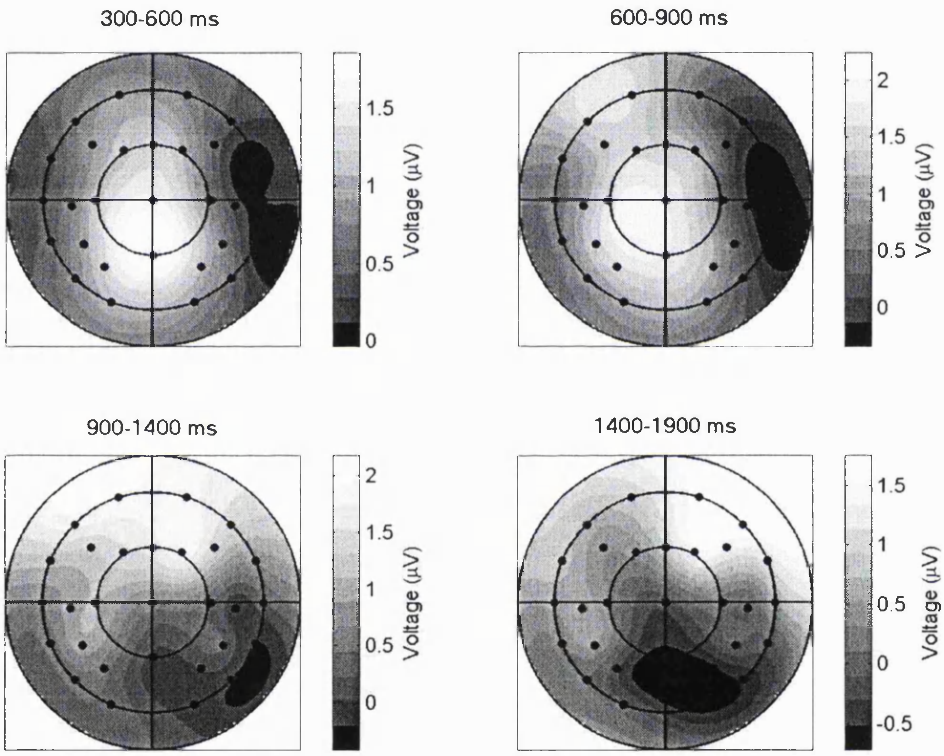

Figure 8.10. Voltage spline maps showing the topographies of the old/new effect for Old pairs (differences between Hit and Old-New CR) across four latency regions in the test phase of Experiment 5.

8.4.2.2 Test Phase Topographical Analyses

The topographical distributions of the old/new effect for Old pairs and the 'false recognition effect' for Intra pairs are shown in figures 8.10 and 8.11. Both effects began in the 300-600 ms time region with a maximum over the central scalp. The effects shifted to the left scalp in the 600-900 time region and to right frontal sites in the 900-1400 and 1400-1900 time regions. The topographies of these two effects were very similar across the four EEG recording epochs. ANOVAs showed that the topographical distributions of the Old/New effect for Old pairs and the false recognition effect for Intra pairs were statistically indistinguishable. The difference between the two effects did not interact with time regions or electrode sites (all Fs<1). However, the interaction between time region and electrode sites was significant [F(5.3,95.7)=5.52, p<0.001], indicating that the distributions of both effects changed with time, as would be expected given the pattern in figure 8.6.

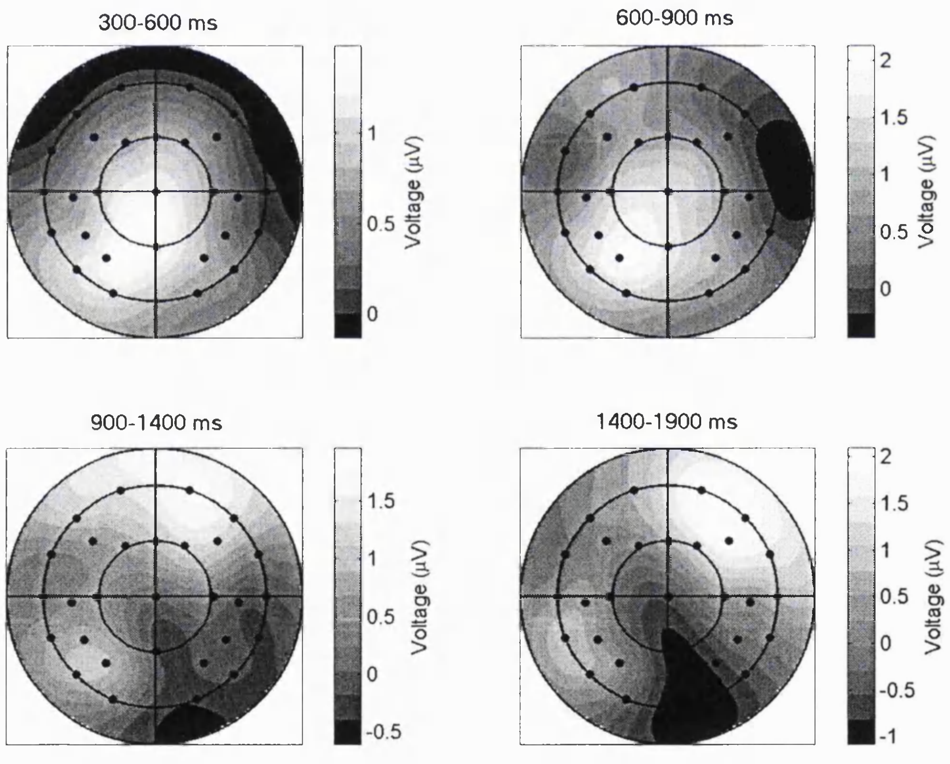

Figure 8.11. Voltage spline maps showing the topographies of the false recognition effect for Intra pairs (differences between Intra FA and Old-New CR) across four latency regions during the test phase of Experiment 5.

8.4.2.3 Summary of Test Phase ERP Results

ERPs associated with correctly classified Old pairs were more positive than those associated with correct rejections to Old-New pairs. In the 300-600 ms time region, this positivity was distributed over the central scalp at superior sites. Between 600ms and 900 ms, the positive-going effect was larger over the left hemisphere. From 900 ms to the end of the recording epoch, the positive effect shifted to frontal sites and was larger over the right than the left hemisphere. The ERPs associated with hit trials were more positive-going than the ERPs associated with false alarms to Intra pairs over left frontal scalp regions in the 900-1400 ms time region. However, statistically indistinguishable left parietal and right frontal effects, in terms of both amplitude and topography, were observed when comparing the ERPs associated with false alarms to Intra pairs, and the ERPs associated with hits to Old pairs, with those associated with correct rejections to Old-New pairs.

8.5 Discussion

8.5.1 Behavioural Performance at Test

The experimental procedure employed in the current experiment was the same as that employed in Experiment 2, except that study pairs belonging to the same list were presented one at a time in the current experiment, but were presented concurrently in Experiment 2. In the current experiment, Intra and Inter pairs gave rise to markedly different false alarm rates, with the former items yielding the higher rate. This finding, replicating the results of Experiment 2, suggests that gist memories were formed for study lists during the encoding phase, and led subjects to respond differently to Intra pairs and Inter pairs on the subsequent memory test. Partial information derived from the gist memories allowed the rejection of Inter pairs that contained initial words incongruent with a gist memory. However, the same partial information biased subjects to accept Intra pairs, which were congruent with the gist. The difference between the false alarm rates for Intra pairs and for Inter pairs was comparable in the current experiment and in Experiment 2. This finding suggests that presenting study pairs of the same list one at a time or concurrently does not affect the formation of gist memories for the study lists.

The pattern of behavioural responses to Old pairs and Intra pairs in the current experiment was, however, different from that observed in Experiment 2. In Experiment 2, the false alarm rate for Intra pairs was the same as the hit rate for Old pairs. By contrast, in the current experiment, the hit rate was significantly higher than the false alarm rate for Intra pairs, suggesting that subjects in the current experiment did better in discriminating Old pairs from Intra pairs than subjects in Experiment 2. Furthermore, the response times associated with false alarms to Intra pairs and hit trials in Experiment 2 were not different from each other. In the current experiment, however, the response time associated with false alarms to Intra pairs was longer than that associated with hit trials. It was also found that while the hit rate was correlated with the false alarm rate for Intra pairs in Experiment 2, they were not correlated with each other in the current experiment (see table 8.4).

Table 8.4. The correlation between the proportions of old responses to different stimulus types in Experiments 2 and 5 (*: p<.05; n.s.: nonsignificant).

Experiment 2	Intra	Inter	Old-New
Hit	.49*	-.36 (n.s.)	-.34 (n.s.)
Intra		.20 (n.s.)	.08 (n.s.)
Inter			.78*
Experiment 5	Intra	Inter	Old-New
Hit	.34 (n.s.)	-.07 (n.s.)	.06 (n.s.)
Intra		.61*	.55*
Inter			.87*

The different ways of presenting study stimuli in the two experiments seem likely to have been responsible for the different patterns of performance for Old and Intra pairs in the two experiments. A plausible explanation is that presenting study pairs individually, in comparison to presenting them concurrently, permitted more information that is specific to studied pairs to be encoded at study and support the later retrieval. Both Old and Intra pairs can be identified by retrieving partial information from the gist memories. However, only Old pairs can be identified by retrieving pair-specific information, which resulted in a higher hit rate than the false alarm rate for Intra pairs.

8.5.2 ERP Effects Observed at Test

In contrast to the different patterns of behavioural responses to Old pairs and Intra pairs, the ERP effects obtained at test for these two classes of items were not distinguishable from each other. The left parietal and right frontal effects, thought to index recollection-based and post-retrieval monitoring processes respectively, were observed for both correctly identified Old pairs and incorrectly classified Intra pairs. The scalp distributions of the left parietal and right frontal effects for correctly identified Old pairs were statistically indistinguishable from those for incorrectly identified Intra pairs. This finding, replicating Experiment 2, suggests that recollection and post-retrieval monitoring processes are similarly involved in false alarms to Intra pairs and hits to Old pairs. Nevertheless, this finding is at variance with the notion derived from behavioural results that pair-specific information is differently involved in identifying Old pairs and Intra pairs. As pair-specific information contributed to identifying Old pairs but not to identifying Intra pairs, the ERP effects associated with Old and Intra pairs might have been expected to be different to reflect the different quantity or quality of information involved in these two response categories. Specifically, given that pair-specific information concerns the association between the initial and second words, its contribution to identifying Old pairs should be recollection-based as associative recognition (Yonelinas, 1997), and should have been reflected by the left parietal effect (Donaldson & Rugg, 1998).

The question therefore arises why the ERP effects, particularly the left parietal effect, observed for Old pairs and Intra pairs were indistinguishable from each other. One possible answer is that the left parietal effect is not sensitive to the difference between pair-specific information and partial information derived from the gist memories. Therefore, although Old pairs and Intra pairs were not identified on exactly the same bases, this subtle difference was not reflected by the left parietal effect. An alternative answer is that although Old pairs could be identified on the basis of pair-specific information, a large proportion of Old pairs were, in fact, identified on the basis of partial information derived from gist memories as Intra pairs. The contribution of pair-specific information in identifying Old pairs was relatively smaller than that of partial information, which plays a major role in identifying both Old and Intra pairs. Therefore, the left parietal effect observed for both Old and Intra pairs reflected mainly the contribution of partial information derived from gist memories, and was not different for these two response categories.

8.5.3 ERP Effects Observed at Study

The main issue addressed in the current experiment was the relation between the ERPs elicited by the word pairs at study and the accuracy of the subsequent memory test for these word pairs. Two classes of subsequent memory effects, concerning the neural correlates of successful encoding for identifying Old pairs and that for rejecting Intra pairs respectively, were examined. These two classes of subsequent memory effect are hereafter referred to as 'subsequent memory effect for Old pairs' and 'subsequent memory effect for Intra pairs' respectively. The subsequent memory effect for Old pairs takes the form that, for study pairs serving as Old pairs at test, the ERPs were more positive when these pairs were subsequently correctly identified than when they were incorrectly rejected. A similar positive-going effect for items associated with later correct memory judgements, as opposed to items associated with later incorrect memory judgments, was revealed in the subsequent memory effect for Intra pairs. For the study pairs containing second words that subsequently appeared in Intra pairs, the ERPs were more positive when the Intra pair was correctly rejected than when it was incorrectly identified. Both classes of subsequent memory effect onset at around the same time and had a similar duration. Nevertheless, the scalp distributions of the two subsequent memory effects were not the same. The subsequent memory effect for Old pairs was distributed over bilateral frontal regions, whereas the subsequent memory effect for Intra pairs was located over the left hemisphere. In the discussion that follows, possible encoding processes indexed by these two subsequent memory effects are discussed.

Except for its late onset, the frontally distributed subsequent memory effect for Old pairs closely resembles the subsequent memory effects observed in several previous studies in which subjects were encouraged to adopt elaborative encoding strategies (e.g., Fabiani, Karis, & Donchin, 1990; Paller et al., 1987; Van Petten & Senkfor, 1996; Weyerts et al., 1997). It has been suggested that this frontally distributed subsequent memory effect represents elaborative or inter-item associative encoding (Fernandez, Weyerts, Tendolkar, Smid, Scholz, & Heinze, 1998; Mangels, Picton, & Craik, 2001). Among these studies, the one conducted by Weyerts et al. (1997) is of particular interest in the present context. Subjects in their study were presented with unrelated word pairs at study, and engaged in two types of deep encoding task. In an associative task, subjects made a semantic association between the two members of each word pair, whereas in the non-associative task, subjects made semantic judgments separately to each of the two words. Weyerts et al. (1997) found that ERPs elicited by word pairs presented in the associative task were more positive-going when these word pairs were subsequently recognised than when they were subsequently incorrectly rejected. This subsequent memory effect, which was maximal over frontal sites, was however not observed for word pairs presented in the non-associative task. Weyerts et al. interpreted this effect as reflecting elaborative processing on the association between the two words.

In light of these previous findings, it seems reasonable to suppose that the subsequent memory effect for Old pairs observed in the current experiment reflects the elaborative and associative processing of the two words. A study pair is more likely to be correctly identified on the subsequent memory test if elaborative and associative processes are engaged during encoding, such that the two constituent words are bound together firmly. However, this inter-item associative interpretation might not be entirely suitable for the subsequent memory effect for Old pairs. One characteristic of the design employed in the current experiment is that the initial words and the second words of the same study list belong to separate semantic categories. The semantic relations between the initial words, together with the semantic relations between the second words, thereby promote the formation of gist memories for each list. With this design, the target of the associative processes might be the two semantic categories the initial and second words belonged to, rather than the two constituent words of each pair. If it was this case, the subsequent memory effect for Old pairs might be the neural correlate of the formation of memories of word pairs sharing a similar associative relation, rather than the neural correlate of forming association between the initial and second words of a specific word pair.

Examining the subsequent memory effect for Intra pairs might shed some lights on the issue of whether the subsequent memory effect for Old pairs reflects associative processing on the initial and second words, or on the semantic categories these words belonged to. An Old pair can be identified either by retrieving information specific to the study pair or retrieving the gist of the study list the pair belongs to. By contrast, Intra pairs can be rejected only when pair-specific information is retrieved to oppose the influence of the gist memory, which biases subjects to incorrectly accept Intra pairs. Therefore, pair-specific information is of more importance for rejecting Intra pairs than for accepting Old pairs. If the subsequent memory effect for Old pairs reflect associative processing on the initial and second words that promotes the encoding of pair-specific information, the same pattern of subsequent memory effect should have been observed for rejecting Intra pairs. Nevertheless, the scalp distributions of the two subsequent memory effects for Old pairs and for Intra pairs were different. This observation suggests that the encoding processes correlated with the subsequent memory effect for Old pairs do not fully correspond to the processes that promote the encoding of pair-specific information. It is plausible that the subsequent memory effect for Old pairs is correlated with associative processing that promotes the formation of the gist memory.

The different scalp distributions of the subsequent memory effects for Old pairs and for Intra pairs may be related to the different demands on pair-specific information for identifying Old pairs and rejecting Intra pairs. It is plausible that the subsequent memory effect for Intra pairs reflects the neural correlates of the successful encoding of pair-specific information, which is exploited to oppose the influence of gist memory on the subsequent associative recognition test. The question that follows is what attributes of a specific study pair were encoded to oppose the influence of the gist memory on the subsequent memory test? One candidate is the position in the study lists where the study pairs, whose second words subsequently appeared in correctly rejected Intra pairs, were presented. If there was a particular pattern of the distributions of these pairs in the study list, for instance most of them were located in the initial or final part of the list, the subsequent memory effect for Intra pairs might simply reflect the effect of presentation order. This unappealing possibility can however be excluded, as the positions in the study list of the study pairs that were used to generate Intra pairs were not different according to whether the resulting Intra pairs were rejected or accepted at test. Another candidate is the characteristics of some particular study pairs, whose combinations were salient and distinctive relative to other study pairs. It is possible that better memories were formed for these distinctive pairs than for other non-distinctive pairs, such that most correctly rejected Intra pairs were generated from the distinctive study pairs. However, examining the correctly rejected Intra pairs revealed that these pairs were formed from a variety of different words. Therefore, it is unlikely that the subsequent memory effect for Intra pairs merely reflects the distinctive characteristic of a small set of study pairs.

A more interesting possibility is that the subsequent memory effect for Intra pairs, given its left hemispheric distribution, reflects processing of the lexical or semantic relations between the initial and second words at study. Specifically, the initial and second words were integrated into a unitary code through the associative processing of the phonological and semantic properties of the two constituent words. This proposal resembles the contextual integration hypothesis for the N400 component, which suggests that the amplitude of the N400 component reflect the ease with which an item can be integrated with its context (Rugg, 1990; Rugg & Doyle, 1994). Nevertheless, it should be noted that the subsequent memory effect for Intra pairs observed in the current experiment is not necessarily the manifestation of N400 components due to their differences in the onset latencies, scalp distributions, and polarities. The resulting integrated unitary code of the initial and second words could be viewed as the verbatim representation of a specific study pair as suggested in fuzzy trace theory (Reyna & Brainerd, 1995), which is independent from but not necessarily incongruent with the gist representation of the study list. The verbatim representation therefore supports pair-specific information to be exploited to reject Intra pairs, which are consistent with the gist memory but incongruent with the verbatim representation.

A question that follows is how the pair-specific information encoded at study, as reflected by the subsequent memory effect for Intra pairs, is utilised on the subsequent test? Specifically, how does the pair-specific information interact with the partial information derived from gist memories to reject Intra pairs. An appealing proposal is the recall-to-reject strategy (Clark, 1992; Clark & Gronlund, 1996): the second word of the Intra pair activates the verbatim representation of the original study pair that contains the second word of the Intra pair. Pair-specific information derived from the verbatim representation, which shows that the second word was paired with another initial word at study, then allows the Intra pairs to be correctly rejected. Examining the test phase ERP results showed, however, that no sign of a left parietal effect was observed when comparing the ERPs elicited by correctly rejected Intra pairs and Old-New pairs. This null effect provides little support for the recall-to-reject hypothesis that the original studied pairs were recollected to reject the rearranged Intra pairs.

It might be worth considering the absence of the left parietal effect to correct rejections to Intra pairs together with the finding that the left parietal effect was indistinguishable for hits to Old pairs and false alarms to Intra pairs. Both findings converge to suggest that the exploitation of pair-specific information at test, either to accept Old pairs or to reject Intra pairs, is not reflected by the left parietal effect. One possible explanation for this observation is that processing resources at test are differently allocated to the partial information derived from gist memories and to the pair-specific information derived from verbatim memories. It has been suggested that the left parietal effect is sensitive to the task relevance of retrieved information, and might not be observed when retrieved information is not attended (Herron & Rugg, in press). For instance, Herron and Rugg, in a study employing an exclusion task, reported that correct rejections to nontargets were associated or were not associated with the left parietal effect, depending on the retrieval strategies adopted by subjects. The strong semantic relations between study pairs in the current experiment might render both Old and Intra pairs better cues for gist memories than for the verbatim memories, such that processing resources were allocated to information retrieved from gist memories but not to pair-specific information retrieved from verbatim memories. This might explain why the left parietal effect was not observed in false alarms to Intra pairs, and was indistinguishable for correctly identified Old pairs and incorrectly classified Intra pairs.

Chapter 9. General Discussion

9.1 Introduction

This chapter seeks to bring together the behavioural and ERP findings of the five experiments contained within this thesis, and illustrate how they are generally related to the study of recognition memory. It will begin with a brief summary of the findings from each of the five experiments. This will be followed by a more detailed discussion of the various issues that arose from these experimental findings, including the implications for the study of memory errors and the implications for the functional significance of the ERP effects reviewed in Chapter 4.

9.2 Summary of Experimental Findings

In the study phase of the five experiments, subjects were shown lists of word pairs formed by pairing one of two (Experiments 1,2,4,5), or one of four (Experiment 3), associated words with a group of semantically related or unrelated words. At test, subjects differentiated old pairs from various kinds of rearranged pairs and Old-New pairs, in which a new second word was paired with an old initial word. ERP effects and Remember/Know judgements associated with inaccurate endorsements, or source judgement errors, to these rearranged pairs were examined to investigate whether these errors comprise 'recollection' of episodic details, or alternatively these errors solely reflect undifferentiated familiarity.

Experiment 1: Investigating the Involvement of Recollection in Gist-Based Source Judgement Errors with the Remember/Know Procedure.

In experiment 1, the second words of the study pairs belonging to the same list were semantically related with each other. It was expected that the semantic relations between the initial words and the semantic relations between the second words would encourage the formation of gist memory for each study list. This proposal was supported by the much higher false alarm rate for Intra pairs, generated by re-pairing study pairs belonging to the same list, than for Inter pairs, generated by re-pairing study pairs belonging to different lists. There were also more false alarms to Intra pairs than to Theme pairs, which contained an old initial word and a new second word that was semantically related to the second words the initial word had been paired with at study. The different false alarm rates for Intra and Theme pairs support the notion that false alarms to Intra pairs were not based solely on poor encoding quality. The involvement of recollection and familiarity in memory judgements was examined with the Remember/Know procedure. The finding that Intra pairs attracted more 'R' and 'K' responses than Inter pairs suggests that the excessive false alarms to Intra pairs in comparison to Inter pairs was contributed to by both the recollection of partial information and familiarity.

Experiment 2: Investigating the Involvement of Recollection in Gist-Based Source Judgement Errors with ERPs.

Experiment 2 employed the same experimental design as that described for Experiment 1, with the exception that Theme pairs were not included as test stimuli. Replicating the results of Experiment 1, the false alarm rate for Intra pairs was markedly higher than that for Inter pairs. The left parietal ERP old/new effect and the right frontal effect were observed when comparing the ERPs to correctly endorsed Old pairs with the ERPs to correctly rejected Old-New pairs. The left parietal and right frontal effects were also observed in ERPs to incorrectly endorsed Intra pairs. The topographic distributions of these effects for Old pairs and for Intra pairs were indistinguishable. In contrast, no evidence for the left parietal and right frontal effects were observed in the ERPs to false alarms to Inter pairs. It was argued that the gist-based source judgement errors (i.e., false alarms to Intra pairs) were mediated by the same process supporting the veridical memories for Old pairs, and reflected false recollection of the study episode.

Experiment 3: Investigating the Necessary Conditions for Gist Memory to Modulate Recollection-Based Source Judgement Errors with the Remember/Know Procedure.

The recollection-based source judgement errors for Intra pairs observed in Experiment 2 might have resulted from three characteristics of the study pairs used to generate Intra pairs: (1) the semantic relation between the initial words, (2) the semantic relation between the second words, and (3) the spatial/temporal proximity shared by the study pairs. Experiment 3 aimed to disentangle the influence of these three factors. The false alarm rate for rearranged pairs was found to be higher when the initial words of the study pairs were associated words than when they were not, regardless of whether the second words of these study pairs were semantically related with each other. On the other hand, the false alarm rate for rearranged pairs was not affected by whether the study pairs belonged to the same list or to different lists. It was therefore argued that, in comparison to the semantic relation between the second words, the semantic relation between the initial words of study pairs played a major role in the formation of gist memory. The contribution of the semantic relation between the initial words to gist memory was amplified by the spatial/temporal proximity shared by these study pairs. The involvement of recollection in source judgement errors was examined with the Remember/Know procedure. The number of 'R' responses to rearranged pairs was modulated by the semantic relation between the initial words of the study pairs only when they belonged to the same list. Additionally, the semantic relation between the second words of study pairs had no effects on the number of 'R' responses to rearranged pairs. These findings suggest that both the semantic relations between the initial words and the spatial/temporal proximity shared by the study pairs were required to modulate the involvement of recollection in source judgement errors for rearranged pairs.

Experiment 4: Investigating the Necessary Conditions for Gist Memory to Modulate Recollection-Based Source Judgement Errors with ERPs.

The role of the semantic relation between the sources to be discriminated on source judgement errors was further examined in Experiment 4. Two kinds of rearranged pairs (Associated Intra and Unassociated Intra) were employed, both generated by re-pairing study pairs belonging to the same list. The spatial/temporal proximity and the semantic relation between the second words of the study pairs used to generate the two classes of rearranged pairs were kept constant. Associated Intra and Unassociated Intra pairs differed only in that the former were generated by re-pairing study pairs whose initial words were semantically related, whereas the latter were generated by re-pairing study pairs whose initial words were unrelated. The false alarm rate for Associated Intra pairs was higher than that for Unassociated Intra pairs, suggesting that gist memories were formed for study pairs whose initial words were semantically related. The left parietal effect and the right frontal effect were observed when the ERPs to correctly identified Old pairs were compared with the ERPs to correctly rejected Old-New pairs. The left parietal effect was also observed for incorrectly endorsed Associated Intra pairs. Nevertheless, the left parietal effect was less sustained for incorrectly classified Associated Intra pairs than for correctly identified Old pairs. It was suggested that the different durations of the left parietal effect for Old pairs and Associated Intra pairs reflected different amounts or quality of information recollected in response to these two classes of items.

Experiment 5: The Subsequent Memory Effect for Gist-Based Memory Errors.

Experiment 5 replicated the experimental design of Experiment 2 with the modification that study pairs were presented one at a time. ERPs elicited by study pairs were compared according to the accuracy of the subsequent memory test for these pairs. The behavioural performance and the ERP results of the memory test generally replicated those of Experiment 2. Two subsequent memory effects, concerning the neural correlates of successful encoding for identifying Old pairs and for rejecting Intra pairs respectively, were reported. For the study pairs that served as Old pairs at test, the ERPs were more positive when these pairs were subsequently correctly identified than when they were incorrectly rejected. This positive-going effect was located over the anterior scalp. For the study pairs containing second words that subsequently appeared in Intra pairs, the ERPs were more positive when the Intra pair was correctly rejected than when it was incorrectly identified. This positive-going effect was located over the left hemisphere. The different distributions of the two subsequent memory effects were related to the different demands on pair-specific information for identifying Old pairs and rejecting

Intra pairs. It was suggested that the subsequent effect for accepting Old pairs was correlated with associative processing that promotes the formation of the gist memory. The subsequent effect for rejecting Intra pairs was correlated with forming a unitary code or verbatim representation for the initial and second words.

9.3 Implication for Studies of Memory Errors

The aim of studying memory errors is to elucidate the nature of these interesting phenomena and to advance our understanding of the cognitive/neural processes that underpin veridical memories. This aim can be achieved by comparing the characteristics of veridical and erroneous memories, as well as by identifying factors that contribute to the occurrence of memory errors. The experiments reported in this thesis contributes to this issue by demonstrating how the semantic relation between study items, as well as the similarity between study items and lures, modulates the involvement of recollection in false alarms to these lures.

9.3.1 The Nature of Gist-Based Recollection

The experimental procedure employed in this thesis resembled an associative recognition task, in which subjects distinguish test pairs composed of the same words as were presented at study from pairs composed of new combinations of studied words. However, the experiments reported here differed from the standard associative recognition paradigm in two aspects: the repetition of the initial words, and the semantic relations between the constituent members (either initial words only or both initial and second words) of different study pairs. These two characteristics of study pairs incorporated gist-based false recognition into the associative recognition task. Gist memories were formed for study pairs whose constituent members were semantically related, an attribute that rendered these study pairs similar with each other in respect of the associative relation between the initial and the second words. Following fuzzy-trace/gist theory (Reyna & Brainerd, 1995; Payne et al, 1996), Intra and Associated Intra pairs were more likely than

Inter and Unassociated Intra pairs to be incorrectly identified because the former two types of rearranged pairs were consistent with the gist representations. The finding that the left parietal effect was observed in false alarms to Intra and Associated Intra pairs therefore indicates that recollection was elicited in response to lure pairs that was consistent with gist memory.

The questions that follow are what constitute the content of the recollection derived from the gist in response to Intra pairs and Associated Intra pairs? To what extent is the gist supports the recollection of lures the same as the generic information underpins veridical memories? The fuzzy-trace/gist theory does not clearly specify how recollection is elicited by retrieving gist memories. Originally, it was proposed that retrieval of verbatim memories supports recollection of item-specific information, whereas retrieval of gist memories induces feelings of familiarity (Brainerd, Reyna, & Kneer, 1995; Reyna & Brainerd, 1995). In a latter version of fuzzy-trace theory, it was stated that retrieving gist memories can also lead to recollection-based recognition under certain conditions, such as when the DRM procedure is employed (Brainerd & Reyna, 1998, 2002; Brainerd, Wright, Reyna, Morjardin, 2001). Nevertheless, how recollection-based recognition, either for studied items or for the nonpresented lures, is supported by gist memories was not indicated. The same problem exists for the 'constructive memory framework', which suggests that the nonpresented critical lures in the DRM procedure are incorrectly classified on the basis of overall familiarity or similarity of the lure item to the gist memory (Dodson & Schacter, 2001; Schacter et al, 1998).

The ERP effects and the Remember/Know judgements associated with false alarms to the various kinds of rearranged pairs reported in this thesis offer some potential explanations of how 'false recollection' is derived from the gist. As stated in Chapter 6 (Experiments 1 and 2), the semantic relations between the initial words and the semantic relations between the second words encouraged the formation of the gist memory for study pairs, which supported the recollection-based false alarms to Intra pairs. It is therefore reasonable to propose that the semantic attributes of the study pairs constitute the content of the recollection elicited by Intra pairs. Previous studies exploring the characteristics of gist-based false recognition with DRM procedure have shown that both veridical memories for studied words and erroneous memories for nonpresented lures were predominantly composed of information related to the semantic attributes of the study words as opposed to sensory detail (Mather et al., 1997; Norman & Schacter, 1997). An event-related fMRI study of DRM errors conducted by Cabeza et al. (2001) reported that the anterior medial temporal lobe region was similarly activated for recognised studied words and identified critical lures as opposed to rejected new words. Cabeza et al. argued that the similar activation of the anterior medial temporal lobe for veridical and erroneous memories reflected the recollection of semantic information common to the studied words and the critical lures (see also Schacter et al., 1996 for similar argument in a PET study). Similar to this proposal, the indistinguishable left parietal effect observed for Old pairs and Intra pairs observed in Experiment 2 may reflect the recollection of semantic attributes common to the study pairs and lure pairs.

However, the fact that the stimuli employed in the experiments of this thesis were word pairs rather than single words complicates the notion that the semantic attributes of study pairs constitute the content of the recollection elicited by lures. The semantic attributes of the initial words and those of the second words may play different roles in the formation of gist memory and contribute differently to the involvement of recollection in the false alarms to rearranged pairs. The finding in Experiment 4 that the left parietal effect was observed for false alarms to Associated Intra pairs, generated by re-pairing study pairs whose second words were not related, suggests that the semantic relation between the initial words is sufficient to induce recollection-based false alarms to rearranged pairs. It was also found in Experiment 3 that the number of 'Remember' responses to rearranged pairs was modulated by the semantic relation between the initial words but not by the semantic relation between the second words. Taken together, it appears that the semantic attributes of the initial words played a major role in the formation of gist memory that supports recollection-based memory errors. However, it is not necessary that the contents of recollection derived from gist were exclusively the semantic attributes of the initial words. The finding that the left parietal effect was indistinguishable for Old pairs and Intra pairs (Experiment 2), but was less sustained for Associated Intra pairs than for Old pairs (Experiment 4), suggests that the semantic attributes of the second words contribute to the recollection derived from the gist memory. What is not clear is why the number of 'Remember' response to rearranged pairs was not modulated by the semantic relation between the second words but the ERP results suggested that 'full-blown' recollection-driven errors occurred only when both members of rearranged pairs were semantically related to other studied items. A plausible answer is that the Remember/Know judgement and the left parietal effect are different in their sensitivity to recollection. This issue will be further discussed in a later section that addresses the implications of the findings of this thesis for the ERP old/new effects.

An important finding of Experiment 1 was that Intra pairs attracted a higher false alarm rate and more 'R' responses than Theme pairs. It should be noted that Theme pairs were generated by pairing an old initial word with a new second word that was related to the second words the initial word had been presented with at study. Therefore, the second words of Theme pairs, although not shown at study, shared similar semantic attributes with the second words of Intra pairs. In other words, Theme pairs should have been consistent with the gist formed for the study lists as Intra pairs. Nevertheless, different false alarm rates and proportions of 'R' responses were made to these two classes of lures. As argued in the discussion of Experiment 1, this finding suggests that the formation of gist memory was not due to poor encoding quality. The gist was sensitive to whether the second word had been or had not been presented at study. What the gist was insensitive to was which of the two associated initial words the second word had been paired with at study. This finding, together with the finding that the initial words played a major role in the formation of gist memory, suggests that the semantic relations between the initial words functions as a mediator that binds together the semantic attributes of the study pair into the gist. The semantic attributes of the second words, either related or not related with each other, were bound together because they were paired with the same initial word, or because the initial words they had been paired with were strongly associated. This proposal relates to the 'feature binding' problem in source memory (Chalfonte & Johnson, 1996; Henkel & Franklin, 1998; Henkel, Franklin, & Johnson, 2000). Intra pairs and Associated Intra pairs tend to elicit recollection-based false alarms because the semantic attributes of their second words had been bound to the replaced initial word through the semantic association between the original and the replaced initial words.

The left parietal effect was indistinguishable for correctly identified Old pairs and incorrectly classified Intra pairs (Experiments 2 and 5), but was less sustained for incorrectly classified Associated Intra pairs than for correctly identified Old pairs (Experiment 4). These findings indicate that the binding of study pairs into a gist memory, predominantly mediated by the initial words, was also modulated by the semantic attributes of the second words of the study pairs. When the second words were related, the semantic attributes of the study pairs bound in the gist was cohesive. The gist memory of these study pairs supported the recollection associated with false alarms to Intra pairs to the degree that it was indistinguishable from the recollection associated with Old pairs in hit trials. By contrast, the study pairs whose second words were unrelated words were not bound as cohesive as the study pairs whose second words were related with each other. Therefore, the recollection derived from the gist for Associated Intra pairs was of less quantity or quality than the recollection associated with Old pairs in hit trials, which was reflected by the duration of the left parietal effect.

An interesting finding of experiment 3 was that the semantic relation between the initial words interacted with the spatial/temporal proximity shared by the study pairs on the false alarm rate for the rearranged pairs. Crucially, it was found that the semantic relation between the initial words modulated the number of 'R' responses to rearranged pairs only when these rearranged pairs were generated by re-pairing study pairs belonging to the same list. In other words, the spatial/temporal proximity shared by the study pairs was a necessary condition for the semantic relation between the initial words to bind the study pairs into the gist memory, which later supported recollection-based false alarms to rearranged pairs generated from these study pairs. A plausible explanation for this finding is that the representations of the study pairs in the gist were more difficult to separate (i.e., 'pattern separation', McClelland 1995; Schacter et al., 1998) when the study pairs were presented spatially/temporally adjacent at study then when they were presented apart. It appears that the boundary between the different study pairs in the gist memory were blurred but not totally removed if these study pairs were spatially/temporally apart from each other.

In sum, the gist memory that supported false alarms to lure pairs was formed by binding the semantic attributes of the study pairs. The primary reason why study pairs were bound into the gist was that these study pairs shared the same or strongly associated initial words. To what extent the recollection associated with lure pairs is similar to the recollection associated with studied pairs depends on by how cohesively the study pairs were bound in the gist. In addition to the semantic relation between the initial words, the spatial/temporal proximity between the study pairs was also a necessarily condition to bind the study pairs into the gist that can support recollection-based false alarms to rearranged pairs.

9.3.2 The Encoding and Retrieval of Gist Information and Item-Specific Information

One tenet of fuzzy-trace theory is that gist memory, which contains general semantic information about the whole episode, and verbatim memory, which contains item-specific information, are stored in parallel (Brainerd & Reyna, 1998; Brainerd, Reyna, & Kneer, 1995; Reyna & Brainerd, 1995). It was suggested that the encoding of to-be-remembered items initiates parallel encoding processes for the gist and verbatim memories. On the other hand, the constructive memory framework (Schacter et al., 1998), although similar to fuzzy-trace theory in employing the concepts of gist information and item-specific information to explain DRM errors, does not specify separate representations for these two types of information. If gist information and item-specific information are indeed stored independently as suggested by fuzzy-trace theory, different cognitive/neural mechanisms might have been involved when these two types of information are encoded, which can be investigated by recording the brain activity during the encoding stage. The two sets of subsequent memory effect reported in Experiment 5, concerning the neural correlates of successful encoding for identifying Old pairs and for rejecting Intra pairs, might shed some light on this issue. Old pairs could be identified either by retrieving the gist of the study list or by retrieving item-specific information. By contrast, to reject Intra pairs, item-specific information must be retrieved to oppose the influence of gist information. Hence, item-specific information is of more importance for rejecting Intra pairs than for accepting Old pairs. The subsequent memory effects associated with these two classes of accurate memory judgements may therefore be related to the encoding of gist information and item-specific information. The distinct scalp distributions for these two classes of subsequent memory effects suggest that the neural correlates of forming gist memory and of encoding item-specific information are not equivalent. This finding could not confirm that there are separate representations for gist and item-specific information. Nevertheless, it suggests that the encoding of gist information and the encoding of item-specific information do not rely on equivalent cognitive/neural mechanisms.

Another tenet of fuzzy-trace theory, which relates to the notion of parallel verbatim-gist storage, is that the retrieval of gist memory and verbatim memory are dissociated. Whether gist memory or verbatim memory would be activated relies on the characteristics of the retrieval cues supplied by recognition probes (Brainerd & Reyna, 1998). It was suggested that studied items are better cues for verbatim memory than for gist memory, whereas unstudied but related distractors are better cues for gist memory than for verbatim memory (Reyna & Kiernan, 1994). Furthermore, it was suggested that the retrieval of verbatim memory not only supports acceptance of studied items, but can also lead to the rejection of distractors that are consistent with gist memory (Brainerd, Reyna, & Kneer, 1995). Previous studies have reported that the number of DRM errors was lowered when subjects were encouraged to encode and retrieve item-specific information (Israel & Schacter, 1997; Koutstaal, Schacter, Galluccio, & Stofer, 1999; Schacter, Israel, & Racine, 1999). An important question arises concerning how gist information and item-specific information are probed and interact to allow the lures to be rejected. The proposal that verbatim memory is retrieved to reject gist information (Brainerd, Reyna, & Kneer, 1995) is in line with the recall-to-reject strategy (Clark, 1992; Clark & Gronlund, 1996). However, across the three ERP experiments reported in this thesis, no sign of a left parietal effect was observed when comparing the ERPs to correctly rejected lure pairs with ERPs to correctly rejected Old-New pairs. It appears that the exploitation of item-specific information to reject lures at test was not in the form of recollection indexed by the left parietal effect. This null effect, together with the finding that the left parietal effect was observed for false alarms to lure pairs, is at variance with the proposal of fuzzy-trace theory that verbatim memory is recollected to oppose the familiarity derived from gist memory (Brainerd, Reyna, & Kneer, 1995). A plausible explanation is that how item-specific information is exploited at test is modulated by whether information derived from gist is presented in the form of recollection or familiarity. The strong semantic relations between the study pairs might have rendered gist information of more salience than item specific information, such that processing resources were allocated to the former but not to the latter. The left parietal effect was not observed for correct rejections to lure pairs, in which item-specific information was assumed to be exploited, because this effect might not be observed when retrieved item-specific information was not attended (Herron & Rugg, in press).

9.3.3 Source Memory Errors

The repetition of initial words in different study pairs also incorporated source memory into the modified associative recognition task employed in the experiments reported here, such that false alarms to rearranged pairs could be viewed as source memory errors. Note that in previous source memory studies, 'item' and 'source' usually refer to qualitatively distinct attributes of the stimuli. For instance, a series of words are spoken by a male or a female voice. The identity of the words is referred to as 'item', whereas the voices are referred to as 'sources'. In the experiments reported here, by contrast, 'source' and 'item' referred to the initial and second members of a word pair, which were equally salient elements of the stimuli. One might therefore argue that the memory errors reported here do not properly fall under the rubric of 'source memory errors'. However, it should be noted that there has not been a clear definition for the 'source' and the 'item' of an event (Lindsay, Johnson, & Kwon, 1991; Van Petten, Senkfor, & Newberg, 2000). A general distinction between the 'source' and 'item' is that the former was presented in multiple stimuli, whereas the latter was presented in one specific stimulus. There is a many-to-one mapping between 'item' and 'source'. (Glisky, Rubin, & Davidson, 2001; Van Petten, Senkfor, & Newberg, 2000). In the studies reported here, an initial word was paired with different second words to form multiple study pairs, whereas a second word was shown in only one study pair. Such characteristics of the study pairs rendered the initial words and the second words conform to the definition of 'source', which occurs across multiple stimuli, and the definition of 'item', which occurs in one stimulus. In the test phase of experiments reported here, a second word ('the item') was presented with an initial word ('the source') to form the test pair. Subjects had to judge whether the initial word was the same one that had been paired with the second word at study. In such a procedure, a test pair could be viewed as the combination of the 'copy cues' for the source and the item. The accuracy of the source judgement was related to the source-item pairings probed or activated by these test pairs. False alarms to rearranged pairs could be viewed as 'source judgement errors' resulted from accepting incorrect source-item pairings probed or activated by the rearranged pairs.

The manipulation of the semantic relation between the initial words rendered the source-item pairing more similar for study pairs whose initial words were related words than for study pairs whose initial words were unrelated words. It was not surprising to find that there were more source judgement errors for rearranged pairs generated from similar study pairs than for those generated from dissimilar study pairs, as memory errors occur when items from different sources share common features (Chalfonte & Johnson, 1996; Henkel & Franklin, 1998; Henkel, Franklin, & Johnson, 2000). Nevertheless, it was novel to find that different brain activities were associated with these two classes of source judgement errors. Previous studies have demonstrated that, when there was similarity existing between different sources, imprecise partial information of these sources might be derived and influence source memory performance (Dodson, Holland, & Shimamura, 1998; Dodson & Johnson, 1996; Gruppuso, Lindsay, & Kelley, 1997; Yu & Bellezza, 2000). However, the format of partial information utilised in source memory tasks has yet to be thoroughly examined. It has been suggested by behavioural studies, which employed the Remember/Know procedure and ROC techniques to investigate source memory, that partial information is involved in source memory judgements in the form of familiarity (Qin, Raye, Johnson, & Mitchell, 1999; Hicks, Marsh, & Ritschel, 2002). Consistent with this proposal, it was found in Experiments 1 and 3 that there were more 'K' responses to rearranged pairs generated by study pairs whose initial words were related than when these initial words were unrelated. On the other hand, the finding that the number of 'R' responses to rearranged pairs was also modulated by the semantic relation between the sources (i.e., the initial words) suggests that partial information might also be retrieved in the form of recollection. This notion was further supported by the finding that the left parietal effect was observed for false alarms to Intra pairs (Experiments 2 & 4) and Associated Intra pairs (Experiment 3), as these rearranged pairs were incorrectly identified on the basis of partial information.

How was partial information derived from gist memory involved in recollection-based source judgement errors? A plausible answer to this question is related to the 'source activation account' proposed by Dodson and Shimamura (2000) to explain the cue dependence effect of source memory (see Chapter 2). They suggested that the contextual information presented at test, either congruent or incongruent with the study context, activated source information that facilitates or interferes with the identification of the accurate sources. The properties of other experienced episodes might affect source judgments via some mediator, such as features or components common to different events. In the case of the experiments reported here, it was the semantic attributes of the initial word that might function as the mediator. For study pairs whose initial words were semantically related with each other, there were many semantic attributes in common and relatively few features that can differentiate different source-item pairings. A rearranged pair generated from such study pairs might activate the semantic attributes common to the study pairs' related initial words. These common attributes might in turn activate the attributes or features of the replaced initial word, which had not been paired with the second word at study, and bias subjects to make inaccurate source judgements.

9.4 Implications for ERP Effects of Recognition Memory

In the foregoing discussion, the characteristics and the underlying mechanisms of memory errors reported in this thesis were addressed by examining the ERP effects, whose functional significance has been generally agreed, associated with these memory errors. Reciprocally, examining how memory errors were associated with the ERP effects could advance the understanding of the functional significance of these ERP effects. The following sections discuss the implication of the ERP findings of this thesis for the ERP effects of recognition memory reviewed in Chapter 4.

9.4.1 Parietal Old/New Effect

The parietal old/new effect has been suggested to be associated with recognition accompanied by recollection. This proposal was based on a large array of evidence showing that the left parietal effect was sensitive to variables that assumed to affect recollection more than familiarity (for review see Allan, Wilding, & Rugg, 1998; Friedman & Johnson, 2000; Rugg & Allan, 2000; chapter 4). As would be expected, a parietal effect was presented in the ERPs for correctly identified Old pairs as opposed to correctly rejected Old-New pairs in the three ERP experiments reported here. Furthermore, the parietal effect was not observed for false alarms to rearranged pairs that was not consistent with or similar to study pairs, such as Inter pairs (Experiment 2) and Unassociated Intra pairs (Experiment 4). The presence and absence of the parietal effect for hits to Old pairs and false alarms to such rearranged pairs is in line with the findings of Wilding and Rugg (1996), who suggested that this effect is sensitive to the accuracy of source judgments. It was also consistent with the findings of Donaldson and Rugg (1998), who proposed that associative judgements to intact pairs are based almost exclusively on recollection, whereas those to rearranged pairs are made on the basis of a failure to recollect. Nevertheless, the finding that the parietal effect was observed for false alarms to Intra pairs (Experiments 2 & 5) and to Associated Intra pairs (Experiment 4) appears to suggest that the parietal effect is not necessarily sensitive to the accuracy of source memory. Whether or not the parietal effect is found for source judgement errors depends on the mechanism underlying these errors. When information that is imperfectly diagnostic of different sources is recollected, the parietal effect can be associated with source judgement errors.

Previous studies have reported the parietal effect in association with the gist-based false recognition elicited in the DRM procedure (see Chapter 4 for review). For instance, Duzel and colleagues (Duzel et al., 1997) employed the Remember/Know procedure and observed the parietal old/new effect for 'Remember' responses to both old items and lure items. Likewise, Nessler and colleagues (Nessler et al., 2001) reported that the parietal effect was observed in ERPs associated with false recognition of lure items. This effect also appears to be evident in a study by Johnson and colleagues (Johnson et al., 1997), although the relevant statistical analyses were not reported. It is interesting to note that whether the parietal effect was of similar magnitude for old items and lure items varied in these studies. In the studies of Duzel et al. (1997) and Johnson et al. (1997), it was found that the parietal effect was of similar magnitude for old and lure items. In the study of Nessler et al. (2001), the parietal ERP old/new effects associated with the true and false recognition were indistinguishable when conceptual similarity between the study words was emphasised during the time of encoding (Category group). However, the parietal effect was smaller for false recognition than for true recognition when item-specific information was emphasised at study (Item group). Nessler et al. argued that the semantic relations between the study words were attracted different amount of attention in these two conditions, which resulted in different amounts of activation for the lures in the latter test. The different patterns of parietal effects associated with false recognition in these two groups might therefore reflect the different quality or quantity of the semantic information recollected in response to the lures in these two groups. Similarly, the findings that the parietal effect was indistinguishable for Old pairs and Intra pairs (Experiment 2) but was less sustained for Associated Intra pairs than for Old pairs (Experiment 4) might reflect different amounts of information recollected in response to these two classes of rearranged pairs. Taken together, these data provide further evidence that the parietal effect indexes recollection in a graded fashion (Wilding & Rugg, 1996; Wilding, 2000). Moreover, it appears that semantic information that cannot differentiate study items from lure items can modulate the magnitude or duration of the parietal effect.

In the experiments contained within this thesis, the involvement of recollection in source judgement errors was indexed by the 'R' response of the Remember/Know procedure and by the parietal old/new effect. However, it seems that the 'R' response and the parietal effect were not fully consistent with each other in indexing recollection. For instance, the percentage of 'old' responses assigned with the 'R' judgement ('Remember/Old ratio') was the same for Intra pairs and Inter pairs (Experiment 1). This finding indicated that, proportionally, the contribution of recollection involved in these two classes of memory errors was equivalent. Nevertheless, the parietal effect was observed for false alarms to Intra pairs but not for false alarms to Inter pairs (Experiment 2), suggesting that recollection was involved in memory errors for the former but not for the latter items. In addition, the proportion of 'R' response to rearranged pairs was not affected by whether the second words of the study pairs were semantically related (Experiment 3), indicating that the semantic relation between the second words had no effect on the involvement of recollection in memory errors. This finding is in variance with the conclusion drawn from ERP findings that 'full-blown' recollection-driven errors occurred only when both members of rearranged pairs were semantically related to other studied items.

One plausible explanation for the inconsistency between the 'R' response and the parietal effect in indexing recollection relates to the different ways the Remember/Know procedure and the parietal effect index recollection. As noted above, the parietal effect indexes recollection in a graded fashion, such that its magnitude is correlated with the quality or quantity of recollected information. In contrast, the Remember/Know procedure adopts mutually exclusive, binary 'R' and 'K' responses to index recognition associated with and without recollective experience. The different ways of indexing recollection thus render the parietal effect and the Remember/Know procedure different in their sensitivity to recollection. The different sensitivity of the 'R' response and the parietal effect to recollection has been demonstrated in an ERP study of word frequency effect in recognition (the fact that low frequency words are recognised more accurately than high frequency words). Rugg, Wells, and Doyle (unpublished, cited in Rugg, 1995) reported a larger parietal effect for recognised low frequency words associated with 'R' responses than for ERPs to high frequency words. It was suggested that different amounts of information was recollected in response to low and high frequency words, which was reflected by the parietal effect in a graded fashion but similarly gave rise to 'R' response. In a similar vein, the difference between the quantity/quality of recollection elicited by Intra pairs and Inter pairs might be sufficient to modulate the occurrence or magnitude of the parietal effect, but fail to yield different proportion of 'R' responses.

One difficulty for the foregoing interpretation is to explain why the presence of the parietal effect was all-or-none rather than graded for Intra pairs and Inter pairs, given that both types of rearranged pairs attracted 'R' responses. A plausible answer for this question relates to the notion that the parietal effect is sensitive to the 'task relevance' of retrieved information, and might not be observed when retrieved information is not attended (Herron & Rugg, in press). The semantic relations between the study pairs might render gist information of study pairs, which was available for Old pairs and Intra pairs but not for Inter pairs, more salient and relevant to the task than any other type of information that might be retrieved. Therefore, the parietal effect was observed only for Intra pairs but not at all for Inter pairs. On the other hand, subjects made R/K judgements after a test pair was judged old. Any information that elicited recollective experience associated with the test pair, either relevant or irrelevant to the memory task, would lead subjects to make the 'R' response. Hence, the recollection indexed by the parietal effect might not be equivalent to that indexed by the 'R' responses. It is possible that the information retrieved in response to Intra pairs and Inter pairs that contributed to 'R' responses to these two classes of rearranged pairs was heterogeneous. By contrast, the recollection indexed by the parietal effect was only available for Intra pairs but not for Inter pairs. This might explain why both Intra pairs and Inter pairs attracted 'R' judgements but the parietal effect was observed only for the former but not the latter.

9.4.2 Right Frontal Effect

The right frontal effect is thought to reflect monitoring or evaluation processes that operate on the products of a retrieval attempt in a strategic or goal-directed manner (Allan, Wolf, Rosenthal, & Rugg, 2001; Ranganath & Paller, 2000; see Chapter 4). In the three ERP experiments reported here, the right frontal effect was observed when comparing the ERPs to correctly classified Old pairs with the ERPs to correctly rejected Old-New pairs. There was no sign of a right frontal effect in association with false alarms to rearranged pairs that were not consistent with gist memories, such as Inter pairs (Experiment 2) and Unassociated Intra pairs (Experiment 4). The pattern of the right frontal effect for rearranged pairs that were consistent with gist memory for the study pairs, however, differed across the experiments. In Experiments 2 and 5, the right frontal effect was found to be indistinguishable for correctly identified Old pairs and incorrectly classified Intra pairs, suggesting that the information recollected in response to these two classes of stimuli was subjected to equivalent levels of post-retrieval monitoring and evaluation. By contrast, the incorrectly identified Associated Intra pairs in Experiment 4 failed to elicit a reliable right frontal effect.

The presence and absence of the right frontal effect for Old pairs and Associated Intra pairs in Experiment 4, both associated with the parietal effect, provided further evidence for the notion that these two effects are dissociable and the right frontal effect is not obligatory to recollection (Rugg, Allan, & Birch, 2000; Wilding & Rugg, 1997b). The absence of the right frontal effect in false alarms to Associated Intra pairs might suggest that these lures were incorrectly endorsed because post-retrieval monitoring processes were not engaged to evaluate information retrieved in response to the pairs. However, the fact that the right frontal effect was observed in false alarms to Intra pairs (Experiments 2 & 5) suggests that the post-retrieval processes indexed by the effect were insufficient to allow rejection of the Intra pairs, perhaps because what was recollected in response to Old and Intra pairs was so similar.

Why was the right frontal effect observed in false alarms to Intra pairs (Experiments 2 & 5) but not in false alarms to Inter pairs (Experiment 2) and Unassociated Intra pairs (Experiment 4)? One possible answer is that the engagement of the monitoring processes indexed by the right frontal effect was contingent on whether the information retrieved in response to a test pair was consistent with any gist memories formed at study. Note that gist memories for study pairs sharing similar associative relations can on the one hand support correct recognition of Old pairs, and on the other hand lead to incorrect endorsement of rearranged pairs that were consistent with gist memories. Subjects might therefore adopted a strategy that whenever gist-consistent information was retrieved in response to a test pair, monitoring processes were engaged to examine whether the test pair was an Old or rearranged pair. Hence the right frontal effect was observed for both correctly identified Old pairs and incorrectly classified Intra pairs, as information retrieved in response to both classes of items was consistent with gist memories. Moreover, the indistinguishable parietal effect for Old pairs and Intra pairs suggested that the recollection elicited by these two classes of items was of similar quality/quantity, which might be the reason why the post-retrieval monitoring processes failed to reject Intra pairs. By contrast, Inter pairs and Unassociated Intra pairs were generated by re-pairing study pairs belonging to different gist memories, such that no gist-consistent information was retrieved in response to these pairs to engage the post-retrieval monitoring processes reflected by the right frontal effect.

On the other hand, the information retrieved in response to Associated Intra pairs (Experiment 4) was also consistent with the gist memories of the study pairs. Why was the right frontal effect present in false alarms to Intra pairs but not in false alarms to Associated Intra pairs? A plausible answer is that the emergence of the right frontal effect is related to the richness or amount of gist-consistent information that was retrieved in response to the test pairs (see Donaldson & Rugg, 1998 for a similar argument). By this argument, the post-retrieval monitoring processes reflected by the right frontal effect are engaged only when the quality or amount of information retrieved from gist memory exceeds some threshold. Although gist-consistent information was recollected in response to Associated Intra pairs, the quality or amounts of the recollected information might not exceed the threshold to initiate the post-retrieval monitoring processes indexed by the right frontal effect. Supporting evidence for this interpretation comes from the finding that the left parietal effect was less sustained in duration for Associated Intra pairs than for Old pairs, which was argued to reflect the different quality or quantity of recollection elicited by these two classes of test pairs.

The foregoing interpretation for the right frontal effect suggests that the engagement of the post-retrieval monitoring processes indexed by this effect could be selective when certain information retrieved from the episodic memory is equivocal for making recognition judgement, such as gist-consistent information that can lead to correct and incorrect endorsements. It is also suggested that to engage the post-retrieval monitoring processes, the amount or quality of the retrieved information must exceed some threshold. Further investigation of the boundary conditions for the occurrence of the right frontal effect will be needed.

9.4.3 Early Frontal Effect

The early frontal effect has been linked to recognition based on familiarity because of its relative insensitivity to variables that affect recollection more than familiarity (Curran, 1999; Curran, 2000; Curran & Cleary, 2003; Rugg et al., 1998; Ullsperger et al, 2000).

Across the three experiments contained within this thesis, no clear sing of the early frontal effect was observed when the ERPs elicited by correctly identified Old pairs and incorrectly classified rearranged pairs were compared with the ERPs elicited by correctly rejected Old-New pairs. The absence of the early frontal effect for incorrectly identified Inter pairs and Unassociated Intra pairs was particularly surprising, as false alarms to these two classes of rearranged pairs were through non-recollective mechanisms.

The failure to observe the early frontal effect does not necessarily imply that familiarity was not involved in the veridical memories for Old pairs or the erroneous memories for rearranged pairs. One possibility is that the familiarity involved in the source judgement errors observed in the present studies is of a different informational form from that indexed by the early frontal effect, which so far has been linked with item, rather than associative, memory. It has been reported that the early frontal effect may not be an obligatory correlate of familiarity-based recognition. In a study investigating context effects on the neural correlates of recognition memory, Tsivilis, Otten, & Rugg (2001) presented subjects with objects superimposed on landscape scenes that served as contexts. At test, subjects were required to identify studied objects without considering the contexts they were paired with. The early frontal effect was observed for objects paired with the same study context (SAME pairs) and those paired with different studied contexts (REARRANGED pairs), but not with objects paired with unstudied new contexts (OLD/NEW pairs). Crucially, the behavioral performance in a later Remember/Know experiment did not differ between REARRANGED and OLD/NEW pairs, suggesting that the contribution of recollection and familiarity to these two classes of items were almost identical. Based on these findings, Tsivilis et al. suggested that the early frontal effect might not be directly related to familiarity-based recognition, but might reflect processes 'downstream' from those responsible for computing familiarity, such as novelty detection. It is interesting to note that the early frontal effect was observed for REARRANGED pairs in the study of Tsivilis et al. (2001) but was not observed for the rearranged pairs in the experiments contained within this thesis. This discrepancy might arise from the difference between the tasks employed in these two studies. Subjects in the study of Tsivilis et al. made simple old/new judgements to the object member of the object-context pair without considering the context member. By contrast, subjects in the experiments reported here made associative judgements on the source-item pairings, hence both members of the test pair had to be considered. The assessment of familiarity might be modulated by whether only one member or both members of the test pair had to be considered, which resulted in different patterns of early frontal effect for rearranged pairs in the study of Tsivilis et al. (2001) and the experiments reported here. It would be of interest to further investigate the functional significance of the early frontal effect with stimuli consisting of multiple components.

9.5 Conclusions

The present studies examined the cognitive/neural processes involved in source memory errors for similar and dissimilar source-item pairings. The behavioural results indicated that gist memory was formed for similar source-item pairs that shared semantically related constituent members, from which partial information was derived and led to incorrect endorsement of gist-consistent lures. Such gist-based source memory errors were associated with the parietal ERP old/new effect, suggesting that these errors comprised 'false recollection' of episodic details. By contrast, the parietal effect was not observed in source memory errors for dissimilar source-item pairs, suggesting that these memory errors were through alternative, non-recollective mechanisms.

The formation of gist memory mainly relied on the semantic relation between the sources, which functions as a mediator that binds together the semantic attributes of study episodes into the gist. It was argued that these semantic attributes constituted the content of false recollection derived from gist memory. However, ERP results indicated that whether gist memory supports false recollection of lures to the same extent as generic information underpins veridical memories relied on both the semantic relations between the sources and the semantic relation between the items of study episodes. False recollection supported by gist containing semantic attributes of both constituent members of source-item pairs was qualitatively indistinguishable from veridical recollection, as indexed by the parietal ERP effect, and was subjected to equivalent levels of post-retrieval monitoring with veridical recollection, as indexed by the right frontal ERP effect. These results suggested that the duration of the parietal effect for false recollection might reflect the richness or amounts of information derived from gist memory, which must exceed some threshold to engage the post-retrieval monitoring processes indexed by the right frontal effect.

The present studies also provided an opportunity to examine the brain activity associated with the encoding of gist information and verbatim information. The scalp distributions of the subsequent memory effect for identifying studied source-item pairs, which could rely on either retrieving gist information or verbatim information, and that for rejecting gist-consistent lures, which required retrieving information specific to studied episodes, were different. This finding suggests that episodic encoding is not a unitary process, and different cognitive operations are involved in encoding gist and verbatim information of episodic events.

Appendix 1. Stimuli of Experiment 1

Pairs of associated words used as the initial words of study/test pairs.

Associated words		Association strength	Associated words		Association strength
kennel	dog	89.6	rodent	rat	71.4
omelette	egg	85.7	repeat	again	69.0
husband	wife	81.0	tadpole	frog	69.0
cobweb	spider	79.2	captain	ship	69.0
brother	sister	77.1	request	ask	66.7
wrong	right	76.2	envelope	letter	66.7
black	white	76.2	doorbell	ring	66.7
found	lost	75.6	saloon	bar	69.1
vase	flower	73.3	pram	baby	67.4
confetti	wedding	72.9	tusk	elephant	64.6
library	book	71.7	less	more	64.4
orchard	apple	71.5	near	far	64.3

Groups of semantically related words used as the second words of study/test pairs.

Theme	Associates							
window	door	pane	ledge	house	curtain	view	sash	shutter
	glass	shade	sill	open	frame	breeze	screen	cleaner
smell	nose	sniff	hear	nostril	scent	stench	perfume	rose
	breathe	aroma	see	whiff	reek	fragrance	salts	odour
cold	hot	warm	ice	frigid	heat	freeze	shiver	frost
	snow	winter	wet	chilly	weather	air	Arctic	sneeze
rough	smooth	road	sandpaper	ready	uneven	rugged	boards	gravel
	bumpy	tough	jagged	coarse	riders	sand	ground	tumble
cup	mug	tea	coaster	handle	straw	soup	drink	sip
	saucer	measuring	lid	coffee	goblet	stein	plastic	lip
soft	hard	pillow	loud	fur	fluffy	furry	kitten	tender
	light	plush	cotton	touch	feather	downy	skin	cuddly
sleep	bed	awake	dream	snooze	doze	snore	peace	drowsy
	rest	tired	wake	blanket	slumber	nap	yawn	night
anger	mad	hate	temper	ire	happy	hatred	calm	enrage
	fear	rage	fury	wrath	fight	mean	emotion	annoy
sweet	sour	sugar	good	tooth	honey	chocolate	cake	pie
	candy	bitter	taste	nice	soda	heart	tart	meat
trash	garbage	can	sewage	junk	sweep	pile	landfill	litter
	waste	refuse	bag	rubbish	scraps	dump	debris	bin
chair	table	legs	couch	recliner	wood	swivel	sitting	bench
	sit	seat	desk	sofa	cushion	stool	rocking	back
smoke	cigarette	blaze	pollution	gas	fire	stink	lungs	stain
	puff	billows	ashes	chimney	tobacco	pipe	flames	cough

high	low	up	tower	above	noon	sky	airplane	elevate
	clouds	tall	jump	building	cliff	over	dive	hall
doctor	nurse	lawyer	health	dentist	ill	office	surgeon	cure
	sick	medicine	hospital	physician	patient	stethoscope	clinic	stick
thief	steal	crook	money	bad	jail	villain	bank	criminal
	robber	burglar	cop	rob	gun	police	bandit	theft
mountain	hill	climb	top	peak	glacier	bike	range	ski
	valley	summit	molehill	plain	goat	ridge	steep	pinnacle
slow	fast	stop	snail	delay	turtle	speed	sluggish	molasses
	lethargic	listless	cautious	traffic	hesitant	quick	wait	pace
music	note	piano	radio	melody	concert	symphony	orchestra	rhythm
	sound	sing	band	horn	instrument	jazz	art	play
needle	thread	eye	sharp	prick	haystack	hurt	syringe	knitting
	pin	sewing	point	thimble	thorn	injection	cloth	fix
river	water	lake	boat	swim	run	creek	fish	winding
	stream	sea	tide	flow	barge	brook	bridge	deep
rubber	elastic	gloves	ball	springy	galoshes	latex	flexible	stretch
	bounce	tire	eraser	foam	soles	glue	resilient	fibres
city	town	state	streets	country	village	big	suburb	urban
	crowded	capital	subway	council	metropolis	mayor	county	people
bread	butter	Eat	rye	milk	jelly	crust	wine	toast
	food	sandwich	jam	flour	dough	slice	loaf	cheese
foot	shoe	toe	sandals	yard	ankle	boot	sock	mouth
	hand	kick	soccer	walk	arm	inch	knee	loose

Unrelated words used as the second words of Old-New test pairs.

cookie	think	computer	pattern	message	part	cheap	remote
element	chain	song	maze	process	invite	lunch	peer
major	draw	jargon	bestow	fashion	beside	comment	gentle
seminar	pavement	fee	flick	safe	service	evil	last
attend	act	feast	bulb	plug	story	ease	cast
ear	crew	critic	crash	mark	courage	fortune	planet
omit	center	invoice	norm	share	leaf	return	roof
member	enroll	notify	west	period	exact	labor	focus
gather	watch	drug	tool	direct	rush	figure	picture
giant	sad	take	exhibit	theory	problem	form	dial
today	opera	behave	slight	dragon	long	devote	pierce
silence	film	eager	sale	advance	wish	cycle	tank

Appendix 2. Stimuli of Experiments 2 and 5

Pairs of associated words used as the initial words of study/test pairs.

Associated words		Association strength	Associated words		Association strength
kennel	dog	89.6	library	book	71.7
omelette	egg	85.7	orchard	apple	71.5
husband	wife	81.0	rodent	rat	71.4
cobweb	spider	79.2	repeat	again	69.0
brother	sister	77.1	tadpole	frog	69.0
wrong	right	76.2	captain	ship	69.0
black	white	76.2	request	ask	66.7
found	lost	75.6	envelope	letter	66.7
vase	flower	73.3	doorbell	ring	66.7
confetti	wedding	72.9	saloon	bar	69.1

Groups of semantically related words used as the second words of study/test pairs.

Theme	Associates							
window	door	Pane	ledge	house	curtain	view	sash	shutter
	glass	Shade	sill	open	frame	breeze	screen	cleaner
smell	nose	Sniff	hear	nostril	scent	stench	perfume	rose
	breathe	Aroma	see	whiff	reek	fragrance	salts	odour
cold	hot	warm	ice	frigid	heat	freeze	shiver	frost
	snow	winter	wet	chilly	weather	air	arctic	sneeze
rough	smooth	road	sandpaper	ready	uneven	rugged	boards	gravel
	bumpy	tough	jagged	coarse	riders	sand	ground	tumble
cup	mug	tea	coaster	handle	straw	soup	drink	sip
	saucer	measuring	lid	coffee	goblet	stein	plastic	lip
soft	hard	pillow	loud	fur	fluffy	furry	kitten	tender
	light	plush	cotton	touch	feather	downy	skin	cuddly
sleep	bed	awake	dream	snooze	doze	snore	peace	drowsy
	rest	tired	wake	blanket	slumber	nap	yawn	night
anger	mad	hate	temper	ire	happy	hatred	calm	enrage
	fear	rage	fury	wrath	fight	mean	emotion	annoy
sweet	sour	sugar	good	tooth	honey	chocolate	cake	pie
	candy	bitter	taste	nice	soda	heart	tart	meat

trash	garbage	can	sewage	junk	sweep	pile	landfill	litter
	waste	refuse	bag	rubbish	scraps	dump	debris	bin
chair	table	legs	couch	recliner	wood	swivel	sitting	bench
	sit	seat	desk	sofa	cushion	stool	rocking	back
smoke	cigarette	blaze	pollution	gas	fire	stink	lungs	stain
	puff	billows	ashes	chimney	tobacco	pipe	flames	cough
high	low	up	tower	above	noon	sky	airplane	elevate
	clouds	tall	jump	building	cliff	over	dive	hall
doctor	nurse	lawyer	health	dentist	ill	office	surgeon	cure
	sick	medicine	hospital	physician	patient	stethoscop e	clinic	stick
thief	steal	crook	money	bad	jail	villain	bank	criminal
	robber	burglar	cop	rob	gun	police	bandit	theft
mountain	hill	climb	top	peak	glacier	bike	range	ski
	valley	summit	molehill	plain	goat	ridge	steep	pinnacle
slow	fast	stop	snail	delay	turtle	speed	sluggish	molasses
	lethargic	listless	cautious	traffic	hesitant	quick	wait	pace
music	note	piano	radio	melody	concert	symphony	orchestra	rhythm
	sound	sing	band	horn	instrument	jazz	art	play
needle	thread	eye	sharp	prick	haystack	hurt	syringe	knitting
	pin	sewing	point	thimble	thorn	injection	cloth	fix
river	water	lake	boat	swim	run	creek	fish	winding
	stream	sea	tide	flow	barge	brook	bridge	deep

Unrelated words used as second words of Old-New test pairs.

cookie	think	computer	pattern	today	opera	behave	slight
element	chain	song	maze	silence	film	eager	sale
mayor	draw	jargon	bestow	message	part	cheap	remote
seminar	pavement	fee	flick	process	invite	lunch	peer
attend	act	feast	bulb	fashion	beside	comment	gentle
ear	crew	critic	crash	safe	service	evil	last
omit	center	invoice	norm	plug	story	ease	cast
member	enroll	notify	west	mark	courage	fortune	planet
gather	watch	drug	tool	share	leaf	return	roof
giant	sad	take	exhibit	period	exact	labor	focus

Appendix 3. Stimuli of Experiment 3

Associated words used as the initial words of study/test pairs

brandy	gin	drunk	vodka
kid	adult	parent	baby
comedian	humour	clown	wit
diamond	jewel	necklace	pearl
blouse	sleeve	collar	shorts
bee	sting	hornet	hive
antique	old	ancient	age
prison	arrest	convict	prosecute
belief	faith	worship	bible
oval	cylinder	circle	sphere
tree	leaf	forest	stump
laboratory	physics	molecule	electron
victory	prize	defeat	triumph
supper	lunch	banquet	meal
stone	solid	pebble	meteor
fraud	alias	fake	lie

Groups of related words used as the second words of study/test pairs in the 'related' condition.

Theme	Associates							
window	door	pane	ledge	house	curtain	view	sash	shutter
	glass	shade	sill	open	frame	breeze	screen	cleaner
smell	nose	sniff	hear	nostril	scent	stench	perfume	rose
	breathe	aroma	see	whiff	reek	fragrance	salts	odour
cold	hot	warm	ice	frigid	heat	freeze	shiver	frost
	snow	winter	wet	chilly	weather	air	arctic	sneeze
rough	smooth	road	sandpaper	ready	uneven	rugged	boards	gravel
	bumpy	tough	jagged	coarse	riders	sand	ground	tumble
cup	mug	tea	coaster	handle	straw	soup	drink	sip
	saucer	measuring	lid	coffee	goblet	stein	plastic	lip
soft	hard	pillow	loud	fur	fluffy	furry	kitten	tender
	light	plush	cotton	touch	feather	downy	skin	cuddly

sleep	bed	awake	dream	snooze	doze	snore	peace	drowsy
	rest	tired	wake	blanket	slumber	nap	yawn	night
anger	mad	hate	temper	ire	happy	hatred	calm	enrage
	fear	rage	fury	wrath	fight	mean	emotion	annoy
sweet	sour	sugar	good	tooth	honey	chocolate	cake	pie
	candy	bitter	taste	nice	soda	heart	tart	meat
trash	garbage	can	sewage	junk	sweep	pile	landfill	litter
	waste	refuse	bag	rubbish	scraps	dump	debris	bin
chair	table	legs	couch	recliner	wood	swivel	sitting	bench
	sit	seat	desk	sofa	cushion	stool	rocking	back
smoke	cigarette	blaze	pollution	gas	fire	stink	lungs	stain
	puff	billows	ashes	chimney	tobacco	pipe	flames	cough
high	low	up	tower	above	noon	sky	airplane	elevate
	clouds	tall	jump	building	cliff	over	dive	hall
doctor	nurse	lawyer	health	dentist	ill	office	surgeon	cure
	sick	medicine	hospital	physician	patient	stethoscope	clinic	stick
thief	steal	crook	money	bad	jail	villain	bank	criminal
	robber	burglar	cop	rob	gun	police	bandit	theft
mountain	hill	climb	top	peak	glacier	bike	range	ski
	valley	summit	molehill	plain	goat	ridge	steep	pinnacle

Unrelated word groups used as the second words of study/test pairs in the 'unrelated' condition

service	packet	layout	place	debt	union	sensor	shrink
extent	shoot	snug	mind	boat	boost	strike	classics
pale	sneak	issue	nylon	snack	suffix	patriot	sight
breadth	arousal	year	surf	reclaim	fireplace	seize	penalty
trial	wage	angle	eagle	officer	fulfill	scarf	flour
coast	spread	rural	chaotic	murder	car	armor	sharp
distinct	effect	shortcut	square	unreal	wound	increase	tutor
cell	magic	lethal	comic	twisted	humor	induce	settlers
parcel	stuff	vote	crowd	statue	sketch	learn	seep
scatter	missing	lodge	edge	rule	beggar	remote	label
clear	poetic	lucky	heap	gist	fit	jaguar	tider
power	pledge	temple	cover	eyelids	league	soul	official

list	cope	broke	send	dog	liberal	plan	dragon
sort	safety	trace	basement	socket	muse	wed	head
guest	match	therapy	invert	original	flood	affect	equip
chance	reward	fever	topic	cattle	play	density	attest
stony	beef	long	vague	gear	cheese	blade	pint
buffer	depth	task	rich	sock	report	feeble	opera
fuzzy	only	morality	idol	swim	pack	twice	linkage
vehicle	razor	concert	runway	spider	fasten	declare	borrow
sound	relief	copper	store	truck	swamp	giving	context
seek	worry	contact	spoon	corrupt	stamp	static	state
circuit	bizarre	portray	share	value	summon	lobby	stance
postage	bilingual	assess	circus	suitcase	tent	mist	crouch
red	about	tear	name	lock	shore	deck	echo
piano	unique	hide	central	chronic	adoption	most	congress
obscure	porch	energy	equality	estate	question	thumb	debate
band	museum	language	picnic	variety	subtract	cloak	teach
stew	cruise	class	due	knight	vintage	neck	crystal
rotate	camel	cruel	relax	image	earth	bland	thigh
page	convert	land	orbit	ginger	ability	modern	riot
box	stray	birth	slight	grape	serum	tank	leader

Unrelated words used as the second words of Old-New test pairs.

cookie	think	computer	pattern	gather	watch	drug	tool
element	chain	song	maze	giant	sad	take	exhibit
mayor	draw	jargon	bestow	today	check	behave	monkey
seminar	pavement	fee	flick	silence	film	eager	sale
attend	act	feast	bulb	message	emperor	cheap	distant
ear	crew	critic	crash	process	invite	part	peer
omit	centre	invoice	norm	fashion	beside	comment	gentle
member	enroll	notify	west	safe	discuss	evil	last

Appendix 4. Stimuli of Experiment 4

Pairs of associated words used as the initial words of the study/test pairs

brandy	vodka
kid	baby
comedian	clown
blouse	collar
bee	hornet
lunch	meal
faith	bible
prosecute	convict
oval	circle
tree	forest
physics	electron
victory	defeat
stone	pebble
brush	comb
antique	ancient
frost	winter
jewel	pearl
hat	cap
planet	star
sport	team

chorous	voice
corn	harvest
heart	surgery
fraud	fake
table	chair
cigarette	pipe
tragedy	disaster
bacteria	virus
thief	robber
dice	gamble
cake	pie
school	study
cotton	silk
brother	sister
essay	paper
bruise	scar
cup	mug
package	mail
ear	listen
king	queen

Groups of unrelated words used as the second words of study/test pairs.

stony	beef	long	vague	gear	cheese	Blade	pint
buffer	depth	task	rich	sock	report	feeble	opera
fuzzy	only	morality	idol	swim	pack	twice	linkage
vehicle	razor	concert	runway	spider	fasten	declare	borrow
sound	relief	copper	store	truck	swamp	giving	context
seek	worry	contact	spoon	corrupt	stamp	static	state
circuit	bizarre	portray	share	value	summon	lobby	stance
postage	bilingual	assess	circus	suitcase	tent	mist	crouch
parcel	stuff	vote	crowd	statue	sketch	learn	seep
scatter	missing	lodge	edge	rule	beggar	remote	label
clear	poetic	lucky	heap	gist	fit	jaguar	tide
power	pledge	temple	cover	eyelids	league	soul	official

list	cope	broke	send	dog	liberal	plan	dragon
sort	safety	trace	basement	teaspoon	muse	wed	head
guest	match	therapy	invert	original	flood	affect	equip
chance	reward	fever	topic	cattle	play	density	attest
service	packet	layout	place	debt	union	sensor	shrink
extent	shoot	snug	mind	boat	boost	strike	classics
pale	sneak	issue	nylon	snack	suffix	patriot	sight
breadth	arousal	year	surf	reclaim	fireplace	seize	penalty
trial	wage	angle	eagle	officer	fulfill	scarf	flour
coast	spread	rural	chaotic	murder	car	armor	sharp
distinct	effect	shortcut	square	unreal	wound	increase	tutor
cell	magic	lethal	comic	twisted	humour	induce	settlers
red	about	tear	name	lock	shore	deck	echo
piano	unique	hide	central	chronic	adoption	most	congress
obscure	porch	energy	equality	estate	question	thumb	debate
band	museum	language	picnic	variety	subtract	cloak	teach
stew	cruise	class	due	knight	vintage	neck	crystal
rotate	camel	cruel	relax	image	earth	bland	thigh
page	convert	land	orbit	ginger	ability	modern	riot
box	stray	birth	slight	grape	serum	tank	leader
door	provide	shark	step	vacancy	colony	section	soda
mile	navy	legacy	coin	toast	loan	dread	rival
parrot	slave	brief	cousin	shake	slope	capacity	sausage
signify	precise	slip	knife	flat	bait	tube	lemon
figure	movie	survey	divide	mixture	thick	invade	trivial
area	peach	luxury	rose	exclude	contrast	skin	receive
degree	crack	valley	hill	model	permit	evidence	diver
island	chamber	spare	blanket	spoil	explorer	tender	system

Unrelated words used as the second words of Old-New test pairs

cookie	think	direct	rush	today	check	invoice	norm
element	chain	theory	problem	silence	film	notify	west
mayor	draw	edit	little	message	emperor	drug	tool
seminar	pavement	advance	wish	process	invite	take	exhibit
attend	act	computer	pattern	fashion	beside	behave	monkey
cycle	crew	song	maze	safe	discuss	eager	sale
omit	centre	jargon	bestow	plug	story	cheap	distant
member	enroll	fee	flick	mark	courage	part	peer
gather	watch	feast	bulb	weight	file	comment	gentle
giant	sad	critic	crash	period	exact	evil	last

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