

Research report

# Event-related potential studies of associative recognition and recall: electrophysiological evidence for context dependent retrieval processes

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## Abstract

To investigate the neural correlates of episodic recollection the ERP correlates of memory for new associations (recently studied novel word pairs) were investigated using two tasks, associative recognition and associative recall. For the recognition task subjects discriminated old from new word pairs and, for pairs judged old, reported whether the pairs were intact or recombined (compared to at study). For the recall task, subjects discriminated old from new words and, for each word judged old, reported its study associate. ERPs were recorded at test from 25 scalp electrodes, with a 1944-ms recording epoch. In Experiment 1, the tasks were randomly interleaved. Consistent with previous findings, relative to the ERPs for correctly classified new items, the ERP correlates of successful associative recognition consisted of a sustained left parietal positivity, and two frontal positivities, one early and bilateral, the other occurring later and showing a right-sided maximum. In contrast to previous findings, successful associative recall elicited similar effects to those found for recognition. Topographic analyses revealed that the distribution of these retrieval-related ERP effects were similar across the two tasks, suggesting that the recognition and recall of associative information gives rise to activity in overlapping, if not the same, neural populations. In Experiment 2 the tasks were blocked. In contrast to the findings of Experiment 1, successful associative recall elicited left parietal and late onsetting right frontal positivities, in the absence of the early bilateral frontal positivity. This finding suggests that frontally-distributed memory-related ERP effects are both neurally and functionally dissociable. Specifically, we argue that the functional significance of the early frontally distributed ERP effect cannot be accounted for by the ‘post-retrieval processing’ hypothesis that is taken to account for the late right frontal effect, suggesting that episodic recollection itself is neither neurally nor functionally homogenous. © 1999 Published by Elsevier Science B.V. All rights reserved.

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## 1. Introduction

There is converging evidence that performance on episodic memory tasks depends upon a network of brain regions. Among the most important of these regions are the hippocampus and adjacent medial temporal structures (the ‘medial temporal memory system’ [2,6,22]), and the prefrontal cortex [23,25]. Whereas the medial temporal system is thought to play an obligatory role in the retrieval of recently acquired episodic information, the role of the prefrontal cortex is generally regarded as more flexible,

supporting a range of processes that are called into play to differing extent by different retrieval tasks, e.g., Refs. [11,21].

The findings from recent event-related potential (ERP) studies of episodic memory retrieval are consistent with the foregoing framework. One ERP correlate of episodic memory—the ‘left parietal old/new effect’—is characterised by a positive shift in ERPs to words correctly recognised as old relative to ERPs to new words. The effect starts around 400 ms post-stimulus and is maximal over the left temporo-parietal scalp. The findings from a variety of studies suggest that the left parietal effect is elicited selectively by test items that engender retrieval of contextual information from their encoding episode (recollection) (e.g., Refs. [12,16,20,26,27]; for a recent review, see Ref. [1]). Specifically, the effect appears to index retrieval processes associated with recollection, and that it

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is an indirect reflection of the contribution of the medial temporal lobe memory system to episodic retrieval. This hypothesis is supported by a variety of evidence, including (i) the functional properties of the effect, which suggest it is elicited in circumstances in which the medial temporal lobe would be expected to be engaged during memory retrieval and (ii) ERP and neuroimaging studies of recognition memory indicating that the left parietal effect and activity in hippocampal formation share sensitivity to depth of study processing, a well known method of manipulating the probability of recollection [17].

A second ERP correlate of episodic memory is the ‘right frontal old/new effect’. This effect was first demonstrated in a study of source memory by Wilding and Rugg [27], and consists of a positive shift which is maximal over right frontal electrodes. In that study, the effect onset at about the same time as the left parietal old/new effect, but showed a markedly more sustained time course. Because the right frontal effect was larger in ERPs elicited by items that received correct rather than incorrect source judgments, Wilding and Rugg [27] proposed that it too reflected processes associated with the successful recollection of prior episodes.

Whereas there seems to be a strong link between recollection and the left parietal effect, this link is weaker in the case of the right frontal effect. For example, the right frontal effect is seldom prominent in ERPs elicited in simple recognition memory tasks (see Ref. [1]), and Wilding and Rugg ([29], see also Ref. [28]) identified a situation in which even successful source memory was not accompanied by the effect. Consequently, Wilding and Rugg suggested that the right frontal effect reflects ‘post-retrieval’ processes, supported by right prefrontal cortex, that are recruited in certain circumstances to operate on the products of episodic retrieval, a hypothesis that receives support from both neuropsychological and neuroimaging evidence. For example, Curran et al. [3] described a patient who, following a right prefrontal lesion, committed excessive recognition false alarms, an impairment attributed by the authors to deficient monitoring of memory retrieval. Also Rugg et al. [13] obtained direct evidence from positron emission tomography (PET) that the activity of right prefrontal cortex varies according to probability of successful memory retrieval, demonstrating that neural activity in this region was greater during the processing of ‘old’ than ‘new’ recognition memory test items.

Like source memory, the ability to retrieve recently learnt associations between two items is heavily dependent upon episodic memory. In both cases, memory for the test items per se is not sufficient to support accurate performance. Whereas successful source memory depends on the ability to recollect the association between a study item and its encoding context, associative memory requires recollection of information about the relationship between a pair of study items. Memory for recently acquired associations can be assessed in a variety of ways, two of which

are relevant here. Associative *recognition* requires subjects to discriminate between pairs of old items that maintain their pairing between study and test, and pairs that have been recombined between the study and test phases. By contrast, associative *recall* requires subjects to retrieve the associate of a recently studied test item presented in isolation.

The relationship between ERP old/new effects and episodic recollection has been investigated using both associative recall (Rugg et al. [14]) and associative recognition (Donaldson and Rugg [4]). In the study of Rugg et al. [14], subjects first learned a series of novel word pairs. At test one member of each study pair was presented, intermixed with new words. Subjects were required to judge whether each test item was old or new, and for each word judged old, to report its study partner. In keeping with the proposal that it indexes episodic retrieval, a significant left parietal effect was elicited only by those recognised old words for which associative recall was successful. There was, however, no sign of a right frontal old/new effect.

Donaldson and Rugg [4] performed two experiments to investigate the ERP effects elicited during associative recognition, only the first of which is relevant here. The study phase of that experiment was very similar to that of Rugg et al. At test, new pairs of items were intermixed with pairs of old items, which were presented in either the ‘same’ pairing as at study, or in a ‘rearranged’ pairing. The task was to discriminate between old and new pairs, and for pairs judged old, to discriminate between same and rearranged pairs. Relative to the ERPs elicited by both new and rearranged pairs, the ERPs elicited by correctly classified same pairs exhibited left parietal *and* right frontal old/new effects, along with an earlier, bilateral frontally distributed old/new effect.

The findings from the studies of Rugg et al. [14] and Donaldson and Rugg [4] suggest that associative recall and associative recognition have different electrophysiological correlates. Whereas in both tasks recollected items gave rise to a left parietal old/new effect, frontally distributed old/new effects were only elicited by recollected items during associative recognition.

These findings appear to be at odds with the functional account of the right frontal old/new effect proposed by Wilding and Rugg [27] (see above). One might take the view that the information retrieved on tests of associative recall and source memory is so disparate that the differential engagement of post-retrieval processes is to be expected (the argument put forward by Rugg et al. [13] to account for their lack of a right frontal effect). It is difficult, however, to see how this argument can be extended to the comparison between associative recall and associative recognition. On the face of it, the two tasks require retrieval of the same kind of information (pertaining to novel associations), and there is no principled reason for supposing that recognition places greater demands on post-retrieval processing than does recall.

The conclusion that there is an inconsistency between the findings of Rugg et al. and Donaldson and Rugg is, however, based upon a comparison between two studies that differed in many respects other than their task demands. Experiment 1 was designed to allow the ERP correlates of associative recognition and recall to be compared in the same subjects, when extraneous procedural differences between the tasks were kept to a minimum. Thus, the two tasks were compared in a randomised experimental design, and ERPs were recorded from considerably more electrodes (25 vs. 13), and for a longer recording epoch (1944 vs. 1436 ms) than those employed by Rugg et al. [13]. At issue is the question of whether, under these conditions, the frontally distributed ERP old/new effects associated with the successful retrieval of novel associations differ as a function of task.

## 2. Experiment 1: materials and methods

### 2.1. Subjects

Twenty right-handed students participated in the experiment, paid at the rate of £5.00 per hour. Data from three subjects were discarded due to there being insufficient artifact-free trials in the critical response categories. An additional subject was discarded due to a technical failure. The mean age of the remaining subjects was 20.9 years (range: 18–31 years), 10 of whom were female.

### 2.2. Experimental stimuli

The experimental stimuli comprised a set of 880 medium frequency (mean: 19.1 per million, range: 10–30 per million) nouns and verbs (ranging from four to eight letters in length) selected from the Francis and Kucera corpus [5]. The 880 words were used to form 440 semantically and associatively unrelated word pairs, of which 400 were used as critical items, and the remaining 40 for training.

The experimental design is shown in Table 1, along with examples of each class of item. For associative recognition half of the old items maintained their pairing between study and test ('same' pairs), whereas the remaining half were randomly re-paired ('rearranged' pairs). As with the original pairing procedure, the generation of rearranged pairs was constrained such that the resulting items were semantically and associatively unrelated. For associative recall, test items comprised the first word of a study pair and a row of Xs. The position of the word and Xs was counterbalanced and the number of Xs (ranging from 4 to 8) did not correspond to the length of the words' original partners.

The 400 critical word pairs were used to generate eight study-test lists (each of which was presented to two subjects) such that across lists, each word pair was employed equally frequently for each task. The use of word pairs as

Table 1

Experiment 1. Experimental design for a single study-test block, showing the different classes of stimuli, and associated correct responses

Phase	Class of item	Example	Response
<i>Study list</i>			
	40 word pairs	dog-box chain-glue plant-ride green-hotel	
<i>Test list</i>			
Associative recognition	10 same pairs	dog-box	Old: same
	10 rearranged pairs	chain-ride	Old: rearranged
	20 new pairs	rock-stamp	New
Associative recall	20 old items	green-×××	Old: hotel
	20 new items	creep-××××	New

Items from the two tasks were randomly intermixed during both the study and test phases.

study items was also counterbalanced across lists, such that each pair served equally often as an 'old' or 'new' test item. The items used to form 'same' or 'rearranged' pairs for the associative recognition task were also counterbalanced across lists. Item order within each list was also randomised. Finally, each of the resulting study-test lists was separated into five blocks, such that each study block contained 40 word pairs, and each test block contained 80 pairs of stimuli: 20 'old' items and 20 'new' items for each task.

In addition to the critical experimental lists, a training list was also generated, according to the same procedure as for the critical items, but containing only 20 study pairs and 40 test items.

### 2.3. Experimental tasks and procedure

The experiment was run over five study-test blocks, preceded by the initial training session. Prior to the training session subjects were fitted with an ERP recording cap (see below) and informed that they were taking part in a memory experiment. In both the study and test phases, stimuli were presented in upper case white letters against a black background on a TV monitor. Words and strings of Xs were displayed in central vision just above and below a central fixation point (see above). At the viewing distance of 1 m, the stimuli subtended a maximum vertical visual angle of approximately 0.7°, a maximum horizontal angle of approximately 2.0°, and were separated vertically by approximately 0.7°.

The study phases were self-paced. On each trial an initial fixation character (!) was displayed, signalling that the subject should begin when ready. When the appropriate response key was pressed this character was replaced with a second fixation character (+), displayed for a duration

of 800 ms. This character was then replaced with a word pair, displayed for 1000 ms, followed by the return of the original fixation character. Subjects were instructed to generate and say out loud a short sentence incorporating the two words. They were then free to begin the next trial.

Each test phase followed immediately after the study phase. Subjects were told that they would have to perform two tasks, each task being cued with a different fixation character. The ‘\*’ character signalled an associative recognition trial, and the ‘#’ character signalled a trial requiring associative recall. Each trial began with the presentation of one of these fixation characters, displayed for 800 ms. Following a 124-ms period during which the screen was blank, the test items were presented for a duration of 300 ms. The screen then remained blank for a further 3 s, at which time another fixation character ‘?’ was presented for 4 s, which signalled that the subject should respond. The next trial then began. During the test phase the interval between the onset of successive test items was 10 s.

For both test tasks subjects were required to make verbal responses, which were monitored and recorded by the experimenter. Examples of the correct response for each type of test stimuli are shown in Table 1. For the associative recognition task subjects were instructed to make an initial old/new judgement for each pair, responding ‘old’ to pairs judged as studied, and ‘new’ to pairs judged as unstudied. For pairs judged as being old an additional response was required, ‘same’ for words judged as having maintained their study pairing, ‘rearranged’ for words judged as being from separate study pairs, and ‘don’t know’ when uncertain. An initial old/new judgement was also required for the associative recall task. Again, for any word judged to be old an additional response was required, either to report the word’s original study partner, or if unable to do so, to respond ‘don’t know’.

To reduce the number of trials containing EEG artifact, subjects were instructed to relax during each test phase, to minimise body and eye movement, and to maintain fixation (blinking and moving their eyes only when the question mark was in view).

#### 2.4. ERP recording

Scalp EEG was recorded from 27 tin electrodes, 25 of which were embedded in an elasticated head cap. The recording montage was based on the International 10–20 system [8]. Midline sites were Fz, Cz and Pz. Left and right hemisphere sites were: Fp1/Fp2, F3/F4, F7/F8, LF/RF (frontal, 75% of the distance between Fz and F7/F8), C3/C4, T3/T4, LT/RT (anterior temporal, 75% of the distance between Cz and T3/T4), P3/P5, T5/T6, LP/RP (parietal, 75% of the distance between Pz and T5/T6), and O1/O2. An additional EEG channel was also recorded from the right mastoid. Inter-electrode impedance

levels were kept below 5 k $\Omega$ . All EEG channels were recorded with respect to a reference electrode positioned on the left mastoid, and were re-referenced off-line to represent a linked mastoid recording. EOG was recorded from bipolar electrodes positioned above the supra-orbital ridge of the right eye and adjacent to the outer canthus of the left eye.

Both EEG and EOG were amplified with a bandwidth of 0.03 Hz to 35 Hz (3 dB points). All signals were sampled at a rate of 8 ms per point for a recording epoch of 2048 ms, beginning 104 ms prior to stimulus onset. In forming ERPs, trials on which one or more channels showed drift from baseline greater than 55  $\mu$ V, or on which base-to-peak EOG amplitude exceeded 98  $\mu$ V, were excluded. To ensure an acceptable ERP signal/noise ratio, a minimum of 16 artifact free trials were required from each subject for each critical response category.

### 3. Results

Behavioural and ERP data were analysed using repeated measures ANOVA, applying the Greenhouse–Geisser correction for non-sphericity where necessary [7]. *F* ratios are reported with corrected degrees of freedom (*df*).

#### 3.1. Behavioural data

Table 2 shows the probability of an ‘old’ response to old and new items on the initial old/new judgement of each task. Recognition accuracy (measured as [ $p_{\text{hit}} - p_{\text{false alarm}}$ ]) was superior in the recognition task ( $t_{15} = 11.33$ ,  $p < 0.001$ ).

The hit rates on the associative recognition task were 97% and 93% for the same and rearranged pairs respectively; these rates differed significantly ( $t_{15} = 4.24$ ,  $p = 0.001$ ). Table 2 also shows the proportion of correct associative judgements made to pairs that were judged old (no subjects responded ‘don’t know’ to these items); these proportions did not differ significantly. Too few false

Table 2

Experiment 1. Mean percentage (standard deviations, S.D.) of old responses on the initial old/new judgement for both associative recognition and associative recall

Judgement	Class of item	
	Old	New
Old/new recognition		
% ‘Old’: recognition	94.9 (3.2)	2.3 (2.5)
% ‘Old’: recall	80.4 (8.1)	4.4 (3.2)
Associative recognition	Same	Rearranged
% ‘Correct’	90.0 (5.8)	90.1 (5.5)

The subsequent probability of a correct associative recognition response is also shown for same and rearranged pairs (contingent upon a correct old/new response).

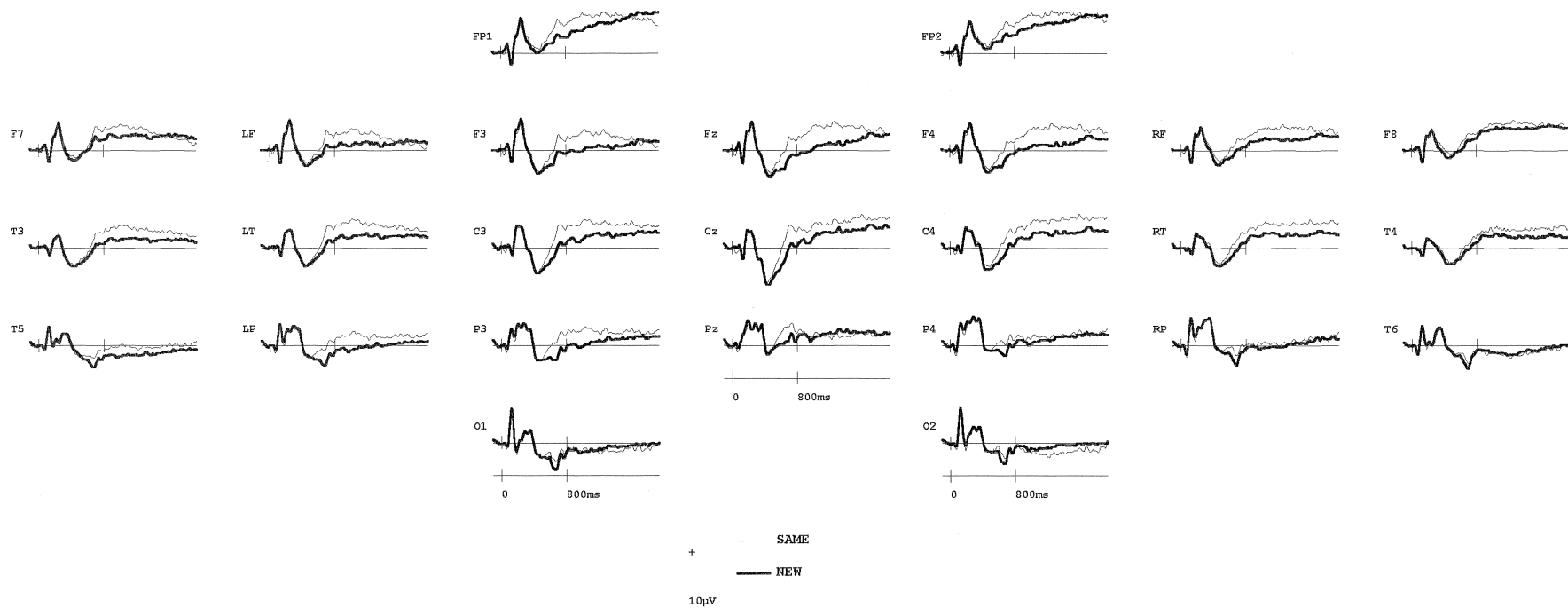


Fig. 1. Experiment 1. Grand average ERPs for the recognised (same) and new response categories for associative recognition. All 25 electrode sites are shown, arranged as if looking down onto the top of the head (see Section 2 for further details of the recording montage and electrode locations).

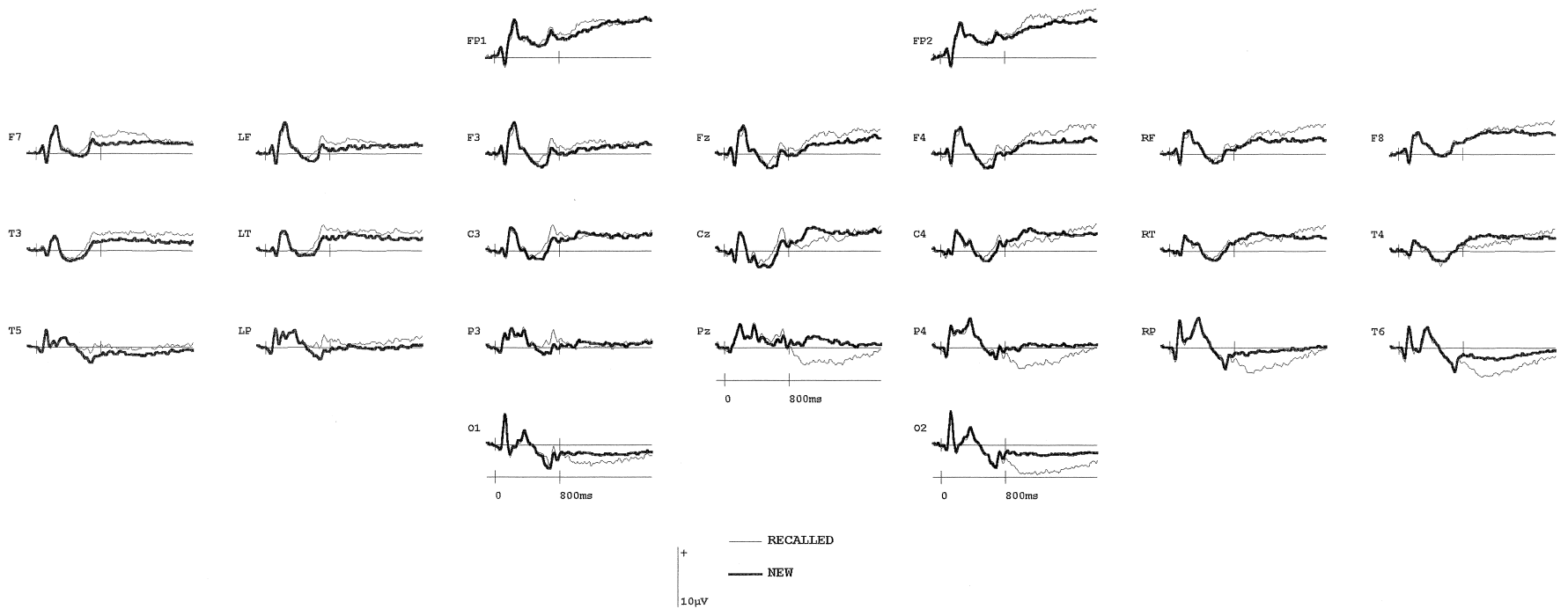


Fig. 2. Experiment 1. Grand average ERPs for the recalled and new response categories for associative recall. Electrodes shown as in Fig. 1.

alarms were made to permit an analysis of the associative judgements to these items.

Of those old words that were correctly recognised in the associative recall task, 49% were associated with the correct recall of their study partner, 43% elicited a ‘don’t know’ response, and the remaining 8% elicited an incorrect response.

### 3.2. ERP data

As the focus of interest is in the contrast between the neural correlates of successful associative memory on each task, analysis of the ERP data was restricted to two response categories for each task. For associative recognition these categories were correctly classified new pairs (henceforth ‘new pairs’), and same pairs that were both recognised as old and correctly classified as ‘same’ (‘recognised’ pairs). For associative recall the categories were correctly classified new words (‘new words’), and recognised old words for which the studied associate was correctly recalled (‘recalled’ words). The mean number of trials contributing to the ERPs for associative recognition was 81 and 38 for the ‘new’ and ‘recognised’ response categories respectively. For associative recall the mean number of trials was 79 and 35 for the ‘new’ and ‘recalled’ response categories respectively.

Fig. 1 shows the grand average ERP waveforms for the associative recognition task from all 25 electrode sites. The waveforms diverge from approximately 600 ms post-stimulus onset, with the ERPs for the recognised pairs

becoming more positive than those for new pairs. This positive shift is larger over the left than the right hemisphere at temporo-parietal electrodes, but is distributed more bilaterally at frontal electrodes. The left temporo-parietal positivity remains (but decreases in size) throughout the recording epoch. From approximately 1400 ms post-stimulus the bilateral frontal positivity is replaced by a right-sided effect.

Fig. 2 shows the grand average ERP waveforms for associative recall, again from all 25 electrode sites. As was the case for the recognition data, the waveforms begin to diverge from approximately 600 ms post-stimulus onset, with the ERPs for recalled pairs becoming more positive than those to new items, and exhibiting a left greater than right asymmetry at both frontal and temporo-parietal electrodes. At temporo-parietal sites the positivity is replaced from approximately 900 ms by a right-sided negative-going effect, which continues until the end of the recording epoch. At frontal sites a right-sided positive-going effect is evident from approximately 1400 ms post-stimulus.

### 3.3. Rationale for the ERP analyses

The principal aim of this experiment was to investigate whether frontally distributed old/new effects are present in the ERPs for each task, and if so, to characterise and compare them. Consequently, the analysis of the magnitudes of old/new effects focused upon the ERPs from the lateral frontal electrodes (F7/F8, LF/RF, and F3/F4; the same frontal sites employed in the work of Donaldson and

Table 3

Experiment 1. Results of the ANOVAs of the magnitude analyses, for each task, over each latency region

	600–900 ms	900–1400 ms	1400–1900 ms
<i>Associative recognition</i>			
Frontal			
RC	$F_{1,15} = 12.63, p < 0.005$	$F_{1,15} = 10.71, p = 0.005$	–
RC × HM	–	–	$F_{1,15} = 6.80, p < 0.05$
RC × ST	$F_{1,1,17.0} = 6.06, p < 0.05$	$F_{1,2,18.4} = 11.12, p < 0.005$	$F_{1,2,17.4} = 5.29, p < 0.05$
RC × HM × ST	–	$F_{1,3,19.8} = 4.03, p < 0.05$	$F_{1,5,22.4} = 4.34, p < 0.05$
Parietal			
RC	$F_{1,15} = 9.96, p < 0.01$	$F_{1,15} = 7.21, p < 0.05$	–
RC × HM	$F_{1,15} = 7.33, p < 0.05$	$F_{1,15} = 8.42, p < 0.05$	$F_{1,15} = 4.84, p < 0.05$
RC × ST	$F_{1,1,16.2} = 12.66, p < 0.005$	$F_{1,2,18.5} = 7.06, p < 0.05$	–
<i>Associative recall</i>			
Frontal			
RC	$F_{1,15} = 7.29, p < 0.05$	–	–
RC × HM	–	–	$F_{1,15} = 17.84, p = 0.001$
RC × HM × ST	$F_{1,6,23.9} = 5.68, p < 0.05$	$F_{1,4,21.6} = 7.47, p < 0.01$	$F_{1,4,20.6} = 5.68, p < 0.05$
Parietal			
RC	–	$F_{1,15} = 7.79, p < 0.05$	–
RC × HM	$F_{1,15} = 17.39, p = 0.001$	$F_{1,15} = 19.53, p < 0.001$	$F_{1,15} = 14.15, p < 0.005$
RC × ST	–	$F_{1,3,18.9} = 11.99, p < 0.005$	–
RC × HM × ST	–	$F_{1,2,17.5} = 13.19, p = 0.001$	$F_{1,5,23.2} = 12.99, p < 0.001$

Only significant effects involving the factor of response category are reported.

RC = Response category, HM = Hemisphere, ST = Electrode site.

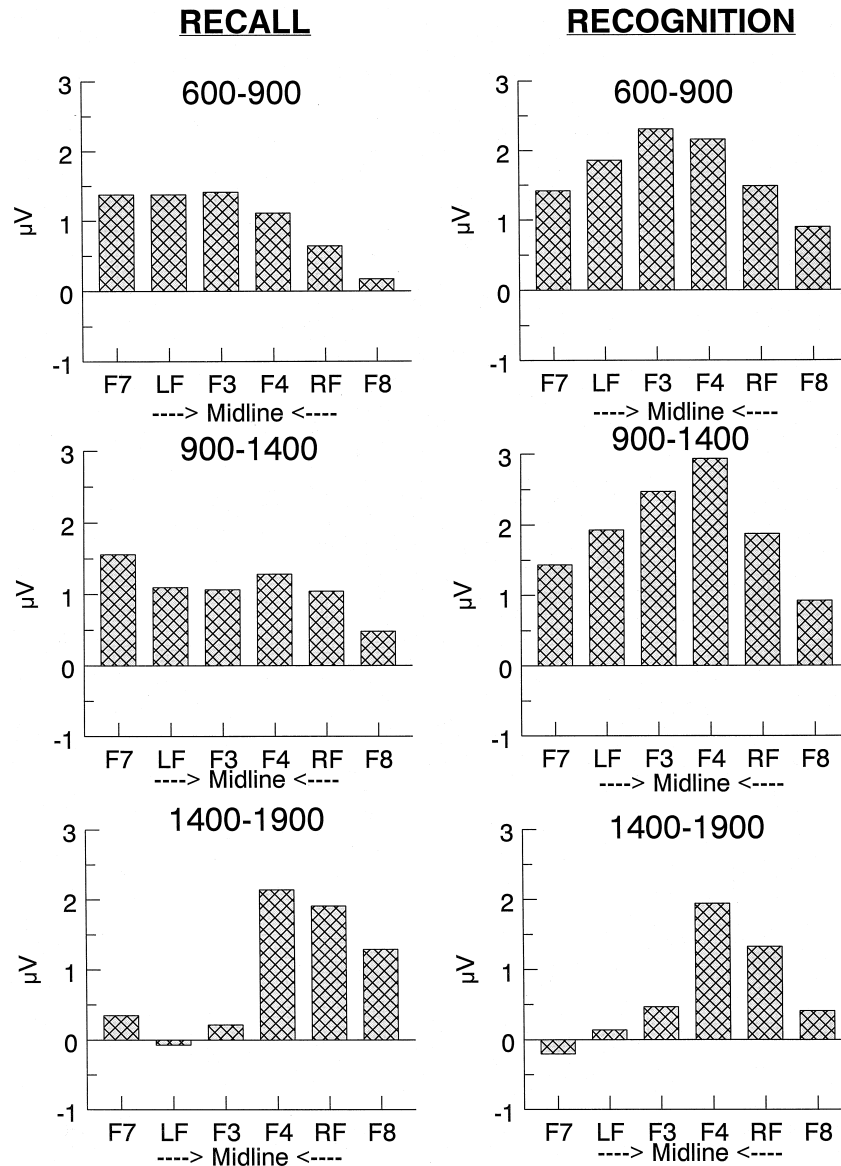


Fig. 3. Experiment 1. Mean amplitudes of the difference between the ERPs for correct old and new responses, shown separately for recall (left column) and recognition (right column) during the 600–900 ms (top), 900–1400 ms (middle) and 1400–1900 ms (bottom) latency regions. Values are shown for the lateral frontal electrodes employed in the initial within task, within epoch analyses. The data are shown for the left and right hemispheres, with sites arranged as on the head (inferior-to-superior on the left, superior-to-inferior on the right).

Rugg [4]). The ERPs were analysed by measuring mean amplitude (relative to the 102 ms pre-stimulus baseline) in three latency regions; 600–900, 900–1400 and 1400–1900 ms. These regions were selected, on the basis of visual inspection of the waveforms, as those which best captured the pattern of old/new effects as they evolved over time. The 1400–1900 ms region extends beyond the recording epoch employed by Rugg et al. [13].

Analysis was initially performed separately for each task to assess the reliability of the old/new effects within each latency region. These analyses employed ANOVA with factors of response category (old vs. new), hemisphere, and site (F7/8 vs. LF/RF vs. F3/4). The results

of these analyses are shown in Table 3.<sup>2</sup> Only significant *F* values are reported, and as interest lies solely in differences between the ERPs associated with each response category, significant effects that do not involve the factor of response category are not reported. Fig. 3 illustrates, for each task and latency region, the mean amplitude differ-

<sup>2</sup> Results from the analysis of the data from analogous temporo-parietal sites (T5/T6, LP/RF, and P3/P4) are also shown in the table. These analyses demonstrate the presence of statistically significant old/new effects over temporo-parietal scalp electrodes, similar to those found previously in the studies of Rugg et al. [13] and Donaldson and Rugg [4].



ence between the ERPs for old and new response categories.

### 3.4. Magnitude analyses

#### 3.4.1. Associative recognition

As can be seen in Table 3, analysis of the data from the 600–900 ms latency region revealed significant differences between the ERPs to the recognised and new response categories over frontal scalp sites, in the form of a significant interaction between response category and site. Fig. 3 shows that this interaction reflects the fact that the ERPs for recognised pairs were more positive going than those to the new pairs, and that this positivity increases as electrodes approach the midline. Table 3 also shows that significant old/new effects were present for the 900–1400 and 1400–1900 ms latency regions, with the ANOVAs giving rise in both cases to three way interactions between response category, hemisphere and site. Fig. 3 shows that for the 900–1400 ms epoch, this interaction reflects a positive going shift in the ERPs to recognised pairs. This effect is larger at the sites near the midline, and falls off

more rapidly over the right than the left hemisphere. For the 1400–1900 ms epoch the interaction reflects a positive going shift that again increases in size as electrodes get closer to the midline. In contrast to the pattern found in the earlier epochs, however, this shift is restricted largely to electrodes over the right hemisphere.

#### 3.4.2. Associative recall

Table 3 also shows the results of the ANOVAs comparing the ERPs for recalled and new pairs. As Fig. 3 shows, for the 600–900 ms data, the significant three way interaction between category, hemisphere and site reflects the presence of a frontal old/new which is larger over the left than the right hemisphere. The involvement of site in the interaction reflects the fact that the positive shift is distributed evenly across electrode sites over the left hemisphere, but is focused towards the midline over the right hemisphere. A similar pattern of effects can be seen for the 900–1400 ms region, for which there is a significant interaction between category, hemisphere and site.

The results of the ANOVA for the 1400–1900 ms region also revealed a significant three way interaction

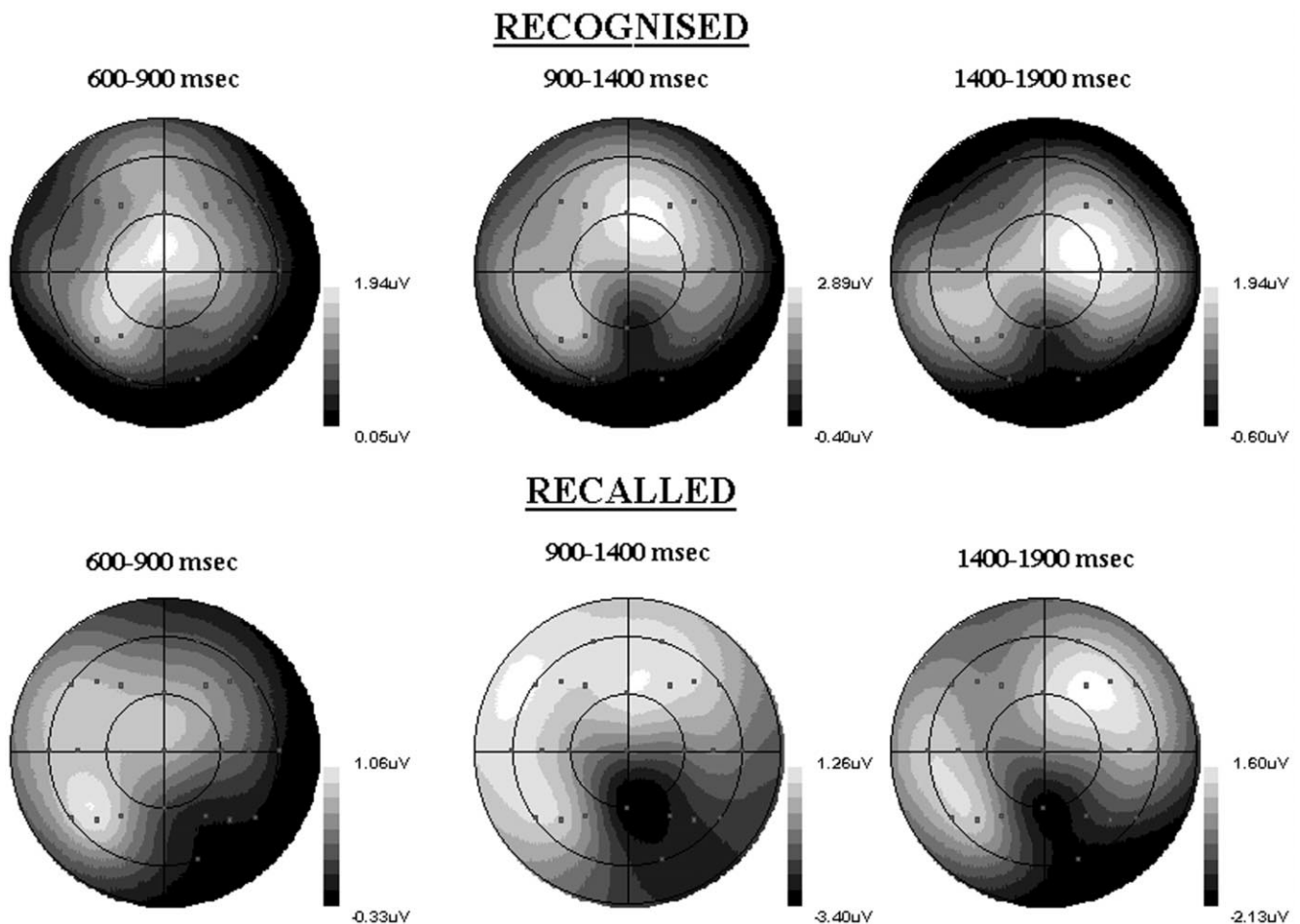


Fig. 4. Experiment 1. Topographic maps illustrating the scalp distribution of the old/new effects for associative recognition (top row) and associative recall (bottom row), over the 600–900, 900–1400 and 1400–1900 ms latency regions. Each map is shown as if looking down onto the top of the head. The scale bar to the right of each map indicates the maximum and minimum of the voltage range.

between category, hemisphere, and site (see Table 3). Once again, this interaction reflected the presence of a positive going old/new effect in the ERPs for the recalled items. Fig. 3 shows that the pattern of effects differs from that found in the earlier epochs. The positive going old/new effect is now restricted to the right hemisphere, increasing in magnitude as the electrodes approach the midline.

### 3.5. Topographic comparisons

Since there were statistically significant old/new effects for both tasks in all three latency regions, it was possible to compare the scalp distributions of the effects in each region as a function of task. These topographic analyses contrasted the scalp distributions of the differences in amplitude between the ERPs to the old and new response categories (see Fig. 4). They were conducted initially on the data from all 25 electrodes (factors of task and site), followed by planned ANOVAs of the data from lateral frontal electrodes (factors of task, hemisphere, and site). The difference scores were rescaled to eliminate the confounding effects of differences in the magnitude of the old/new effects [10].

#### 3.5.1. 600–900 ms

The initial ANOVA comparing the distribution of the effects across all 25 sites failed to reveal a significant task by site interaction ( $F < 1$ ). Similarly, the planned ANOVA restricted to lateral frontal electrodes revealed no effects that involved the factor of task (maximum  $F = 1.22$ ). Thus, there was no evidence that the scalp distribution of the old/new effects for recognition and recall differed during this epoch.

#### 3.5.2. 900–1400 ms

The initial ANOVA revealed a significant interaction between task and site ( $F_{3,4,51,3} = 4.46$ ,  $p = 0.005$ ), indicating that the distribution of old/new effects varied according to task. The ANOVA restricted to the data from lateral frontal electrodes also revealed a significant interaction between task and site ( $F_{1,3,19,2} = 7.14$ ,  $p < 0.025$ ). As can be seen from Fig. 4, this interaction reflects the fact that for recall, the frontal old/new effects are distributed relatively evenly across the frontal electrodes, whereas for recognition the effects are more sharply focused towards the midline.

#### 3.5.3. 1400–1900 ms

Neither the initial nor the planned ANOVA revealed any effects involving the factor of task (maximum  $F = 2.20$ ), indicating that the scalp topographies of the old/new effects in each task were statistically equivalent (see Fig. 4). Importantly, the planned ANOVA revealed a significant effect of hemisphere, along with an interaction between hemisphere and site ( $F_{1,15} = 18.56$ ,  $p = 0.001$ , and

$F_{1,4,21,3} = 18.28$ ,  $p < 0.001$ , respectively). In demonstrating that the old/new effects in this latency region were larger over the right than the left frontal scalp these findings echo the magnitude analyses described previously. They also indicate that these asymmetries, and their relative magnitudes across the homotopic electrode pairs, were statistically equivalent across the two tasks.

## 4. Discussion

As indexed by the initial ‘old/new’ decision, item recognition was highly accurate for both tasks, albeit more so for associative recognition than recall. The difference between the tasks with respect to the accuracy of item recognition most likely lies in the fact that two retrieval cues, and hence two opportunities to recognise a study item, were available on associative recognition trials, whereas only one cue was available for recall.

On both components of the associative recognition task performance was substantially better than in the study of Donaldson and Rugg [4]. This difference between the previous and the present study is almost certainly a reflection of the fact that fewer study items were employed in the present experiment (200 vs. 100 pairs). Performance on the first component of the associative recall task was similar to that reported by Rugg et al. [13], but the proportion of recognised words associated with correct recall was somewhat higher (49% vs. 36%). This difference too seems likely to reflect the employment in the present study of shorter study lists than were employed previously (128 pairs in Rugg et al.).

Performance on the second component of each task indicated that, in both cases, there was accurate recollection of a substantial proportion of the study episodes. In the case of associative recall, the probability of reporting a correct study associate by chance is vanishingly small; thus, it can be assumed that recollection was the basis for performance on essentially every trial on which recall was successful. By contrast, for the associative recognition task, chance responding would of course give rise to a correct associative judgement on 50% of trials. However, given that subjects’ judgements were accurate more than 90% of the time, it is safe to assume that guessing played only a small role in these judgements. Following Yonelinas [30], we assume that on the great majority of trials on which subjects correctly endorsed recognised word pairs as ‘same’, this judgement was based on recollection of the association formed at study.

The ERP effects obtained during the associative recognition task closely resemble those reported by Donaldson and Rugg [4]. Recognised pairs elicited a sustained left parietal effect, the onset of which was roughly concurrent with a bilaterally distributed frontal positivity that, from approximately 1300 ms post-stimulus, evolved into a right frontal effect which persisted until the end of the recording

epoch. In the associative recall task, the ERPs from the posterior scalp closely resembled those from the first study to employ this task [13], in that they exhibited an initial left parietal effect that was followed by a sustained, right-sided negativity.

Topographic analyses revealed that the scalp distributions of the old/new effects in each task were statistically equivalent for the 600–900 and 1400–1900 ms latency regions. However, it should be noted that this was not the case for the intervening region, where, among other distributional differences, frontal effects were distributed more diffusely across the scalp in the recall task than they were in the recognition task. This finding suggests that, for this latency region at least, the patterns of neural activity (and, presumably, the cognitive operations) engaged by the two tasks differed, at least in part. This is unsurprising, given the quite different retrieval cues and demands of the two tasks. What is more surprising, perhaps, is the finding that in the latency regions preceding and following this one, the patterns of neural activity associated with successful recollection in each task were so similar. Despite their procedural differences, it would appear that the two tasks engage many of the same cognitive operations.

For present purposes the key question is whether, in the associative recall task, the ERPs from frontal electrodes are more similar to those described by Rugg et al. or by Donaldson and Rugg. The answer is clear: the pattern of old/new effects obtained from the frontal electrodes in the recall task was very similar to that found for recognition, and not at all like that reported by Rugg et al. Frontal effects were evident from approximately 600 ms post-stimulus, becoming increasingly right-sided with time. Thus, at least in the experimental context employed here, successful associative recall does differentially engage the generators of the frontal old/new effects.

How can the present findings be reconciled with those of Rugg et al.? In the case of the late-onsetting right frontal effect observed here for associative recall, there may be nothing to reconcile. Rugg et al. employed a sampling epoch that terminated 1434 ms post-stimulus, and would therefore have been unable to observe a right frontal effect onsetting as late (ca. 1400 ms) as the one evident in Figs. 2 and 4. In light of the present findings, therefore, and contrary to the view of Rugg et al. [13] (see also Ref. [1]), there is no reason to believe that associative recall fails to engage the processes reflected by the right frontal old/new effect.

Unlike in the case of the right frontal effect, there is a clear discordance between the findings of the present study and those of Rugg et al. with regard to ‘early’, bilateral, frontal old/new effects. In the present study these effects onset around 600 ms, well within the recording epoch employed by Rugg et al. There was, however, no sign of such effects in the data from that study (see Ref. [13], Fig. 1). Clearly, the present findings are inconsistent with those of Rugg et al. [13] and indicate that, at least under the

experimental conditions employed here, successful associative recall does differentially engage the generators not only of the late right frontal effect, but also the earlier onsetting bilateral frontal effect.

Why should the present findings be so different from those of Rugg et al. [13]? One possible reason for the presence of the frontally distributed effects in the ERPs for successful associative recall in the present study is that the effects are sensitive to the overall experimental ‘context’ in which the task was performed. In the experiment of Rugg et al. all test trials belonged to the same task. In the present experiment, however, subjects were required to switch between tasks on a trial-by-trial basis. It is possible therefore that the requirement to constantly switch between tasks was in some way responsible for the presence of the early frontal effects in the present associative recall task (cf. Refs. [9,19]). By this account, the frontal old/new effects found for associative recall should not be present if the task is presented under conditions where subjects are not required to switch between two tasks on a trial-by-trial basis. Experiment 2 was designed to investigate this possibility.

## 5. Experiment 2: Introduction

Experiment 2 was designed to investigate whether the frontally distributed old/new effects in the ERPs for successful associative recall in Experiment 1 resulted from the requirement to switch between tasks on a trial-by-trial basis. Accordingly, the experimental design was modified so that task was now a blocked rather than a randomised variable. If the frontal old/new effects observed for the associative recall task in Experiment 1 were a consequence of inter-trial switching between this task and associative recognition, the effects should be absent in Experiment 2. Note that, although subjects performed both recognition and recall tasks in Experiment 2, the focus of interest lies in the question of whether changing from a random to a blocked design influenced the pattern of old/new effects found for associative recall. Consequently, only the data from the recall task are presented.<sup>3</sup>

## 6. Materials and methods

### 6.1. Subjects

Twenty-one subjects (paid at the rate of £5.00 per hour) participated in the experiment, none of whom had taken

<sup>3</sup> Subjects performed both tasks in Experiment 2, but only the data for associative recall are of interest. Nonetheless, as would be expected, the associative recognition data closely resembled those described in Experiment 1 and by Donaldson and Rugg [4].

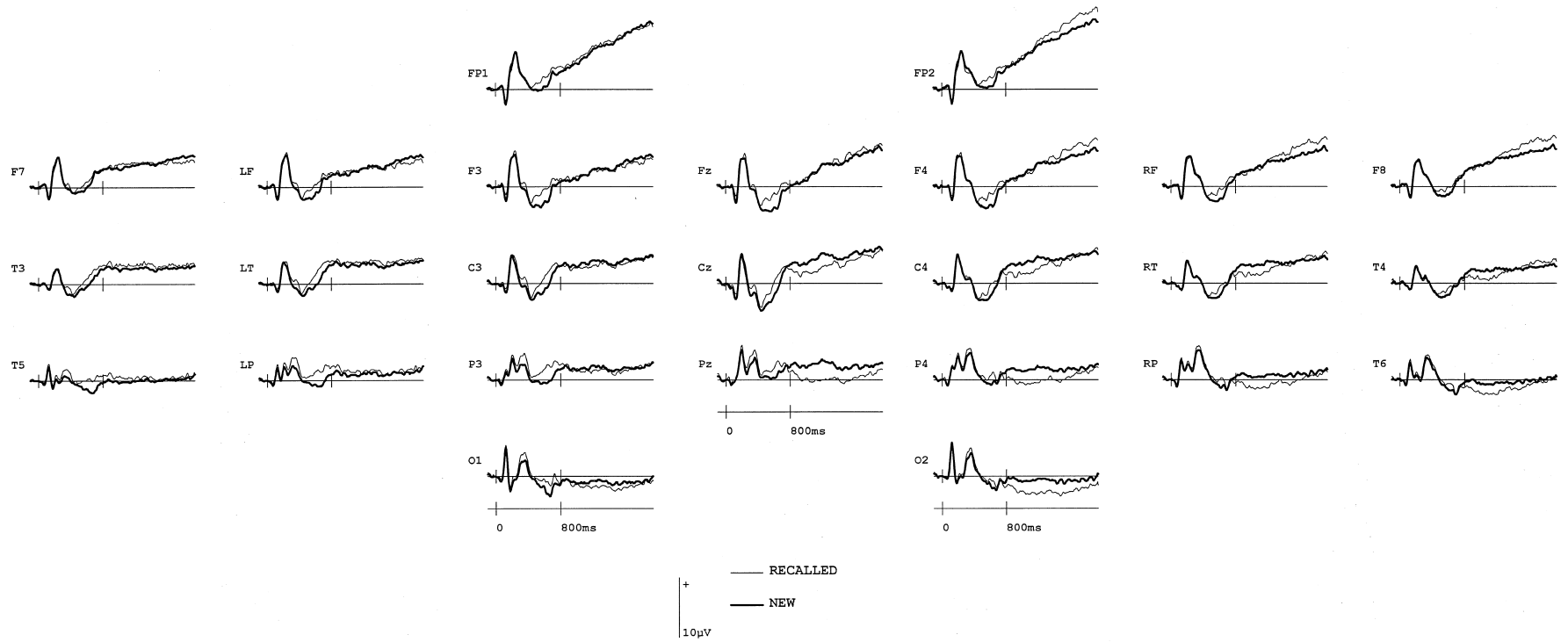


Fig. 5. Experiment 2. Grand average ERPs for the recalled and new response categories for associative recall. Electrodes shown as in Fig. 1.

part in Experiment 1. Two subjects failed to complete the experiment due to technical failure, and the data from three other subjects were discarded due to a lack of artifact free trials. The remaining 16 subjects (5 females, 11 males) had a mean age of 22.8 years (range: 17–31 years).

## 6.2. Experimental stimuli

The experimental stimuli comprised the same 440 word pairs that were employed in Experiment 1 (400 critical pairs, and 40 practice pairs). The experimental procedure for each task was the same as those used in Experiment 1, as was the method for generating and counterbalancing the study-test lists.

The critical difference between the present and previous experiment was in the separation of the recognition and recall trials into different blocks. Each subject was presented with four study-test blocks, two for associative recognition, and two for associative recall. Each study block contained 50 word pairs, and each test block contained 100 pairs. An AABB design was employed, such that half of the subjects performed the two associative recognition blocks first, whereas the remaining subjects performed the associative recall blocks first. The AABB design was chosen (rather than ABBA or ABAB designs) to minimise the number of switches between tasks.

A training block was also generated for each task. These were presented immediately before the administration of the first experimental block of the appropriate task.

## 6.3. Experimental procedure and ERP recording

The study and test phases procedures were identical to those employed in Experiment 1, except for the blocking of trials. Prior to the first training block subjects were provided with instructions for the first task, and were not informed of the second task until immediately before the training block for that task. In all other respects the experimental procedures, instructions and response requirements were maintained from Experiment 1, as were the EEG recording and analysis procedures.

## 7. Results

### 7.1. Behavioural data

The probability of an ‘old’ response to test items on the initial old/new judgement for associative recall was similar to that found in Experiment 1. Subjects accurately recognised 82.3% (S.D., 7.2%) of old items, and committed false alarms to 6.2% (S.D., 5.8%) of new items. Of those items correctly recognised as old, 48% were associated with correct recall of their study partner, 44% elicited a ‘don’t know’ response, and the remaining 8% elicited an incorrect response.

### 7.2. ERP data

ERPs were formed for the same response categories of the associative recall task as in Experiment 1. The mean number of trials were 79 and 34 for new and recalled pairs, respectively. Fig. 5 shows the resulting grand average ERP waveforms. The pattern of effects seen over temporoparietal electrodes is similar to those found in Experiment 1. Relative to the ERPs for correctly rejected new items, the ERPs for the recalled items exhibit a positive going shift, with a left greater than right asymmetry. As in Experiment 1, from approximately 900 ms this effect is replaced by a right-sided negative going effect, which continues until the remainder of the recording epoch. By contrast, the pattern of effects found over frontal electrodes differs somewhat from that found in Experiment 1 (cf. Fig. 2) in that there is little sign of early frontal old/new

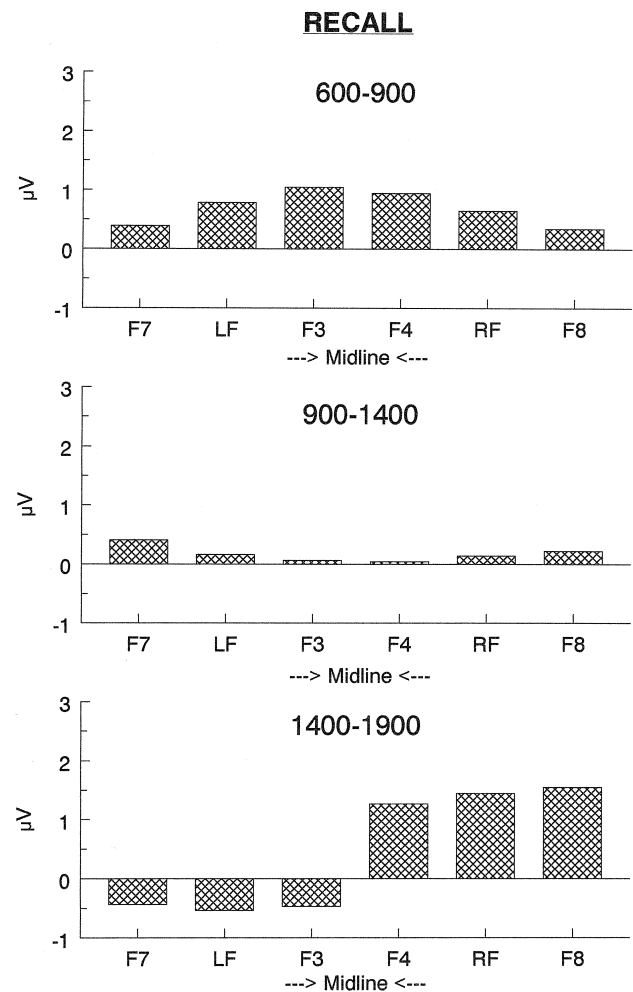


Fig. 6. Experiment 2: Mean amplitudes of the difference between the ERPs for correct old and new responses for associative recall during the 600–900 (top) ms, 900–1400 ms (middle) and 1400–1900 (bottom) ms latency regions. Data are shown as in Fig. 3.

effects. However, a right frontal effect is however clearly evident from approximately 1400 ms post-stimulus.

The magnitudes of the ERP old/new effects were analysed in the same way as those in Experiment 1, employing the same electrode sites and latency regions. Inspection of the old/new effects revealed however that they onset slightly earlier in the present experiment than in Experiment 1. Consequently, analyses were performed on the data from an additional, earlier, latency region (400–600 ms). The results of these analyses were consistent with those found for the subsequent 600–900 ms latency region and, because they do not affect the interpretation of the experimental findings derived from the analyses of the later regions, they are not reported in detail. Fig. 6 illustrates the mean amplitude differences between the ERPs for the old and new response categories, shown separately for each latency region. Because significant frontal old/new effects were only found during a single latency region, additional topographic analyses were not conducted.

### 7.3. Magnitude analyses

Table 4 shows the results of the analysis comparing the ERPs for recalled and new pairs. As Fig. 6 shows, the results confirm the impression gained from Fig. 5 that there are no significant frontal old/new effects for the 600–900 and 900–1400 ms latency regions (maximum  $F = 1.62$  and  $0.34$ , respectively).

Notwithstanding the absence of frontal old/new effects during the 600–900 and 900–1400 ms latency regions, Table 4 shows that the ANOVA for the 1400–1900 ms region revealed a significant interaction between response category and hemisphere. As Figs. 5 and 6 both indicate, this interaction is due to the presence of a right frontal old/new effect during this latency region. Thus, significant frontal old/new effects were only found during the 1400–1900 ms epoch, when they exhibited a right-sided maximum.

Table 4  
Experiment 2. Results of the ANOVAs of the magnitude data for each latency region in Experiment 2

Associative recall			
	600–900 ms	900–1400 ms	1400–1900 ms
Frontal			
RC × HM	–		$F_{1,15} = 20.23$ , $p < 0.001$
Parietal			
RC × HM	$F_{1,15} = 26.81$ , $p < 0.001$	$F_{1,15} = 33.02$ , $p < 0.001$	$F_{1,15} = 6.48$ , $p < 0.05$

Only significant effects involving the factor of response category are reported.

RC = Response category, HM = Hemisphere.

## 8. Discussion

Performance measures for associative recall in Experiment 2 were similar to those found for this task in Experiment 1 ( $p_{\text{hit}} - p_{\text{false alarm}}$  for the initial recognition decision was 0.76 in each experiment, and the proportions of recognised items attracting successful recall differed by only 1%). Given these strikingly similar patterns of performance across the two experiments, differences in the associated ERP findings cannot be attributed to differences in the probability of successful recollection.

The key question addressed by Experiment 2 concerns the pattern of frontally distributed old/new effects for associative recall; was the pattern of frontal old/new effects found for this task in Experiment 1 a result of the requirement to switch between this task and associative recognition? With respect to the late-onsetting, right frontal effect the answer is clearly negative. As in Experiment 1, a right frontal old/new effect was present in the ERPs from approximately 1400 ms post-stimulus. Thus, it can be concluded that successful associative recall engages the generators of the right frontal old/new effect even when the task is performed in a blocked format, and that the failure of Rugg et al. [14] to find the effect is a simple consequence of the employment of too short a recording epoch.

The present findings also shed further light on the earlier-onsetting bilateral frontal effect that was associated with successful recall in Experiment 1. Unlike in that experiment, the right frontal old/new effect in the present experiment was not preceded by a bilateral effect during the 600–900 and 900–1400 ms latency regions (cf. Figs. 2 and 5). Thus the present findings differ from those of Experiment 1, and instead resemble those of Rugg et al. [14]. Taken together, the present and previous findings suggest that when associative recall is tested in isolation, successful recall is not associated with a relatively early-onsetting bilateral frontal old/new effect. Furthermore, the fact that the earlier bilateral and later right frontal effects dissociated across experiments for the recall task adds weight to previous findings [4,28] which suggest that the two effects reflect functionally distinct cognitive operations.

## 9. General discussion

The aim of this study was to investigate the apparent inconsistency between the findings of Donaldson and Rugg [4] and Rugg et al. [14] with respect to frontally distributed ERP old/new effects in the tasks of associative recognition and associative recall, respectively (see Section 1). The focus of the study was the question of whether, and if so why, ‘right frontal’ old/new effects were elicited in

associative recognition, but not associative recall, a pattern of results inconsistent with current views of the functional significance of these memory-related ERP effects, e.g., Ref. [1]. The findings from the present experiments resolve this apparent inconsistency. The findings indicate that associative recall does indeed engage the cognitive operations reflected by the right frontal old/new effect, as would be expected of a task which places a significant burden on post-retrieval processing [15]. In sum, the cognitive operations reflected by the right frontal old/new effect appear to be common across associative recognition and recall.

In both of the tasks employed in the present study the right frontal effect emerged somewhat later (ca. 1300–1400 ms) than was observed in previous studies of either source memory (ca. 800–900 ms; Rugg et al. [13]) or associative recognition (ca. 1000–1100 ms; Donaldson and Rugg [4]). There are several possible explanations for this delay. In the case of associative recall, the delay may simply be a consequence of the nature of the task, reflecting the additional time required to retrieve episodic information in this task relative to others. However, the finding that the right frontal effect was also relatively delayed in associative recognition suggests that other factors must also have played a role. One notable possibility arises out of the fact that, unlike in Wilding and Rugg [27] and Donaldson and Rugg [4], responses to test items were withheld until 3 s post-stimulus offset. This delay between the presentation of the test item and response initiation may have resulted in the slower engagement of post-retrieval processing than when responding was speeded.

In the case of the earlier-onsetting, bilateral frontal old/new effect, the picture is less clear. The effect was present for both tasks when they were randomly intermixed, but was absent for associative recall when the tasks were blocked. These findings raise the intriguing questions of why this effect should be so sensitive to trial structure, why this sensitivity should be manifest only for recall, and, finally, what its functional significance might be given that recall performance was essentially identical across the two experiments? The present findings give few, if any, clues to the answers to these questions.

It is also unclear whether the earlier-onsetting bilateral effect reflects activity in the same neural generators that are responsible for the right frontal effect, along with a contribution from additional (left-localised) generators, or whether instead they reflect activity in a separate population of generators. Either way, given that in two studies [18,24] very similar frontal effects were found to onset earlier than the left parietal old/new effect held to index the retrieval of episodic information (see Section 1), it seems unlikely that they can be accommodated by the ‘post-retrieval’ hypothesis put forward to account for the right frontal old/new effect (e.g., Refs. [1,15,27]). Rather, it would appear that these effects reflect processes that either initiate or support the process of episodic retrieval.

In summary, the present findings indicate that, contrary to the impression given by previous findings [14], the recollection of associative information, whether in the context of associative recall or associative recognition, is accompanied by the right frontal ERP old/new effect, a putative index of ‘post-retrieval’ processing ([1,27]). In demonstrating that the right frontal effect is elicited during associative recall, the present study extends the range of memory tasks in which this effect is observed, and in combination with other recent findings (e.g., Ref. [24]), suggests that frontally distributed old/new ERP effects reflect processes that are both neurally and functionally dissociable. Finally, the present findings add further weight to the boarder claim [1] that recollection itself is neither neurally nor functionally homogeneous.

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