

Recognition memory for new associations: electrophysiological evidence for the role of recollection

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Abstract—The electrophysiological correlates of recognition memory for new associations were investigated in two experiments. In both experiments subjects first studied unrelated word pairs. At test, they were presented with old words in the same pairing as at study (same pairs), old words in a different pairing from study (rearranged pairs), and pairs of new words. In Experiment 1 the test requirement was to discriminate between old and new pairs and, for any pair judged old, to then judge whether the pair was the same or rearranged. In Experiment 2 the requirement was merely to discriminate between old and new pairs. Event-related potentials (ERPs) were recorded for correctly classified same, rearranged and new pairs. The ERPs elicited by same pairs exhibited a similar pattern of effects in both experiments. Relative to the ERPs to new pairs, these effects took the form of sustained positive shifts with two distinct scalp maxima, over the left temporo–parietal and right frontal scalp respectively. ERPs to rearranged pairs showed effects which were similar in scalp topography, but markedly smaller in magnitude. This pattern of ERP effects closely resembles that found previously for test items defined as recollected on the basis of their attracting a successful source judgement. The findings therefore suggest that associative recognition memory shares some of the recollective processes that are engaged by the requirement to retrieve contextual information about a study episode. The findings from Experiment 2 indicate that the processes associated with the recollection of associated pairs are engaged regardless of whether the retrieval of associative information is an explicit task requirement. © 1998 Elsevier Science Ltd. All rights reserved.

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Introduction

The idea that recognition memory is based on two distinct processes, recollection and familiarity, is central to "dual process" theories of recognition [1–4]. Recollection refers to conscious retrieval of the original study episode in which an item (usually a word) occurred. Thus, recollection provides information both about the prior occurrence of an item, and the context of that occurrence. By contrast, familiarity-based recognition is not accompanied by information from specific study episodes, and therefore provides no means for making discriminations on the basis of contextual information. Recollection is commonly viewed as the outcome of a relatively slow, effortful, search-like, process which can be brought under conscious control, whereas familiarity is seen as reflecting a faster, more automatic, process [5, 6].

Dual process theory has provided the framework for the interpretation of findings from several recent eventrelated potential (ERP) studies of recognition memory (e.g. Refs. [7-9]; for reviews see Refs. [10-12]). These studies have revealed a characteristic pattern of scalprecorded neural activity-the ERP "old/new effect"which is associated with successful recognition. The old/ new effect takes the form of a positive shift in the ERPs for words which are correctly recognised as old (hits), compared to those correctly judged new. The effect typically onsets between 300 and 400 ms post-stimulus, lasts for around 400-600 ms, and is maximal over left temporo-parietal sites. The effect is not found for unrecognised old words (misses), or for new words incorrectly identified as old (false alarms). It therefore appears to be a reflection of brain activity contributing to, or contingent

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upon, the retrieval of information required to make accurate recognition responses.

A range of evidence supports the idea that the ERP old/new effect is an electrophysiological correlate of recollection [7, 8, 13–15]. Perhaps the most convincing evidence comes from studies in which recollection has been operationalised as the ability to make accurate source judgements [9, 16, 17]. The rationale behind such studies is that items can be assigned to their correct source only if their encoding context is successfully retrieved. Hence, differences between ERPs elicited by items attracting correct and incorrect source judgements can be taken to be ERP correlates of recollection. In the experiments of Wilding and Rugg [16], subjects heard words at study that were presented in either a male or female voice. At test, subjects were required to judge whether items were old or new, and, for each item judged old, to report the gender of the voice in which it had been presented at study. Wilding and Rugg found that the magnitude of the left parietal old/new effect was larger in the ERPs associated with recognition that was accompanied by an accurate source judgement, than when it was accompanied by an inaccurate judgement.

In addition to the left parietal effect, the data of Wilding and Rugg [16] demonstrated the existence of a second old/new effect, which was also sensitive to whether or not recognition was accompanied by recollection. This effect also onset around 400 ms post stimulus, but was dissociable from the left parietal effect by virtue of its more extended time course, and its right frontal scalp distribution. Like the left parietal effect, the "right frontal" old/new effect was larger in ERPs associated with correct rather than incorrect source judgements.

Wilding and Rugg argued that the prominence of the right frontal effect in their studies of source memory reflected the fact that, unlike standard tests of recognition memory, source judgements necessitate the explicit retrieval of study context. They argued that the right frontal effect reflects processes which operate upon recollected information to generate a representation of the retrieved episode (cf. Ref. [18]). They further argued that such representations are necessary for accurate source discriminations, but not for making simple old/new discriminations, hence the absence of a prominent right frontal effect in previous ERP studies of recognition memory.

The present experiments extend previous findings by employing an associative recognition task to vary the likelihood that experimental items will be recollected. Tests of recognition memory for associative information (associative recognition) involve memory for word pairs rather than individual words. At test subjects must distinguish pairs composed of the same words as were presented at study (same pairs) from pairs composed of new combinations of studied words (rearranged pairs). In contrast to old/new recognition (item recognition), where subjects are presented with a mixture of old and new words, all the words in a typical associative recognition test have been studied. Thus, it is memory for the relationship between the members of a pair which is critical for accurate performance.

As already noted, the dual-process framework proposes that accurate item recognition can be based on either familiarity or recollection. By contrast, it has been argued that associative recognition is based solely on recollection, as the recovery of information about word pairing is only available if memory for the original study episode is retrieved [19, 20]. Thus, according to this argument, familiarity-based recognition cannot support associative recognition judgements.

This argument has recently received support from the findings of Yonelinas [21], who contrasted the receiver operating characteristics (ROCs) for item and associative recognition memory. Yonelinas found that ROC curves for item recognition were best fitted by a model of performance which assumes a contribution from both familiarity and recollection (see also Ref. [22]), whereas the ROC curves for associative recognition were best fitted by assuming that performance was based on recollection alone. Thus, Yonelinas' data support the suggestion that performance on tests of item recognition can be based on either recollection or familiarity, but that only recollection can support accurate associative recognition.

Yonelinas' findings also provide an important insight into how rearranged pairs are detected in an associative recognition test. Since recollection is more probable for same than for rearranged pairs, "rearranged" responses could be made by default, whenever a test pair fails to engender recollection. In line with this analysis, Yonelinas' findings suggest that responses to rearranged pairs are indeed more likely to made on the basis of a "default" strategy than upon veridical recollection of a study episode.

In summary, the findings from behavioural studies suggest that accurate performance on tests of associative recognition is based predominantly on the recollection of previous study episodes. Associative recognition thus provides a means of further investigating the putative ERP correlates of recollection. Specifically, if the ERP effects described by Wilding and Rugg [16] do indeed reflect processes linked to recollection of specific prior episodes, the effects should be more prominent, relative to unstudied pairs, for word pairs that maintain their pairing between study and test than for those in which the pairing is changed. The two experiments reported below explore this hypothesis.

Experiment 1 was designed to be analogous with the source memory procedure employed by Wilding and Rugg [16]. To this end the standard associative recognition paradigm was modified by including pairs of new words (new pairs) in the test task, thus providing an ERP baseline equivalent to that used by Wilding and Rugg. At study, subjects viewed a series of unrelated word pairs and at test they were presented with same, rearranged, and new pairs. The test requirement was first to categorise each pair as either old or new, and, for pairs

judged to be old, to perform an associative recognition judgement. According to the reasoning outlined in the previous paragraph, ERPs to pairs correctly judged "same" should resemble those associated with correct source judgements in Wilding and Rugg's study [16]. In contrast, the ERPs to pairs correctly judged "rearranged" should show little or no sign of the ERP correlates of recollection.

Experiment 1

Method

Subjects

Eighteen right handed students participated in the experiment, each paid at the rate of £3.50 per hour. Data from 2 subjects were discarded due to there being insufficient artifact-free trials in the critical response categories. Of the remaining 16 subjects, 10 were female. The mean age of the subjects was 19.6 years (range 17–23 years).

Experimental materials

The stimuli comprised nouns and verbs (ranging from 4–8 letters in length), taken from a set of 1000 medium frequency words (mean 19.1 per million, range 10–30 per million) that had been selected from the Francis and Kucera corpus [23]. 800 words were randomly chosen as critical items, leaving 200 as fillers.

The 800 critical words were used to form 400 semantically and associatively unrelated pairs. These pairs were then randomly allocated into one of two study lists. Each study list was paired with two test lists, each of which contained 400 critical pairs. Two hundred of these pairs were drawn from the alternative study list, and constituted the new pairs. One hundred of the study pairs maintained their pairing between the study and test lists, and the remaining 100 pairs were repaired so as to generate the rearranged pairs. The items that were used to form the rearranged pairs in one of the test lists were employed to form the same pairs in the other, and viceversa. By rotating study and test lists over subjects, it was therefore possible to ensure that every word pair was presented equally often as old or new, and when old, equally frequently as same or rearranged. Four different orderings of the two study lists were created, padded by 5 filler pairs before each set of 100 critical items. The 8 test lists were generated so as to have different quasirandom orderings of items and experimental conditions, and again contained a sequence of 5 fillers prior to each set of 100 critical pairs.

Experimental tasks and procedure

The experiment consisted of a single study-test cycle. In both study and test phases word pairs were presented in central vision (separated by approximately 0.7°), just above and below a central fixation point (see below). The pairs were displayed in white capital letters against a black background. Each word subtended a maximum vertical visual angle of approximately 0.7° and a maximum horizontal angle of approximately 2.0° .

Before the start of the experiment subjects were fitted with an ERP recording cap (as described below). It was then explained that they were taking part in a memory experiment that would be in two phases, and that the aim of the study task was to ensure that they remembered words as a pair. The study phase was self paced. For each trial an initial fixation character (!) was displayed, signalling that the subject could initiate the beginning of a trial. When the appropriate response button was depressed this character was replaced with a second fixation character (+) for a duration of 500 ms. This character was replaced with a word pair, displayed for 500 ms, followed by the original fixation character. Subjects were instructed to generate and say out loud a short sentence that incorporated the two words, following which they were free to begin the next trial.

The test task followed the study phase after an interval of approximately 10 minutes. Each trial consisted of the presentation of a fixation character (!) for 2.4 s, followed by a second fixation character (+) for 500 ms. There then followed a 182 ms blank period, following which the test items were presented for a duration of 300 ms. The screen then remained blank until 1 sec after the first response, at which time a third fixation character (?) was presented for 2.5 s, signalling the need to give the second response if appropriate. The original fixation character then returned, signalling the beginning of the next trial.

Subjects were instructed to make a speeded old/new judgement to each test pair, responding old to pairs that contained studied words, and new to pairs of unstudied items. They were instructed to make this judgement as quickly but also as accurately as possible. The instructions further specified that for pairs judged to be old, a second response should be given when cued to do so. The requirement now was to judge whether the words were in the same pairing as when seen at study, or whether the pairing had changed. The test list was administered in four blocks of 105 pairs, with a short rest break intervening between each block.

Responses were made with the left or right index fingers, which rested on microswitch response keys. The mapping of keys to responses was counterbalanced across subjects such that there was no correlation between hands used for positive responses for each of the two judgements. To reduce the number of trials containing artifact, subjects were instructed to relax, maintain fixation, and minimise body and eye movement, blinking only when the exclamation character was present on the monitor.

ERP recording

Scalp EEG was recorded with respect to the left mastoid from 25 tin electrodes embedded in an elasticated head cap. The recording montage was based on the International 10-20 system [24]. 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/P4, T5/T6, LP/RP (parietal, 75% of the distance between Pz and T5/T6), and O1/O2. An additional channel recorded EEG from the right mastoid, allowing the scalp recordings to be re-referenced off-line to represent recordings with respect to linked mastoids. EOG was recorded bipolarly from electrodes positioned above the supra-orbital ridge of the right eye, and adjacent to the outer canthus of the left eye. Inter-electrode impedance levels were kept below 5 k Ω , and EEG and EOG were each amplified with a bandwidth of 0.03 Hz to 35 Hz (3 dB points). These signals were sampled for an 1536 ms epoch at a rate of 6 ms per point, beginning 102 ms before stimulus onset.

ERPs were formed for 3 critical response categories: correctly classified new pairs (new pairs); same pairs correctly classified as old and same (same pairs); and rearranged pairs correctly recognised as old and rearranged (rearranged pairs). When forming the ERPs, trials on which one or more channels showed drift from baseline greater than 60 μ V, or on which base-to-peak EOG amplitude exceeded 98 μ 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 (cf. Ref. [16]).

Results

Behavioural and ERP data were analysed using repeated measures ANOVA. The Greenhouse-Geisser correction for non-sphericity was used where appropriate [25], and associated F ratios are reported with corrected degrees of freedom. Unless otherwise stated, post hoc contrasts were performed with the Newman–Keuls test and employed a significance threshold of P < 0.05.

Behavioural data

Table 1 shows the probability of an old judgement to same, rearranged, and new pairs. A one way ANOVA of these probabilities revealed a significant main effect [F(2,30) = 181.69, P < 0.001]. Post hoc tests revealed significant differences between each pair of means; subjects were able to discriminate both classes of old pair from new pairs, but did so more accurately for same pairs.

Table 1 also shows the probabilities of correct responses for the associative recognition judgement (con-

Table 1. Mean probability (standard deviations in brackets) of an old response for the initial old/new judgement, and the subsequent probability of a correct associative recognition judgement, for same, rearranged and new pairs. For new pairs, the associative recognition score indicates the proportion of false alarms judged to be rearranged

Response	Same	Rearranged	New		
Old/New P (old)	0.81 (0.15)	0.73 (0.12)	0.18 (0.26)		
$\frac{Associative}{P \text{ (correct)}}$	0.75 (0.14)	0.84(0.13)	0.89(0.1)		

ditionalised on initial recognition performance), as well as the proportion of false alarms receiving a "rearranged" response. Initial analysis of the associative recognition judgements compared the probability of a correct response for all old pairs (i.e. averaged across same and rearranged pairs) against the chance level of 0.5. This revealed that subjects were reliably able to discriminate same from rearranged pairs [t(15) = 15.48, P < 0.001]. Responses to false alarms showed a strong (0.89) and statistically significant [t(15) = 11.71, P < 0.001] bias towards judging such pairs as being "rearranged". To elucidate differences in responses to same and rearranged pairs, the probability of correct associative recognition responses for each class of pair was contrasted with the probability of making the same response to a false alarm. This analysis revealed that the same pairs received significantly more "same" responses than did false alarms [0.75 vs 0.11, t(15) = 15.45, P < 0.001], whereasrearranged pairs received slightly fewer "rearranged" responses than did false alarms [0.84 vs 0.89, t(15) = 2.57,P < 0.025].

Table 2 shows mean RTs for the initial recognition responses. These are shown according to the accuracy of the initial old/new recognition judgement, and also according to the accuracy of the subsequent associative recognition judgement. For the former set of RTs, ANOVA revealed main effects of word pair type and accuracy [F(1.44,30) = 4.57, P < 0.05]; and [F(1,15) = 33.70, P < 0.001], respectively. The main effect of accuracy reflected faster correct than incorrect responses. Post

Table 2. Mean reaction times (ms) separated according to the accuracy of both the old/new recognition responses and the subsequent associative recognition judgement

Same	Rearranged	New		
1583	1686	1574		
1890	1889	1716		
1492	1715			
1734	1629			
	Same 1583 1890 1492 1734	Same Rearranged 1583 1686 1890 1889 1492 1715 1734 1629		

hoc tests revealed that the main effect of word pair type reflected significant differences in RTs between each pair of means. The mean RTs were slowest for the rearranged pairs (1788 ms), and fastest for new pairs (1645 ms), with same pairs occupying an intermediate position (1737 ms).

ANOVA of the RTs conditionalised on accuracy of the associative recognition judgement revealed no main effects. However, the interaction between pair type and accuracy was significant [F(1,15) = 12.22, P < 0.01]. Post hoc tests revealed that for same pairs, RTs were faster for correct than incorrect responses, whilst there were no such differences for rearranged pairs. In addition, for correct responses, same pairs received faster RTs than rearranged pairs, but no such differences were found for incorrect responses.

ERP data

The mean number of trials contributing to the grand average ERPs in the new, same, and rearranged response categories were 129, 49 and 51 respectively. Figure 1 shows these ERP waveforms for all 25 recording sites. Figure 2 shows the ERP waveforms in more detail from those sites-lateral frontal and lateral parietal-most important for demonstrating the existence of the left parietal and right frontal old/new effects observed by Wilding and Rugg [16]. The figures show that the waveforms begin to diverge from one another approximately 600 ms post-stimulus onset, with the ERPs for the same and rearranged pairs becoming more positive than those for new pairs. For same pairs, this positive shift is larger over the left than the right hemisphere at posterior electrodes, but exhibits the opposite asymmetry at anterior electrodes. The positive shift in the ERPs to rearranged pairs is smaller in amplitude, more restricted in time, and confined to posterior electrodes. From around 900 ms, it is replaced by a sustained negativity, which is maximal over the right centro-parietal scalp.

ERPs were quantified by measuring mean amplitude (relative to the 102 ms pre-stimulus baseline) of three successive latency regions: 600–900 ms, 900–1200 ms and 1200–1434 ms. These regions were chosen to allow changes in the pattern of effects over time to be elucidated, and to be roughly comparable with the measures employed by Wilding and Rugg [16]. The differences in the mean amplitude of each latency region between the ERPs to each category of old pair and those to new pairs (the old/new effects) are shown for lateral frontal and temporo–parietal electrodes in Fig. 3.

The analysis of each latency region took the form of an initial global ANOVA on the data from all three response categories, and all 25 electrode sites. In the event of significant effects involving the factor of response category, subsidiary analyses were conducted to elucidate these effects, using data from lateral frontal (F7/F8, LF/RF, F3/F4) and temporo–parietal (T5/T6, LP/RP, P3/P4) sites. The analyses took the form of contrasts between pairs of response categories, employing the factors of category, hemisphere, location (frontal vs temporo-parietal), and site (inferior vs mid-lateral vs superior). The results of these analyses are reported in Table 3. Only significant F values are shown, and as interest lies solely in differences between the ERPs associated with each response category, significant effects which do not involve the factor of response category are not reported.

In addition to the analysis of the amplitudes differences, the scalp topographies of the old/new effects associated with the ERPs to the same and rearranged pairs were also compared. These analyses were conducted on the differences in amplitude between the ERPs to each category of old pair and those to the new pairs. The data were rescaled to eliminate the confounding effects of magnitude differences [26], and subjected to an initial global ANOVA, employing the factors of latency region, response category, and electrode site (all 25 sites). Additional subsidiary ANOVA were also performed, employing the factors of latency region, response category, hemisphere, location and site (as above), to elucidate any significant effects. Thus, these analyses tested for differences in the scalp topography of the old/new effects associated with same and rearranged pairs, and whether the topography of these effects changed over time.

Amplitude analyses

For the 600–900 ms latency region, the global ANOVA revealed a main effect of response category [F(1.9,28.8) = 13.67, P < 0.001], but no other significant effects. For the two subsequent regions, the global ANOVA gave rise both to a main effect of response category (900–1200: [F(1.7,24.8) = 9.52, P = 0.001]; 1200–1434: [F(1.7,26) = 8.77, P < 0.005]) and to interactions between category and site (900–1200: [F(4.7,70.2) = 2.44, P < 0.05]; 1200–1434: [F(5.3,78.8) = 2.90, P < 0.025]). In light of these significant effects, subsidiary ANOVAs, contrasting each pair of response categories, were performed for each latency region. The results of these ANOVAs are shown in table 3 and elucidated in the following sections.

Same vs New: The ANOVAs comparing the ERPs to same and new pairs for the 600–900 and 900–1200 ms latency regions revealed several significant effects, including four way interactions between category, hemisphere, location and site (see Table 3). As can be seen in Fig. 3, in each case these effects reflect the greater positivity of the ERPs to same pairs. This positivity is markedly asymmetric in favour of the left hemisphere at temporo– parietal sites, but is almost symmetrical frontally. The combination of asymmetric old/new effects posteriorly, and bilateral effects frontally, accounts for the involvement of the factors of category, hemisphere, and location in the four way interaction. Not illustrated in Fig. 3, but evident in Fig. 1, is the reason for the involvement of



Fig. 1. Experiment 1: Grand average ERP waveforms elicited by correctly classified same, rearranged and new pairs. Electrode locations are as described in the text, and arranged as if looking down onto the top of the head.



Fig. 2. Experiment 1: Grand average ERP waveforms for same, rearranged and new response categories from left and right lateral frontal (LF, RF) and lateral parietal (LP, RP) electrode sites.

electrode site in the four way interactions. This reflects the fact that at both anterior and posterior sites, old/new effects were greater in magnitude at the electrodes nearest to the midline.

The ANOVA for the 1200–1434 ms latency region revealed three-way interactions between category, hemisphere, and location, and between category, location and site. These interactions reflect variations across the scalp in the magnitude of the old/new effects for the same pairs. The interaction with hemisphere and location arose because the old/new effects show a left hemisphere maximum at the posterior electrodes, whereas at frontal sites the old/new effect exhibits a right hemisphere maximum (see Fig. 3). The interaction with location and site reflects the fact that the old/new effects increases in size as electrodes get nearer to the midline at anterior electrodes, but that this is not the case at posterior electrodes (see Fig. 1).

Rearranged vs New: The ANOVA comparing the amplitudes in the 600–900 latency region revealed a single interaction, between response category and hemisphere (see Table 3). As Fig. 3 shows, this effect reflects the fact that the ERPs to rearranged pairs are the more positive going, but only over the left hemisphere. By contrast, for both the 900–1200 and 1200–1434 ms latency regions the subsidiary ANOVA revealed a single significant interaction between response category, hemisphere and location. For both latency regions this interaction reflects the fact that, other than at left posterior electrodes, the old/new effect associated with rearranged pairs tends to be negative- rather than positive-going, an effect that is especially pronounced at right posterior sites (see Fig. 3).

Same vs Rearranged: For the 600–900 ms latency region, the ANOVA contrasting the ERPs to same and

rearranged pairs gave rise to a significant effect of category, and a reliable category by site interaction (see Table 3). As can been seen in Fig. 1, these effects reflect the greater positivity of the ERPs to same than to rearranged pairs, and the fact that this difference is smaller at lateral electrodes than at sites nearer to the midline. Table 3 also shows that the ANOVAs for the 900-1200 and 1200-1434 ms latency regions gave rise to several significant effects, including interactions between response category, hemisphere and location, and between category and site. The three-way interactions reflect the fact that, in these latency regions, the ERPs for same pairs are more positive going than those for rearranged pairs, and that these differences are larger over the right hemisphere at the frontal sites, but larger over the left hemisphere at temporo-parietal sites (see Figs 1 and 3).

Topographic analyses

The scalp topographies of the old/new effects for the same and rearranged pairs are shown for each latency region in Fig. 4. In each case, the effects begin with left temporo-parietal and bilateral frontal maximum, whereas by the latest of the three regions, they exhibit left temporo-parietal and right frontal maxima. The global ANOVA comparing the topographies of the two effects across latency regions revealed a single effect, an interaction between latency region and electrode site [F(4.8,72.7) = 5.91, P < 0.001], and also gave rise to a marginally significant interaction between response category and electrode [F(3.1,46.1) = 2.59, P < 0.07].

The subsidiary ANOVA revealed interactions between latency region and hemisphere, latency region and



Fig. 3. Experiment 1: Differences in mean ERP amplitude for same minus new pairs, and rearranged correct minus new pairs, for the 600–900 ms, 900–1200 ms, and 1200–1434 ms, latency regions. Amplitude measures are averaged over the electrode site indicated and the sites immediately lateral and superior to it.

location, and latency region and site ([F(1.6,24.4) = 3.92,P < 0.05], [F(1.7, 25.6) = 4.91, P < 0.05], and [F(1.7, 25.6) = 4.91, P < 0.05], F(1.7, 25.6) = 4.91, P < 0.05], P < 0.(25.1) = 3.78, P < 0.05] respectively), along with threeway interactions between latency region, hemisphere and location, and between latency region, location and site ([F(1.4,20.9) = 13.85, P < 0.001], and [F(2.1,31.2) =10.43, P < 0.001], respectively). These results reflect a change in the topography of the old/new effects with time. As can be seen in Fig. 4, for both response categories, the effects at temporo-parietal electrodes maintain a strong left hemisphere maximum throughout the recording epoch, whereas those at frontal electrodes become more asymmetric over time. In addition, there was a significant interaction between response category and site [F(1.2, 18.5) = 17.77, P < 0.001]. Figure 4 shows that this effect reflects a tendency for the old/new effects for the rearranged pairs to be distributed somewhat more laterally than those for the same pairs.

Summary of results

The ERP analyses indicate that same and rearranged pairs were associated with old/new effects which, while exhibiting similar topographies, differed markedly in magnitude, with the effects for the same pairs exceeding those for the rearranged items. The distribution of the old/new effects changed over time. In the earliest latency region analysed, they exhibited left parietal and bilateral frontal maxima, whereas by the end of the recording epoch the left parietal effect was accompanied by a distinct right frontal maximum.

Discussion

In agreement with previous findings [27], recognition memory was better for same than for rearranged pairs. These results are easily accommodated by the dual-process model of Yonelinas [21]. According to this model, the probability of familiarity-based recognition should have been equivalent for both types of pair, whereas the probability of recollection would be greater for same than for rearranged pairs. Consequently, recognition memory for same pairs should exceed that for rearranged pairs.

The finding that rearranged pairs were more likely to receive a correct associative recognition judgement than were same pairs may appear paradoxical in light of the foregoing argument. However, the advantage for the rearranged pairs is only an apparent one. The asymmetry in the associative recognition judgements made to false alarms (new pairs falsely judged old) indicates that a strong bias operated in favour of the "rearranged" response option. Subjects were highly successful in opposing this bias when making associative judgements to same pairs, as would be expected if "same" responses are made whenever a word pair engenders strong recollection of the prior study episode. By contrast, the finding that similar proportions of "rearranged" judgements were made to false alarms and to rearranged pairs is consistent with the proposal that such judgements usually reflect a "default" decision made in the absence of recollection.

As expected (see Introduction), same pairs elicited sizeable, robust old/new effects very similar in character to those elicited by "recollected" items in previous studies of source memory [9, 16, 17]. The ERPs elicited by rearranged pairs elicited qualitatively similar, but markedly smaller effects. The effects for the rearranged pairs were relatively short-lived however, especially at left posterior electrodes, where they reversed in polarity from 900 ms onwards.

The findings for the rearranged pairs most likely reflect the summation of small positive-going old/new effects with another, temporally overlapping component that also distinguishes recognised from new pairs. This component is a slow, posteriorly distributed negative wave that was also evident in several previous studies [16, 17,

Experiment 1	Pairwise comparison							
Latency region	Same vs new	Rearranged vs new	Same vs rearranged					
600–900 ms								
RC	F(1,15) = 24.58, P < 0.001	_	F(1,15) = 12.84, P < 0.01					
RC×ST	F(1.2, 17.3) = 16.50, P < 0.001	_	F(1.1, 17.0) = 12.42, P < 0.005					
RC×HM	F(1,15) = 8.34, P < 0.05	F(1,15) = 6.09, P < 0.005						
$RC \times HM \times L \times ST$	F(1.8,27.0) = 4.45, P < 0.05	_	—					
900–1200 ms								
RC	F(1,15) = 9.15, P < 0.01	_	F(1,15) = 21.04, P < 0.001					
RC×ST	F(1.1, 16.4) = 5.12, P < 0.05	_	F(1.1,17.0) = 14.18, P < 0.001					
$RC \times HM \times L$	F(1,15) = 13.83, P = 0.005	F(1,15) = 5.63, P < 0.05	F(1,15) = 5.82, P < 0.05					
$RC \times HM \times L \times ST$	F(1.8,27.0) = 3.87, P < 0.05	_	_					
1200–1434 ms								
RC	F(1,15) = 9.32, P < 0.01	_	F(1,15) = 16.80, P = 0.001					
RC×ST	F(1.1, 16.7) = 5.10, P < 0.05	_	F(1.4,21.3) = 20.84, P < 0.001					
$RC \times L \times ST$	F(1.9,28.8) = 5.95, P < 0.01	_						
$RC \times HM \times L$	F(1,15) = 23.71, P < 0.001	F(1,15) = 11.64, P < 0.01	F(1,15) = 15.90, P < 0.001					

Table 3. Results of the amplitude analyses, comparing each pair of response categories, over each latency region. Only significant effects involving the factor of response category are reported

RC = Response Category, HM = Hemisphere (left vs right), L = Location (anterior vs posterior), ST = Electrode site (inferior vs mid-lateral vs superior).



Fig. 4. Experiment 1: Topographic maps illustrating the distribution of the differences between ERPs to correctly classified same and new pairs (upper row), and between ERPs to correctly classified rearranged and new pairs (lower row), over successive latency regions.

28, 29]. The functional significance of this component is unknown, but the available evidence suggests that it reflects processes more closely associated with responserelated factors than with memory for the eliciting items [17]. As evidenced by the similarity of the scalp distributions of the old/new effects for the same and rearranged pairs, the influence of this component differed little according to pair type. Thus, its relative prominence in the ERPs to rearranged pairs most probably reflects the fact that the small positive-going old/new effects elicited by these pairs exerted less of an offsetting influence than did the much larger effects associated with same pairs.

As noted in the foregoing paragraph, the scalp distributions of the old/new effects for the two classes of old pairs were similar to one another, in each case being characterised by a left parietal maximum that was maintained throughout the recording epoch, and a frontal effect that became progressively more right-sided with time. The topographies of the two effects were not entirely equivalent however, the rearranged pairs exhibiting effects that were distributed more laterally and diffusely than those for the same pairs. In light of the relatively small size of the effects for the rearranged pairs, this result should be treated with caution, as it may reflect little more than the fact that the distribution of these effects was more susceptible to the distorting influence of noise.

The existence of left parietal and right frontal old/new effects for both the same and the rearranged pairs suggests that, so far as can be judged from scalp recorded neural activity [30], successful recognition of these items was accompanied by activation of the same, or at least strongly overlapping, neural populations.* The old/new effects for each type of word pair did however differ in their magnitudes, those for the same pairs greatly exceeding those elicited by the rearranged pairs. On the assumption that these effects are indeed markers for recollection (see Introduction), this finding converges with the behavioural results to suggest that same pairs are more likely to engender recollection during tests of item or associative recognition than are rearranged pairs.

The finding that the old/new effects for same pairs exceeded those for rearranged pairs is reminiscent of the difference between ERPs elicited by words attracting correct or incorrect source judgements reported by Wilding and Rugg [16]. Wilding and Rugg interpreted their findings in light of the proposal that the magnitude of old/ new ERP effects might be proportional to the amount of information retrieved from memory [7]. They suggested that the larger old/new effects for items correctly assigned to source reflected the greater amount of information retrieved about such items relative to those for which the source could not be recollected.

Viewing recollection as a graded rather than an all or none process suggests one possible explanation of the differences between the old/new effects elicited by same and rearranged word pairs in the present experiment. By this argument, rearranged pairs were associated with partial or weak recollection on many trials. For instance, the presentation of a rearranged pair may elicit recollection about the prior occurrence of an individual word, but not about the item with which it was associated.

An alternative, and arguably more parsimonious, explanation of the differences in the magnitudes of the old/new effects for the two classes of word pair is also possible. This account is motivated by the proposal that associative judgements to same pairs are based almost exclusively on recollection, whereas those to rearranged pairs are made largely by "default", due to the failure to recollect [21]. According to this proposal, the ERPs to rearranged pairs would have been formed from a mixture of the few trials on which recollection did occur and the great majority of trials on which it did not. By this argument, therefore, the attenuated old/new effects seen for rearranged pairs do not reflect the occurrence of a small effect on most trials, but result instead from the dilution of an infrequent "full-blown" effect by trials on which there was no effect at all.

These two accounts are not mutually exclusive though, both of the proposed mechanisms may contribute to the differences in the magnitude of the old/new effects seen for same and rearranged pairs. Although it is impossible to determine the relative contributions of the two mechanisms, both accounts imply that recollection is, on average, stronger or more complete for same than for rearranged pairs.

The present findings provide additional information about the frontally distributed old/new effect first described by Wilding and Rugg [16], in that they suggest that the effect comprises at least two temporally and topographically dissociable components. This dissociation is seen most clearly in the ERPs elicited by the same pairs, where old/new effects were at their largest. As is evident from Figs 1 and 4, the frontal effects initially exhibited a bilateral distribution, which only shifted to a right hemisphere maximum after approximately 1200 ms post-stimulus. A similar pattern of effects is evident in the data of Wilding and Rugg [16], although it was not commented on by those authors. However, in a further study of source memory [29] the same authors demonstrated that the dissociation between these two frontal effects was statistically reliable.

The interpretation of the data from Wilding and Rugg's studies [16, 29] is complicated by the fact that the shift in the distribution of the frontal effect coincided with the decline of the left parietal effect. Thus, the shift may merely have reflected a reduction in the contribution

^{*} Despite the need for caution in its interpretation, the finding of a response category by site interaction in the topographic analyses means that there is a possibility that the two classes of old/new effect reflect the activity of at least partially distinct neural generators. In light of the fact that both effects exhibited similar left parietal and right frontal maxima, we assume that if this is the case, the generators of the effects for the two classes of word pair are nonetheless likely to be related to one another both anatomically and functionally.

of the left parietal effect to anterior electrodes over the left hemisphere, rather than changes in the activity of the generators responsible for the frontal effects. In the present experiment the left parietal effect onset around 600 ms and persisted until the end of the recording epoch. During the same interval, the frontal old/new effect nonetheless shifted from a bilateral to a right-sided distribution. This shift cannot therefore be due to a decline with time in the influence of the left parietal effect.

The functional significance of these frontal old/new effects is unclear. Wilding and Rugg [16] argued that the effects (they did not discriminate between the bilateral and asymmetric components discussed above) reflect "post-retrieval" processes that operate on the products of retrieval to generate an episodic representation capable of supporting accurate source discrimination. On the basis of a study [17] in which the right frontal effect was found partially to dissociate from source recollection may not be a sufficient condition for the emergence of the effect. They suggested that, in contrast to the processes reflected by the left parietal old/new effect, those reflected by the right frontal effect may be under a degree of strategic control.

The characterisation of frontal old/new effects as reflections of strategic post-retrieval processing has not been directly tested. The present findings are consistent with this characterisation, in that the imposition of the associative recognition judgement forced subjects to retrieve and make use of contextual (associative) information. Similarly, in the experiments of Wilding & Rugg [16, 17, 29], the imposition of a source judgement required explicit, task-related post-retrieval processing. If the prominent frontal effects observed in Experiment 1 are indeed a consequence of task demands that emphasise the explicit processing of contextual information, then the effects should be attenuated or absent when there is no explicit requirement to make associative recognition judgements. Experiment 2 was designed to test this prediction.

Experiment 2

Introduction

As noted above, the aim of this experiment was to investigate whether the requirement to engage in explicit, task related, "post-retrieval" processing of associative information is a necessary condition for the emergence of the frontal old/new effects found in Experiment 1. This was achieved by modifying the design employed in that experiment so that subjects made only a single old/new judgement to each pair. This modification eliminates the requirement to use associative information to meet the demands of the task. It therefore provides a test of the proposal that the frontal old/new effects observed in the previous experiment are a reflection of this requirement.

Method

Subjects

Eighteen right-handed young adults, none of whom had participated in Experiment 1, were employed. They were remunerated at the same rate as those employed in the first experiment. Data from 2 subjects was discarded due to insufficient artifact-free trials in the critical response categories. The remaining subjects had a mean age of 24.6 years (range 17–34 years), and 5 of them were female.

Experimental materials

Experimental lists were created in exactly the same way as in Experiment 1, with the exception that the number of critical items employed at study and test was halved. The lists were constructed by selecting items from a pool of 400 words which had been selected randomly from the pool of 800 items used in the first experiment. Each study list therefore contained a total of 110 word pairs (100 critical pairs and 10 fillers), whereas each test list totalled 220 pairs (100 new, 50 same and 50 rearranged and 20 fillers).

Experimental task and procedure

Other than for the number of items presented, the study phase was identical to that in Experiment 1. The sequence of events on each test trial was also identical to that in Experiment 1 other than for the fact that the "?" character that served as cue for the second response in that experiment was replaced by the "!" fixation character, which was thus displayed on each trial for 4.9 rather than 2.4 s. Subjects were instructed to respond to each test pair, depressing one response button for new pairs. Speed and accuracy were again given equal emphasis, as was the need to maintain relaxation, to blink only when the "!" character was on the screen, and to avoid excessive movement.

ERP recording

The procedure for recording the ERPs was the same as in Experiment 1, except that the sampling rate was decreased from 6 ms to 8 ms per point, thereby extending the recording epoch to a total of 2048 ms (including a pre-stimulus baseline of 104 ms). This modification was motivated by the fact that in the previous experiment neither the parietal nor the frontal old/new effects had declined to baseline by the end of the 1434 ms poststimulus recording epoch.

 Table 4. Probability (standard deviations in brackets) of an old response for same, rearranged and new pairs

Response	Same	Rearranged	New
Old/New P(old)	0.87(0.09)	0.69 (0.13)	0.22(0.12)

Results

Behavioural data

Table 4 shows the mean probability of an old judgement to same, rearranged and new pairs. An ANOVA comparing these probabilities revealed a significant effect [F(2,30) = 421.39, P < 0.001]. Post hoc tests revealed significant differences between each pair of means. Thus subjects were able to discriminate both classes of old pair from new pairs, and did so more accurately for same than for rearranged pairs.

Table 5 shows the mean RTs for same, rearranged and new pairs, separated according to the accuracy of the recognition response. ANOVA revealed a significant effect of accuracy [F(1,15) = 56.33, P < 0.001], and an interaction between word pair type and accuracy [F(2,30) = 11.61, P < 0.001]. Post hoc tests revealed that correct responses were faster than incorrect responses for same and rearranged pairs, but not for new pairs. In addition, the RTs for correctly classified pairs differed from one another, same pairs attracting the fastest responses, and new pairs the slowest.

ERP data

ERPs were formed for three response categories: correctly classified new pairs, same pairs correctly identified as old (same pairs), and rearranged pairs correctly identified as old (rearranged pairs). The mean numbers of trials contributing to each category of ERPs were 67, 37, and 30 respectively. Figure 5 shows these grand average ERP waveforms for all 25 recording sites, and Fig. 6 shows the ERPs from the left and right frontal and parietal sites only. The figures show that the ERPs for same pairs become more positive than those for new and rearranged pairs from approximately 600 ms post stimu-

 Table 5. Mean reaction times (ms) separated according to word pair type and accuracy of response

Response	Same	Rearranged	New		
Old/New Correct	1308	1522	1608		
Incorrect	1954	1746	1603		

lus onset. This effect exhibits a left hemisphere maximum at posterior sites, and a later-onsetting right hemisphere maximum anteriorly. The ERPs to rearranged pairs show little sign of an equivalent effect, but become more negative than the new pairs from around 900 ms onwards.

As in Experiment 1, the magnitude of ERP effects was quantified by calculating the mean amplitude (relative to the 104 ms pre-stimulus baseline) of the waveforms over successive latency regions. These regions were 600–900 ms, 900–1200 ms, 1200–1500 ms and 1500–1944 ms, the final region covering the extension to the Experiment 1 recording epoch. Analysis of these data followed the same rationale and procedures as in Experiment 1, and the results of these analyses are reported in Table 6.

The scalp topographies of the old/new effects were also analysed. These analyses, conducted on the differences in amplitude between the ERPs to old and new pairs, were employed to test whether the topography of the old/new effects changed over time.

Amplitude analyses

The global ANOVAs of the 600-900, 900-1200 and 1200–1500 ms latency regions each revealed a main effect of response category ([F(1.7,26.1) = 10.16, P < 0.01]; [F(2,30) = 10.96, P < 0.001]; and [F(1.9,29.2) = 15.04,P < 0.001], respectively). For the final 1500–1944 ms region, the ANOVA revealed a main effect of response category, and an interaction between response category ([F(1.9,29) = 17.63,and site P < 0.001], and [F(5.8,86.8) = 3.61, P < 0.01], respectively). The results of the subsidiary ANOVAs comparing each pair of response categories can be seen in Table 6, and are elucidated below.

Same vs New: The ANOVA for the 600–900 ms latency region revealed several significant effects, including an interaction between category, hemisphere, location, and site. These effects reflect the greater positivity of the ERPs to same pairs (see Fig. 7). The involvement of hemisphere and location in the four way interaction reflect the fact that this positive shift exhibits a left hemisphere asymmetry at temporo–parietal sites, and a smaller asymmetry in favour of the right hemisphere at frontal sites. The reason for the involvement of site in the four way interaction is that these effects are more larger at electrodes positioned nearer to the midline than they are laterally.

Table 6 shows that, in each case, the ANOVAs for the remaining latency regions revealed a significant interaction between category, hemisphere and location. As Fig. 7 shows, this pattern of effects reflects the greater positivity in the ERPs for same pairs compared to those for correct new pairs, a difference which is larger over the left hemisphere at temporo-parietal sites, but which predominates over the right hemisphere at frontal sites.

Rearranged vs New: The ANOVA for the 600–900 ms revealed only marginally significant effects. The analyses of the 900–1200 and 1200–1500 ms latency regions



Fig. 5. Experiment 2: Grand average ERP waveforms elicited by correctly classified same, rearranged and new pairs. Electrode sites as for Fig. 1.



Fig. 6. Experiment 2: Grand average ERP waveforms elicited by the same, rearranged and new response categories, for left and right lateral frontal and parietal electrode sites.

Table 6.	Results of the	e amplitude	analyses,	comparing	each p	pair of	response	categories,	over	each	latency	region.	Only	significant
			effects in	volving the	factor	of res	ponse cat	egory are r	eporte	d				

Experiment 2	Pairwise comparison						
Latency region	Same vs new	Rearranged vs new	Same vs rearranged				
	F(1,15) = 24.62, P < 0.001 F(1.2,18.6) = 10.90, P < 0.005 F(1.7,25.1) = 6.07, P < 0.01	$ \frac{-}{F(1,15)} = 4.28, P = 0.056 F(1.3,20.2) = 3.73, P = 0.057 $	F(1,15) = 11.96, P < 0.005 F(1.6,24.6) = 12.87, P < 0.001				
900–1200 RC RC×ST RC×HM×L	F(1,15) = 17.81, P < 0.001 F(1.2,18.1) = 7.34, P < 0.05 F(1,15) = 7.71, P < 0.005	${}$ F(1,15) = 7.10, P < 0.05	F(1,15) = 20.12, P < 0.001 F(1.5,21.8) = 16.71, P < 0.001				
1200–1500 RC RC × ST RC × HM × L	F(1,15) = 19.40, P < 0.001 F(1.2,17.4) = 6.17, P < 0.05 F(1,15) = 7.80, P < 0.05	${}$ F(1,15) = 10.05, P < 0.005	F(1,15) = 25.36, P < 0.001 F(1.7,25.6) = 22.91, P < 0.001				
1500–1944 RC RC×ST RC×L RC×HM×L	F(1,15) = 16.92, P < 0.001 F(1.2,17.4) = 7.63, P < 0.05 $\overline{F(1.2,17.4)} = 11.82, P < 0.005$	$ \overline{F(1,15)} = 5.14, P < 0.05 F(1,15) = 20.09, P < 0.001 $	F(1,15) = 27.31, P < 0.001 F(1.7,25.7) = 39.30, P < 0.001 				

RC = Response Category, HM = Hemisphere (left vs right), L = Location (anterior vs posterior), ST = Electrode site (inferior vs mid-lateral vs superior).

revealed a significant interaction between category, hemisphere and location. The reasons for this interaction can be seen in Fig. 7, which shows that at right temporo– parietal sites the ERPs for rearranged pairs are more negative-going than those for new pairs, whereas at right frontal sites the rearranged pairs are more positive-going. The ANOVA for the final latency region revealed significant interactions between category and location, and between category, hemisphere and location. These findings reflect the fact that over temporo–parietal sites the ERPs for the rearranged pairs exhibit a negative shift, maximal over the right hemisphere, whereas little difference between the response categories is evident at frontal sites.



Fig. 7. Experiment 2: Differences in mean ERP amplitude for same minus new pairs, and rearranged minus new pairs, over the 600–900 ms, 900–1200 ms, 1200–1500 ms and 1500–1944 ms latency regions. Amplitude measures are averaged over the electrode site indicated and the sites immediately lateral and superior to it.

Same vs Rearranged: For all four latency regions, the ANOVAs contrasting the ERPs for rearranged and same pairs revealed a significant effect of response category, and an interaction between response category and site (see Table 6). In each case these effects reflect the facts that the ERPs to the same pairs are more positive-going, and that this difference is larger nearer to the midline (see Fig. 5).

Topographic analysis

Because of their small size, and their marginal reliability in the 600–900 ms latency region, the results of a topographic analysis of the old/new effects associated with the rearranged pairs were considered to be of questionable worth. The analysis of scalp topography was therefore confined to the larger and more robust effects associated with the same pairs. Figure 8 illustrates the scalp topography of these effects over successive latency regions. The figure indicates that the old/new effects for same pairs are remarkably similar across all four latency regions, consisting of two topographically distinct maxima, over left temporo–parietal and right frontal scalp sites respectively.

To investigate whether the topography of the old/new effects evolved over the course of the recording epoch, the topographies of the effects in each latency region were contrasted by ANOVA, employing the data from all 25 sites. This revealed a marginally significant effect of electrode site [F(3.9,58.1) = 2.32, P < 0.07], but no sign of a site by epoch interaction. A follow-up ANOVA was conducted employing the factors of latency region, hemisphere, location (frontal vs temporo-parietal), and site (inferior vs mid-lateral vs superior). This ANOVA gave rise to a main effect of site [F(1.8,27.5) = 7.59, P < 0.005],along with interactions between hemisphere and location [F(1,15) = 13.97, P < 0.005], and hemisphere and site [F(1.7,26.2) = 6.43, P < 0.01], but to no effects of latency region (maximum F = 1.89). These findings confirm the coexistence of left parietal and right frontal effects in these data, but suggest that, unlike in Experiment 1, these effects did not change over time.

Summary of results

As in Experiment 1, the same pairs were associated with sizeable and robust old/new effects. The old/new effects associated with rearranged pairs were, however, small in magnitude, unreliable over the earliest latency region, and supplanted at many electrode sites by a negative-going effect. Again in accordance with the findings of Experiment 1, same pairs were associated with two topographically dissociable old/new effects, a left temporo–parietal maximum and a right frontal maximum. Unlike in the first experiment, however, there was no evidence of a change in the lateral distribution of the frontal old/new effects with time.

Discussion

As in Experiment 1, there was a significant advantage in recognition memory performance for same pairs, despite the fact that the task no longer required memory for associations established at study to be retrieved explicitly. This finding can be interpreted as further evidence for the proposal that same pairs benefit from recollection to a greater extent than do rearranged pairs. The magnitude of the recognition advantage for the same pairs was somewhat larger in the present experiment than in Experiment 1, indicating that the absence of the associative recognition requirement did not cause subjects to



Fig. 8. Experiment 2: Topographic maps illustrating the distribution of the differences between ERPs to correctly classified same and new pairs over successive latency regions.

reduce their dependence on recollection as a basis for responding to the old/new recognition judgement.

In light of these behavioural findings, it would be expected that the ERPs elicited by same and rearranged words pairs would, as in Experiment 1, differ with respect to the magnitude of any ERP correlates of recollection. As a result of the removal of the associative recognition judgement, however, the magnitude of these recollectionrelated ERP effects would likely be smaller than those identified in the first experiment, since it is no longer possible to separate recognised same pairs according to whether or not their study episode was accurately recollected (as was the case in Experiment 1). Thus, the ERPs elicited by such pairs in the present experiment include a higher proportion of trials on which recollection failed than was the case in Experiment 1, leading to a relative "dilution" of the ERP correlates of recollection.

Turning to the ERP data, the critical question posed by the experiment was whether the right frontal old/new effect found in Experiment 1 would remain, despite the removal of the explicit requirement to make an associative recognition judgement. The ERPs to recognised same pairs exhibited statistically reliable right frontal old/new effects similar in character to the right frontal effects found in Experiment 1. Thus the explicit requirement to discriminate between different classes of recognised item is not a necessary condition for the emergence of this frontally distributed old/new effect. Rather, in the context of the recognition of arbitrarily associated word pairs, the engagement of the cognitive operations reflected by the right frontal effect appears to be relatively obligatory in nature.

Unlike in Experiment 1 there was no evidence to suggest that the right frontal effect became more asymmetric over time. The reason for this difference between the findings of the two experiments is unclear. One possibility is that it reflects the change from a test procedure requiring serial responses to one in which only a single response must be made. A similar suggestion was made by Wilding and Rugg [29], who noted that the bilateral effect evident in their data was absent in an earlier study of source memory in which only a single response was required to each test item [17]. This account does nothing however to elucidate the functional significance of the frontallydistributed bilateral effect. Subsequent discussion of the functional and neurological significance of the frontal old/new effects will be confined to the asymmetric component (the right frontal effect), which was equally evident in both experiments.

As expected, both left parietal and right frontal old/ new effects were greater in magnitude in the ERPs to same than to rearranged pairs. As in Experiment 1, at temporo–parietal sites the old/new effect for rearranged pairs became increasingly negative-going over time, reflecting the contribution of the posteriorly distributed negative component discussed earlier (see Discussion of Experiment 1). Unfortunately the small and unreliable old/new effects for the rearranged items precluded the comparison of their topography with the topography of the effects for same pairs.

General Discussion

In both experiments old/new recognition was better for same than for rearranged pairs. In addition, for the associative recognition judgement in Experiment 1, subjects were able to overcome a strong bias towards responding "rearranged" and classify the great majority of the same pairs correctly. As already discussed, these findings are consistent with the proposal that same and rearranged pairs are equally likely to be recognised on the basis of familiarity, but that same pairs are more likely to engender recollection.

It is important to acknowledge however that while the behavioural findings are consistent with a dual-process account, they do not in themselves necessitate such an account. The findings are equally compatible with a single process model in which words in same pairs engender stronger and more complete recollection of their encoding episodes than do words in rearranged pairs, as might be expected on the basis of general principles of memory function such as "encoding specificity" [31] and "transfer appropriate processing" [32].

Likewise, the ERP findings are consistent with both dual- and single-process accounts of recognition. Notably, as was the case in the studies of Wilding and Rugg [16, 17], there was no evidence for an ERP correlate of familiarity based recognition. Such evidence would have taken the form of ERP old/new effects that were either of equivalent magnitude in the ERPs to same and rearranged pairs, or were larger in the ERPs to the rearranged pairs. Although it should be stressed that the absence of such findings cannot be taken as evidence against the proposal that recognition can be based on processes other than recollection, it is evident that the present results provide no support in favour of such a proposal.

Nonetheless, the present findings clearly demonstrate that the electrophysiological correlates of recognition memory for word pairs differ markedly according to whether associations formed at study are maintained or are broken at test. These differences are found in the magnitudes of two topographically dissociable old/new effects. In respect of their scalp distributions and functional properties, these effects closely resemble two previously identified correlates of successful memory retrieval: the left parietal and right frontal old/new effects [10]. The present findings lend support to previous proposals [10, 16, 17, 29] that these ERP effects reflect functional distinct processes engaged during the recollection of prior episodes.

Neuropsychological evidence [33] indicates that recollection depends critically upon the hippocampal formation and associated medial temporal and diencephalic structures (the medial temporal lobe memory system). It has been proposed that the role of this system is to bind or link together in memory the various features of an event at the time it is experienced, allowing its reinstatement in response to an appropriate retrieval cue [e.g. Refs 34–37]. In light of such proposals, the present findings, which indicate that the left parietal effect is sensitive not so much to whether test items are old or new, but whether they preserve information about associations formed during a single prior study episode, add weight to the suggestion that this effect reflects retrieval mediated by the medial temporal memory system [16, 28].

The present findings also provide new information about the right frontal old/new effect. As discussed previously, Wilding and Rugg [16, 17, 29] proposed that this effect reflects processing supported by the prefrontal cortex; specifically, task related post-retrieval processing performed on the products of successful recollection. This proposal is consistent with neuropsychological evidence which suggests that the prefrontal cortex contributes to performance on memory tasks that require the evaluation and employment of remembered information in a strategic, goal directed manner [38, 39].

The findings are consistent with the idea that the right frontal old/new effect reflects successful recollection, in that the magnitude of the effect was markedly larger for the ERPs to same pairs than it was for rearranged pairs. Contrary to what might have been expected on the basis of the proposals of Wilding and Rugg, however, the effect was found not only in Experiment 1, but also in Experiment 2, when the explicit requirement to evaluate and employ recollected information in a goal directed manner was reduced considerably. This finding demonstrates that the right frontal effect is not restricted to memory tasks, such as source memory, in which the correct response is dictated by the content of the recollected information.

Although the right frontal effect appears to be an obligatory correlate of the recollection of associative information, it has not been reported in numerous previous studies of recognition memory for isolated words [for review see Ref. 12]. Recent evidence suggests, however, that the effect can be found in standard old/new recognition tests under certain circumstances. For example, Allan and Rugg [40] found a small right frontal old/new effect in the ERPs to correctly identified old words in a recognition memory task in which accuracy

was very high. Similarly, Schloerscheidt and Rugg [41] reported that successful recognition of pictures of objects was associated with a right frontal old/new effect, again in the context of high levels of recognition accuracy.

Why should right frontal effects be present in these but not in earlier studies of old/new recognition memory? One possible explanation is that the emergence of the right frontal effect is related to the richness or amount of information that is retrieved in response to the test cue. By this argument, the post-retrieval processes reflected by this effect are obligatorily engaged whenever the amount of information retrieved from episodic memory exceeds some threshold, and such post-retrieval processes may sometimes be engaged regardless of task demands. This threshold is less likely to be exceeded when the experimental task requires simple recognition memory of words, than when the encoded information is particularly rich (as in the present experiments), or when a relatively large amount of information must be retrieved in order to satisfy task demands (as in tests of source memory).

That said, it is clear that the right frontal old/new effect is not a necessary consequence of the recollection of a prior study episode, even under circumstances similar to those in the present experiments. Rugg et al. [28] (see Ref. [42] for similar findings) employed a study task very similar to the one used here, but at test presented only one member of each study pair. For each item judged old, subjects were required to recall the word with which it had been associated at study. As would be expected on the basis of the present findings, Rugg et al. found that the left parietal old/new effect elicited by recognised words for which associative recall was successful was larger than the effect elicited by recognised words for which the associate could not be recalled. By contrast, there was no sign of a right frontal effect in the ERPs to the "recollected" items.

Thus, although associative recognition and associative recall might seem to rely upon the recollection of similar information, the two tasks are associated with different electrophysiological "signatures", with only recognition giving rise to the right frontal old/new effect. It will be of interest to determine whether associative recognition and associative recall employ qualitatively different retrieval processes, or whether instead they differ with respect to processes that act upon retrieved information. According to current proposals about the functional significance of the right frontal effect—that it reflects processes that act upon the products of retrieval—the latter is the more likely possibility.

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