The effect of encoding manipulations on neural correlates of episodic retrieval

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Abstract

The present experiments investigated whether the neural correlates of explicit (conscious) retrieval from episodic memory vary qualitatively according to conditions at encoding, as is predicted by current views of the neural basis of memory retrieval. Event-related potential (ERP) correlates of word stem (e.g. MOT\textsubscript{\textsuperscript{-}}) cued recall were compared for items studied under different encoding conditions. In Experiment 1, encoding was either 'shallow' or 'deep' whereas in Experiment 2 the presentation modality of the study items was either visual or auditory. In both experiments robust ERP memory effects were observed for stems completed with explicitly retrieved items from each encoding condition. The effects varied in their magnitude, such that they were largest when elicited by the more memorable class of item in each experiment. The scalp distributions of the effects did not differ according to encoding condition, a finding which offers no support for the view that retrieval involves the literal reinstatement of neural activity engaged at the time of encoding. The findings instead point to the existence of a set of retrieval operations that are engaged regardless of the conditions under which retrieved information is encoded. © 2000 Published by Elsevier Science Ltd. All rights reserved.

Keywords: ERPs; Recollection; Encoding; Cued recall

1. Introduction

The present two experiments employ event-related potentials (ERPs) to investigate whether neural correlates of episodic retrieval vary according to the nature of the information that is retrieved. Current models of episodic memory ([6,7,21,23,35] see also [20,31]) assert that retrieval involves the reinstatement of patterns of neural activity that represented an episode while it was first experienced, a process held to be critically dependent upon the hippocampal formation [35]. The nature of the reinstated information, and hence its neural basis, can vary from one episode to another according to what was encoded. Episodes associated with distinct patterns of cortical activity at encoding should thus give rise to different patterns of neural activity when they are retrieved. Hence, it is possible that the neural correlates of the retrieval of different kinds of study episode, as reflected by ERPs, will differ qualitatively.

Qualitatively different patterns of ERP activity in two or more experimental conditions are demonstrated by contrasting the scalp topography of ERP effects associated with each condition. ERP effects with different topographies reflect differences either in the loci of the generators of the effects, or in the relative levels of activation of multiple neural generators common to each condition. In contrast, differences in the magnitude of ERP effects, in the absence of topographic differences, are usually interpreted as evidence for different levels of engagement of the same neural generators [33].

The present studies employ word-stems (e.g. MOT\textsubscript{\textsuperscript{-}})
as retrieval cues for previously studied words (e.g. MOTOR). Participants were instructed to try to complete each stem with a studied item, or with any other suitable completion if a studied item cannot be recalled. Participants were then required to judge whether the completion was present on the study list ([1] a similar cued recall task has been employed in previous behavioural studies, e.g. [27,28]). The addition of a list membership judgement allows ERPs to be formed for trials where correct completion is accompanied by awareness that the completion is from the study list. Employing this procedure, Allan et al. [1], (see also [2,3]) found that ERPs elicited by stems attracting explicit retrieval of study items were modulated by a sustained positive-going shift relative to ERPs elicited by stems completed with unstudied words. Allan et al. [1] also demonstrated that this ERP 'cued recall effect' was associated selectively with explicit retrieval, and was insensitive to processes responsible for the implicit completion of stems with studied items (i.e. priming [16,27]).

The ERP cued recall effect has an onset latency of around 400 ms post-stimulus, and persists for around 1–1.5 s. The scalp topography of the effect changes over time, indicating that it reflects the activity of multiple neural generators [2,3]. Critically, the magnitude of the effect, but not its topography, varies with the accuracy of memory for contextual details ('source memory') of the episodes in which recalled items were presented [3]. This finding provides strong evidence linking the effect to processes responsible for the explicit retrieval of contextual details, widely considered to be a defining feature of recollection [12,15].

In the first experiment reported here, a 'depth of processing' manipulation was used to vary the nature of the processing accorded to items at study. The logic of this manipulation was that by varying whether participants focused their attention on superficial or semantic attributes of study items, we varied the attributes that were preferentially encoded into episodic memory [25]. At issue is whether the scalp distributions of ERP cued recall effects at retrieval vary according to encoding condition. The encoding manipulation employed is very similar to that employed by Allan, Doyle and Rugg [1] in their initial study of the ERP correlates of cued recall. There was weak evidence in that study to suggest that ERPs are indeed sensitive to depth of study processing. However, the combination of a restricted number of recording sites, low signal-to-noise ratio in the critical waveforms, and low subject numbers justifies further investigation of this issue.

The logic behind Experiment 2 was similar. In this case, however, the encoding manipulation was not of the cognitive operations engaged by the study items, but the sensory modality in which items were presented (visual vs auditory). Thus, we manipulated the sensory attributes that were 'bound' into the episodic representation of each study episode (for evidence that modality information is intrinsic to such representations, see [11]). Once again, the critical question is whether ERPs associated with episodic retrieval differ qualitatively as a function of the encoding history of the retrieved information. To the extent that episodic retrieval does indeed require the reinstatement of neural activity engaged at the time of study, the answer to this question should be affirmative.

2. Methods

2.1. Subjects

Subjects were 24 young adults, each paid £5.00 per hour for participation. All were right-handed native English speakers with normal or corrected-to-normal vision. Of these 24 participants, six did not complete the experiment due to computer failure, illness or failure to obey instructions. Of the remaining 18, the data from two could not be used because they contributed too few trials to ERPs in critical conditions after the rejection of trials containing excessive artifact. Of the 16 remaining participants, nine were female and all were right-handed. Their mean age was 22.6 years (range = 19–35).

2.2. Stimuli

The stimuli were drawn from a pool of 512 words. The first three letters, or stem, of each word were unique, and each stem could be completed with at least five different English words. The 512 item pool was used to form two pools of 240 critical items, and 32 buffer items. Half the participants studied one pool of items, and the remainder studied the other pool. Four study lists, each containing 60 critical items, were created from the 240 critical items in each pool, with two buffer items placed at the beginning and the end of each list. Half of the items in each study list were studied with one task, and the remainder with the other task (see below). One study list was presented in each of four study/test blocks. The task order within each block was randomised. Two versions of each study list were created to ensure that each item was studied in each task equally often. A single test list corresponded to each pair of study lists. Each test list consisted of 78 word stems. The first two stems were buffer items, 16 stems belonged to items drawn from the unstudied word pool, and the remaining 60 stems belonged to the 60 items presented for study. The mapping of lists to study/test block was rotated across participants.
All stimuli were presented visually in white on a black background in upper case on a computer monitor. Word stimuli subtended maximum horizontal and vertical visual angles of 1.5° and 0.4°, respectively, and word-stems subtended maximum horizontal and vertical visual angles of 0.5° and 0.4°, respectively. The presentation of study items was paced by the experimenter. Each study trial began with the presentation of a cue, either an 'O' or an 'X' at the centre of the screen, which indicated the study task for each trial ('O'='semantic task', 'X'='nonsemantic' task). The cue was displayed for 2 s, the screen was blanked and then a word was immediately presented at the centre of the screen for a duration of 500 ms. The experimenter initiated the next trial after the participant had responded (see below).

Each test phase trial began with the display of a cue ('!') at the centre of the screen to inform the participant that the trial had begun. This cue remained on screen for 1 s, and was followed immediately by a fixation asterisk displayed at the same position, also for 1 s. The screen was then blanked for 120 ms, after which a word-stem was displayed for 300 ms, centred on the position occupied by the fixation asterisk. The screen was then blanked for 2.7 s, after which a question mark was displayed to indicate that a verbal response was now required (see below). After a 3 s interval to permit a response to be made, the '!' cue reappeared to begin the next trial.

2.3. Procedure

Once the electrode cap had been fitted, subjects were taken to the experimental booth and seated in front of the stimulus presentation monitor. They were informed that they were about to take part in an experiment assessing their memory for lists of words to be presented in four study/test blocks, but that prior to these a practice study and test phase would be given to familiarise them with the experimental procedures. The practice study phase consisted of eight trials. In each trial a single word was presented visually on the monitor. Each word was to be studied with one of two tasks. The 'deep' task was to judge whether the meaning of the word was pleasant or unpleasant. The subject was instructed to respond on these trials by saying 'pleasant' or 'unpleasant' out loud after having made this judgement for each item. The 'shallow' task involved judging whether the vowels in each word were in alphabetic order. The response on these trials was to say 'alphabetic' or 'non-alphabetic'. Each trial was initiated by the experimenter.

A practice test phase, consisting of 16 trials, was then given. On each trial a word-stem was presented on the monitor. Participants were informed that some of the stems belonged to studied items, and that their task was to try and complete each stem with a studied item. If this was not possible, then the stem should be completed with the first suitable word to come to mind. Responses were to be withheld until a question mark was displayed on the monitor. Two verbal responses were then required. The first was to give a completion for the stem. The second was to say 'old' if the completion was a studied item, and 'new' if not. Each subject was asked to remain as relaxed and as still as possible during the test phase trials to minimise EEG artifacts due to head and body movements. Subjects were further instructed to refrain from blinking during the period beginning with the display of the fixation asterisk and ending with the display of the question mark, thereby minimising the effect of oculomotor artifacts on the EEG.

The first study/test block began once the practise study and test phases had been successfully completed. The duration of each study phase averaged about 5 min. A 2 min rest interval was interposed between each study and test phase. The duration of each test phase was approximately 15 min. Participants were given a short rest break halfway through each test phase.

2.4. ERP recording

EEG was recorded from 27 tin electrodes, 25 of which were embedded in an elasticated cap (Electro-cap). Electrodes were positioned according to the International 10–20 system [18], at Fp1, Fp2, Fz, Cz, Pz and at the following homotopic left and right hemisphere sites: F7/F8, LF/RF (frontal, 75% of the distance from Fz to F7/F8), F3/F4, T3/T4, LT/RT (anterior temporal, 75% of the distance from Cz to T3/T4), C3/C4, T5/T6, LP/RP (lateral parietal, 75% of the distance from Pz to T5/T6), P3/P4, 01 and 02. EEG was recorded with respect to a left mastoid reference. A separate right mastoid channel was also recorded and used to re-reference the EEG off-line to a linked (average) mastoid reference. EOG was recorded bipolarly using electrodes placed just above the supra-orbital ridge of the right eye, and adjacent to the outer canthus of the left eye. All channels were amplified (gain for EEG and EOG channels was 20 k and 4 k, respectively) with a bandpass of 0.03–35 Hz (3 dB points) and sampled on-line at a rate of 8 ms per point with 12-bit resolution. The recording epoch was 2048 ms, beginning 104 ms prior to stimulus onset. The duration of recorded post-stimulus EEG was therefore 1944 ms. Trials on which baseline-to-peak EOG amplitude exceeded 122 μV, drift of the EEG from baseline exceeded 60 μV, or on which saturation of the A/D converters occurred, were excluded from averaging. For each subject, ERPs were formed for conditions in which there were at least 16 artefact-
3. Results

3.1. Behavioural data

The behavioural data are summarised in Table 1. The correct completion rates for stems of deeply and shallowly studied items were corrected by subtracting the baseline completion rate of 8.4%, an estimate of the probability of completing a stem with a studied item by chance. The corrected completion rates were both significantly greater than zero (deep: \( t(15)=18.37, P < 0.001 \) and shallow: \( t(15)=10.38, P < 0.001 \), but more correct completions were made for deeply than shallowly studied items (\( t(15)=8.15, P < 0.001 \)).

The percentage of completions correctly recognised as belonging to the study list (hits), shown in Table 1, were corrected by subtracting the false alarm rate of 3.8%. This false alarm rate was defined as the percentage of completions with unstudied items that were falsely judged to be old. The corrected hit rates for deeply and shallowly studied items were both significantly greater than zero (deep: \( t(15)=18.36, P < 0.001 \) and shallow: \( t(15)=9.24, P < 0.001 \), respectively), and the hit rate for deeply studied items was significantly greater than that for shallowly studied items (\( t(15)=11.72, P < 0.001 \)). Finally, the conditional probabilities of recognition given correct completion also differed significantly as a function of the study manipulation, the rate for deeply studied items being higher (\( t(15)=9.42, P < 0.001 \)).

3.2. ERPs

ERP correlates of explicit retrieval were analysed by contrasting ERPs for three conditions: stems correctly completed with recognised deeply and shallowly studied items (termed deep hit and shallow hit ERPs, respectively); and stems completed with unstudied items given a correct ('new') recognition judgement (correct rejection ERPs). The mean number of trials contributing to ERPs for these three conditions were 50 (range = 28–79), 25.7 (range = 16–48) and 44.1 (range = 36–55), respectively.

Fig. 1 shows grand average ERP waveforms for the three critical conditions at a subset of 12 lateral anterior and posterior electrode sites. Relative to the correct rejection ERPs, the deep and shallow hit ERPs both exhibit sustained positive-going shifts. In each case, the positive-going shifts are initially (ca. 400–1200 ms) greater over the left than right hemisphere, particularly at the more posterior electrode sites. This asymmetry is less evident during the final 800 ms period of the epoch. The deep and shallow hit ERPs also begin to differ from one another at around 400 ms post-stimulus, where the deep hit ERPs are more positive going than the shallow hit ERPs.

ERP analyses employed mean amplitude data from selected latency intervals. The intervals were chosen on the basis of visual inspection of the waveforms, and also to encompass the intervals employed in our previous studies of word-stem cued recall [1–3]. The intervals were 400–800, 800–1200, 1200–1600 and 1600–1944 ms. Two types of analysis were carried out: magnitude analyses contrasting amplitude differences between ERPs in each condition, and topographic analyses contrasting the distribution of differences between the correct rejection and deep and shallow hit ERPs.

3.3. Magnitude analyses

Initial analyses involved ANOVAs of data from all three conditions at all 25 electrode sites (in these, and in all other ANOVAs, F ratios associated with more than one degree of freedom were corrected by the Geisser–Greenhouse procedure [19]). The ANOVAs for each latency interval gave rise to significant interactions between the factors of condition and site (the results of these ANOVAs are summarised in Table 2). The condition by site interactions were further investigated by subsidiary ANOVAs contrasting each pair of conditions at a selected subset of the full electrode data.

Table 1
Experiment 1. Behavioural data

<table>
<thead>
<tr>
<th>Completion rate (%)</th>
<th>Recognition rate (%)</th>
<th>Conditional probability of recognition</th>
</tr>
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<tbody>
<tr>
<td>Deep</td>
<td>50.3 (8.87)</td>
<td>48.4 (8.82)</td>
</tr>
<tr>
<td>Shallow</td>
<td>34.9 (9.53)</td>
<td>24.4 (9.02)</td>
</tr>
<tr>
<td>Baseline</td>
<td>8.4 (3.12)</td>
<td>3.8 (1.98)</td>
</tr>
</tbody>
</table>

* Column 1: mean percent correct completion for stems belonging to studied items (collapsed across recognition decision), along with the baseline correct completion rate. Column 2: mean percent correct completions which were also correctly recognised (note that for the baseline condition, the value in column 2 reflects ‘false alarms’, defined as the percentage of completions with unstudied items that were falsely judged as ‘old’). Column 3: mean conditional probability of recognising a correct completion. SDs are shown in brackets.
montage. The selected sites were located at lateral anterior (F7/F8, LF/RF, F3/F4) and lateral posterior (T5/T6, LP/RP, P3/P4) positions. This subset of sites was chosen to allow the magnitude of differences between each pair of conditions to be assessed as a function of the anterior/posterior, hemisphere and inferior/superior location of the electrode sites, locations where the maxima of cued recall ERP effects have been identified in previous studies [1–3]. Accordingly, the subsidiary ANOVAs employed the factors of condition, location (anterior vs posterior), hemisphere (left vs right) and site (inferior, mid-lateral, superior). The results of the subsidiary ANOVAs are summarised in Table 3, and are described in the following sections.

3.4. Deep hit vs correct rejection

Significant 4-way interactions between condition, lo-
3.6. Deep vs shallow hits

Significant condition by location by site interactions arose in the ANOVAs for each of the four intervals. These were due to the enhanced positivity of the deep hit ERPs. During 400–800 ms amplitude differences were largest at the superior anterior sites and the inferior posterior sites. For the subsequent intervals the condition by location by site interactions were due to differences at anterior sites being predominant at the superior electrodes, while at posterior sites there is no inferior/superior gradient.

3.7. Topographic analyses

The following analyses contrasted the topography of the positive-going shifts in the deep and shallow hit ERPs relative to the correct rejection ERPs. The analyses were conducted upon difference waveforms representing the ERP memory effects for the explicit retrieval of items from each study condition. The difference waves were created by subtracting the correct rejection ERPs from the deep and shallow hit ERPs (‘deep’ and ‘shallow’ effects, respectively). Prior to the analyses the data were rescaled to eliminate the confounding influence of across-interval and across-condition differences in amplitude on the topography of each ERP effect [22].

Fig. 2 depicts the topography of the deep and shallow effects during each of the four selected latency intervals. As is clear from the figure, the effects appear to evolve similarly over time from a left-sided posterior focus to a more anterior distribution focused around the scalp vertex, which extends more over the right than the left hemi-scalp. The topographies of the deep and shallow effects were contrasted initially in a single ANOVA employing the factors of condition (deep vs shallow effect), epoch (all four epochs), and electrode

| Table 2 | Experiment 1. ERP magnitude analyses. A summary of the results of ANOVAs contrasting ERPs for the deep hit, shallow hit and correct rejection conditions, at all 25 electrode sites during the four latency intervals |
|---|---|---|---|---|
| Latency Interval | Condition × Site interaction |
| 400–800 ms | F(4.7,69.8) = 3.54, P < 0.01 |
| 800–1200 ms | F(5.5,82.9) = 5.91, P < 0.001 |
| 1200–1600 ms | F(7.8,116.5) = 3.70, P = 0.001 |
| 1600–1944 ms | F(6.7,100.8) = 2.86, P = 0.01 |

3.5. Shallow hit vs correct rejection

Significant interactions involving condition, location and hemisphere were observed for the 400–800, 800–1200 and 1200–1600 intervals. These were due to the posterior left > right asymmetry of the positive-going shift present in the deep hit ERPs, which was pronounced at the more superior posterior sites. The posterior hemispheric asymmetry was not present during the 1200–1600 and 1600–1944 ms intervals where, in both cases, significant interactions between location and site were observed; these reflect the superior maximum of the positive shift in the deep hit ERPs at anterior sites.

Table 3 | Experiment 1. ERP magnitude analyses. A summary of the results of ANOVAs contrasting each pair of conditions at the selected subset of electrode sites during each latency interval. Only significant effects involving the factor of condition are reported |
<table>
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<tbody>
<tr>
<td>Contrast</td>
<td>400–800 ms</td>
<td>800–1200 ms</td>
<td>1200–600 ms</td>
<td>1600–1944 ms</td>
</tr>
<tr>
<td>Deep vs Shallow hit</td>
<td>CC × AP × ST</td>
<td>CC × AP × ST</td>
<td>CC × AP × ST</td>
<td>CC × AP × ST</td>
</tr>
<tr>
<td></td>
<td>F(1,3,20.0) = 5.94, P &lt; 0.025</td>
<td>F(1,4,21.7) = 13.32, P &lt; 0.001</td>
<td>F(1,6,23.5) = 12.46, P &lt; 0.001</td>
<td>F(1,4,28.8) = 4.74, P &lt; 0.05</td>
</tr>
<tr>
<td>Deep hit vs Correct rejection</td>
<td>CC × AP × HM × ST</td>
<td>CC × AP × HM × ST</td>
<td>CC × AP × ST</td>
<td>CC × AP × ST</td>
</tr>
<tr>
<td></td>
<td>F(1,6,24.2) = 4.55, P &lt; 0.05</td>
<td>F(1,9,29.1) = 4.97, P &lt; 0.025</td>
<td>F(1,3,20.2) = 11.22, P &lt; 0.0025</td>
<td>F(1,7,26.2) = 9.61, P = 0.001</td>
</tr>
<tr>
<td>Shallow hit vs Correct rejection</td>
<td>CC × AP × HM</td>
<td>CC × AP × HM</td>
<td>CC × AP × HM</td>
<td>CC × ST</td>
</tr>
<tr>
<td></td>
<td>F(1,15) = 6.22, P = 0.025</td>
<td>F(1,15) = 7.12, P &lt; 0.025</td>
<td>F(1,15) = 5.16, P &lt; 0.05</td>
<td>F(1,1,17.2) = 7.01, P &lt; 0.025</td>
</tr>
</tbody>
</table>

a CC, condition; AP, anterior/posterior location; HM, hemisphere; ST, electrode site (inferior, mid-lateral, superior).
Fig. 2. Experiment 1: Topographic voltage maps for the 'deep' and 'shallow' effects, showing the relative amplitude of the differences between the correct rejection ERPs and the deep hit and shallow hit ERPs, respectively, during the four latency intervals employed for magnitude and topographic analyses. The scale bar to the right of each map indicates the mean maximum and minimum values of the magnitude of the effect across all sites during each interval.
site (all 25 sites). The ANOVA did not give rise to a significant effect involving the factor of condition (maximum $F = 1.48, P > 0.15$). However, a significant main effect of site ($F(3.6, 54.5)=5.70, P = 0.001$) was observed, and the interaction between epoch and site approached significance ($F(4.1,61.1)=2.30, P = 0.068$). The results of the ANOVA thus confirm the impression given by Fig. 2 that the topographies of the cued recall ERP effects closely resemble one another. However, the marginally significant epoch by site interaction indicates that the effects may vary in their topography with time.

To further investigate changes in the topography of the cued recall ERP effects over time, we employed a subsidiary ANOVA of data (collapsed across the factor of condition) from the subset of 12 lateral anterior and posterior sites used in the foregoing magnitude analyses. The ANOVA employed the factors of epoch (all four epochs), location (anterior vs posterior), hemisphere, and site (inferior, mid-lateral and superior). It gave rise to significant interactions between epoch and hemisphere ($F(1.6,23.4)=7.54, P = 0.005$) and location, hemisphere and site ($F(1.6,23.6)=3.97, P < 0.05$). The epoch by hemisphere interaction occurred because of a shift over time from a left-maximal to a right-maximal distribution (see Fig. 3, which shows the changing pattern of hemispheric asymmetry at the anterior and posterior sites exhibited over time by the effect). The 3-way interaction reflected a tendency for superior sites to show relatively greater voltage over the right hemisphere frontally, and the left hemisphere parietally.

4. Discussion

The probability of correctly completing a stem with a studied word was higher for deeply studied words than for shallowly studied items. More interestingly, depth of processing also influenced the probability of recognising a correct completion; whereas almost all deeply studied completions were recognised as such, only about 70% of shallowly studied completions attracted an 'old' judgement. This finding replicates the results of Allan et al. [1]. It likely reflects the fact that depth of processing operates in two distinct ways in such tasks. First, it influences the probability of direct explicit retrieval of a study item in response to the word stem. Second, for those stems completed implicitly (i.e. via priming), it influences the probability that such completions will be recognised as belonging to the study episode.

Replicating the findings of previous studies (see Introduction), ERPs elicited by stems completed with recognised study items (deep and shallow hit ERPs) demonstrated sustained positive effects, which onset around 400 ms and shifted in scalp distribution with
time. Crucially, while there were differences in the magnitudes of these effects according to whether the completions had been subjected to deep or shallow processing at study, there were no detectable differences in their scalp topographies. The differences in magnitude confirm the trends that were evident in the data of Allan, Doyle and Rugg [1]. The failure to find any evidence for differences in scalp topography suggests that, so far as can be detected with ERPs, the neural correlates of cued memory retrieval do not vary according to whether study items were encoded in terms of their surface or conceptual attributes (cf. [6,7,25]).

Why did the cued recall effects for each encoding condition differ in magnitude, given that we employed a test procedure that was intended to ensure that only completions that were explicitly remembered contributed to the ERPs? It is possible that the ERPs elicited by the two classes of completion may have been differentially diluted by guesses. By this argument, when unsure of the provenance of a completion, participants on some proportion of occasions guessed 'lucky'. Since correct completions that are not accompanied by explicit memory do not lead to ERP cued recall effects [1], trials on which such guesses occurred would not contain such effects. Thus, if guesses contributed to a larger proportion of completed and recognised trials for the shallow than for the deep study conditions, the resulting cued recall effects would be smaller for the former condition. This explanation seems unlikely to hold in the present case, however, since the guessing rate, as estimated by the proportion of false alarms (<4%), appears to be too low to be consistent with the observed differences in the magnitude of the ERP effects.

A related explanation is more likely. According to this account, what differed according to depth of processing was not the proportion of items called old on the basis of a guess, but the proportion of items recognised by successfully retrieving their study episode. Several lines of evidence suggest that recognition judgements can made either on the basis of episodic retrieval (recollection), or as a result of a familiarity judgement that is unaccompanied by the retrieval of episodic information [14,15,39]. It has been argued that one effect of depth of processing is to vary the probability of recollection [10]. If, like recognition memory ERP effects [2,8,34,37,38], cued recall ERP effects are correlates specifically of recollection, it follows that ERPs elicited by completions recognised on the basis of familiarity would not contain such effects, and thus, like guesses, would act to dilute the magnitude of the effects in the shallow hit ERPs relative to the deep hit ERPs.

The foregoing account also bears on the question of why depth of study processing did not affect the scalp topography of the ERP cued recall effects. If the effect of this manipulation was to vary the probability that study items received processing conducive to subsequent recollection, then differences in topography would not be observed. Indeed, to the extent that shallowly studied items were only subsequently recollected if they were subjected to 'conceptual' analysis (i.e., when, regardless of task demands, items received some degree of semantic analysis), one might expect the neural correlates of the retrieval of deeply and shallowly studied words to differ in degree only, and not in kind.

Thus, the failure to find qualitatively different cued recall ERP effects in the present study may have been because the effects were elicited only by items subjected to similar encoding operations, notwithstanding the study task manipulation. The aim of Experiment 2 was to overcome this objection by employing an encoding manipulation — sensory modality — which guaranteed that study items were subjected to differential processing at the time of encoding.

5. Experiment 2

5.1. Introduction

In Experiment 2 a study modality manipulation was employed so as to vary components of processing sensitive to surface (sensory) features of the study stimuli. This manipulation stands in contrast to that employed in Experiment 1, when processing components sensitive to task demands were varied. In the present experiment, study items were presented in either the visual or auditory sensory modalities. This manipulation was chosen on the basis of evidence that, in young subjects at least, modality information is 'automatically' bound into the episodic representations formed during the encoding of 'deeply' processed words [11,26]. Thus, if encoded information is literally 'reinstated' at the time of retrieval (see Introduction), this should be reflected in the scalp topographies of the respective ERP effects, consistent with the fact that auditory and visual processing engage spatially segregated cortical areas.

5.2. Methods

The design of Experiment 2 was analogous to that of Experiment 1, with the exception that 20 rather than 16 participants were employed. The additional participants were required to allow a fully counterbalanced experimental design with five study/test blocks (rather than the four blocks employed in the first experiment). The increase in the number of subjects means that the power to detect condition effects was somewhat greater than in Experiment 1.
5.3. Subjects

Participants were 31 right-handed young adults drawn from the same population as employed in Experiment 1. Each was paid £5.00 per hour for participation. Of these 31 individuals, six did not complete the experiment due to computer failure, illness or failure to obey instructions. Of the remaining 25, the data from five could not be used because they contributed too few artifact-free trials to ERPs in one or more critical condition. The mean age of the remaining 20 participants was 23.1 years (range = 17–32), and nine were female.

5.4. Stimuli

The 512 item pool employed in Experiment 1 was used here to form two pools of 220 critical items. Half of the participants studied one pool of items, and the remainder studied the other pool. Five study lists, each of 44 critical items, were created from the items in each pool. Each study list included two buffer items, drawn from the remaining items in the original pool, which were placed in the first and last position in each list. Half of the items in each study list were presented visually, and the remainder auditorily, in a different random order in each study list (words were spoken in a male voice and sampled at 22.5 kHz and 16-bit resolution). One study list was presented in each of the five study/test blocks. Two versions of each study list were created to ensure that each item was presented in each modality equally often. A single test list corresponded to each pair of study lists. Each test list consisted of 68 word stems. The first two stems belonged to the buffer items from the corresponding pair of study lists. Of the remaining stems, 22 belonged to items drawn from the unstudied word pool, and 44 stems belonged to the 44 critical items presented for study. The mapping of lists to study/test blocks was rotated across participants.

Stimulus presentation details were as for Experiment 1, with the addition that at study half of all items were presented auditorily over headphones at a comfortable volume. Stimulus presentation at test was also as for Experiment 1.

5.5. Procedure

Study phase procedures were as for Experiment 1, except that items were presented both visually and auditorily. The 'X' and 'O' cues used in Experiment 1 to indicate study task were used here to indicate item presentation modality ('O' for visual, 'X' for auditory). The study task for all items was to judge whether their meaning was pleasant or unpleasant (i.e. the 'deep' study task used in Experiment 1). Test phase procedures, including those pertaining to EEG recording, were as for Experiment 1.

6. Results

6.1. Behavioural data

The behavioural data are summarised in Table 4. As for Experiment 1, the baseline completion rate was subtracted from the correct completion rates for each class of studied item ('visual' and 'auditory'). The corrected studied item completion rates were both significantly greater than zero (visual: \( t(19) = 16.21, P < 0.001 \); auditory: \( t(19) = 13.65, P < 0.001 \)), but more correct completions were made with visually than auditorily presented items (\( t(19) = 7.76, P < 0.001 \)). After correcting for guessing (by subtracting the false alarm rate), the recognition (hit) rates for each class of studied item were both significantly greater than zero (for visual items, visual: \( t(19) = 16.20, P < 0.001 \); auditory: \( t(19) = 14.24, P < 0.001 \) for visual and auditory items, respectively). The hit rate for visual items was significantly greater than that for auditory items (\( t(19) = 8.18, P < 0.001 \)). The conditional probability of correct recognition was also greater for visual than for auditory items (\( t(19) = 2.59, P < 0.025 \)).

6.2. ERPs

ERP correlates of explicit memory for studied items were analysed by contrasting ERPs for three conditions: stems correctly completed with recognised visually and auditorily presented items (visual hit and auditory hit ERPs, respectively) and stems completed with unstudied items given a correct ('new') recognition judgement (correct rejection ERPs). The mean number of trials contributing to ERPs for these three conditions was 54.1 (36–79), 43.7 (27–65) and 75.7 (62–96) respectively.

Fig. 4 shows the grand average ERP waveforms for the three critical conditions at a subset of lateral anterior and posterior sites. Relative to the correct rejection ERPs, ERPs for the hit conditions exhibit sustained positive shifts which onset around 400 ms in each case. The positive shifts are initially asymmetrical (left > right) at posterior sites, but become more symmetrical during the final 800 ms of the epoch. The visual and auditory hit ERPs also differ from one another. These differences are largest at central and posterior sites, particularly over the left hemisphere. As for Experiment 1, two sets of ERP analyses were carried out, focusing on magnitude and topographic differences, respectively.
Table 4
Experiment 2. Behavioural data^a

<table>
<thead>
<tr>
<th></th>
<th>Completion rate (%)</th>
<th>Recognition rate (%)</th>
<th>Conditional probability of recognition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual</td>
<td>57.7 (14.3)</td>
<td>56.6 (10.0)</td>
<td>0.98 (0.02)</td>
</tr>
<tr>
<td>Auditory</td>
<td>46.3 (12.1)</td>
<td>44.6 (9.3)</td>
<td>0.96 (0.04)</td>
</tr>
<tr>
<td>Baseline</td>
<td>9.59 (4.34)</td>
<td>2.92 (3.15)</td>
<td>–</td>
</tr>
</tbody>
</table>

^a Column 1: percent correct completion for stems belonging to studied items (collapsed across recognition decision). Column 2: mean percent correct completions that were also correctly recognised (note that as for Table 1, the value shown for the baseline condition reflects 'false alarms' to completions with unstudied items). Column 3: mean conditional probability of recognising a correct completion. SDs are shown in brackets.

Fig. 4. Experiment 2: Grand average ERPs evoked by stems correctly completed with recognised visually and auditorily presented study items (Visual Hit and Auditory Hit ERPs), along with ERPs evoked by stems completed with unstudied items which are correctly rejected (Correct Rejection ERPs). Electrode sites as for Fig. 1.
6.3. Magnitude analyses

The magnitude analyses employed mean amplitude data from the four latency intervals used in Experiment 1. Initial analyses took the form of ANOVAs of data from all three conditions at all 25 electrode sites during each interval. As summarised in Table 5, with the exception of the final 1600–1944 ms interval, these ANOVAs gave rise to significant interactions between the factors of condition and site. Subsidiary ANOVAs were employed to elucidate the interactions, employing data from the lateral anterior (F7/F8, LF/RF, F3/F4) and posterior (T5/T6, LP/RP, P3/P4) sites used in Experiment 1. The results of the subsidiary ANOVAs are summarised in Table 5, and described in the following sections.

6.4. Visual hit vs correct rejection

Significant 3-way interactions between condition, anterior/posterior location and hemisphere were observed during the 400–800, 800–1200 and 1200–1600 ms intervals. In the 400–800 and 800–1200 ms intervals, the interactions were due to the posterior left > right asymmetry of the positivity in the visual hit ERPs. However, during 1200–1600 ms interval the interaction was due to a right > left asymmetry at the anterior sites, while at the posterior sites there was no longer a left > right asymmetry. The condition by site interaction observed during the 1600–1944 ms interval arose because the enhanced positivity of the visual hit ERPs is largest at sites close to the scalp midline, irrespective of their anterior/posterior or hemispheric location.

6.5. Auditory hit vs correct rejection

Significant interactions between the factors of condition, anterior/posterior location and hemisphere were observed for the 400–800, 800–1200 and 1200–1600 ms intervals. For the 400–800 and 800–1200 ms intervals, these interactions were due to the posterior left > right maximum of the positivity in the auditory hit ERPs. In the subsequent 1200–1600 ms interval the posterior asymmetry was not present, but at anterior sites an opposite, right > left, asymmetry was present. The condition × hemisphere and condition × site interactions observed for the final 1600–1944 ms reflect, respectively, the right > left asymmetry, and tendency to a superior maximum, of the positive shift in the auditory hit ERPs.

6.6. Visual vs auditory hits

During the 400–800 ms interval a significant condition by anterior/posterior location by hemisphere interaction was observed. This interaction reflects the enhanced positivity of the visual hit ERPs, most pronounced at left posterior sites. Main effects of condition were observed during the subsequent 800–1200 and 1200–1600 ms intervals. These reflect the enhanced positivity of the visual hit ERPs. During the final 1600–1944 ms interval a condition by hemisphere interaction was observed, due to the enhanced positivity of the visual hit ERPs, which were larger over the left than the right hemisphere sites.

6.7. Topographic analyses

The following analyses contrasted the topography of the positive-going shifts in the ERPs by visual and auditory hits.

### Table 6

Experiment 2. ERP magnitude analyses. A summary of the results of ANOVAs contrasting each pair of conditions at the selected subset of electrode sites during each latency interval. Only significant effects involving the factor of condition are reported.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>400–800 ms</th>
<th>800–1200 ms</th>
<th>1200–600 ms</th>
<th>1600–1944 ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual vs auditory hit</td>
<td>CC × AP × HM</td>
<td>F(1,19)=4.41, P &lt; 0.05</td>
<td>F(1,19)=8.46, P &lt; 0.01</td>
<td>F(1,19)=4.38, P &lt; 0.05</td>
</tr>
<tr>
<td>Visual hit vs Correct rejection</td>
<td>CC × AP × HM</td>
<td>F(1,19)=15.78, P = 0.001</td>
<td>F(1,19)=34.36, P &lt; 0.001</td>
<td>F(1,19)=8.83, P &lt; 0.01</td>
</tr>
<tr>
<td>Auditory hit vs Correct rejection</td>
<td>CC × AP × HM</td>
<td>F(1,19)=5.71, P &lt; 0.05</td>
<td>F(1,19)=18.30, P &lt; 0.001</td>
<td>F(1,19)=7.58, P &lt; 0.025</td>
</tr>
</tbody>
</table>

* CC, condition (within and heard recall plus correct rejection); AP, anterior/posterior location; HM, hemisphere; ST, electrode site (inferior, mid-lateral, superior).
Fig. 5. Experiment 2: Topographic voltage maps for the 'visual' and 'auditory' effects, showing the relative amplitude of the differences between the correct rejection ERPs and the visual hit and auditory hit ERPs, respectively, during the four latency intervals. Scale bar as for Fig. 2.
auditory hits relative to the ERPs to correctly rejected completions. The analyses were conducted upon difference scores representing the ERP cued recall effects for the items recalled from each study condition ('visual' and 'auditory' effects, respectively). Fig. 5 depicts the topography of both effects during each of the four selected latency regions. The effects appear to evolve similarly over time from a left-sided posterior focus to one more anteriorly situated on and to the right of the scalp midline.

Following the procedures used in Experiment 1, the topographies of the effects were initially contrasted in a single ANOVA with factors of condition, epoch and site (all 25 sites). The ANOVA did not give rise to an effect involving the factor of condition ($F_s < 1$), but did give rise to a significant interaction between the factors of epoch and site ($F(6.5,123.8)=5.32, P < 0.001$). A subsidiary ANOVA was employed to elucidate this interaction, employing data (collapsed across study modality) from the same subset of lateral anterior and posterior sites as was employed above.

The ANOVA gave rise to a significant epoch by location by hemisphere interaction $F(1.9,35.6)=8.98, P = 0.001$), the reason for which is evident in Fig. 6. The figure shows changes in the pattern of hemispheric asymmetry at the anterior and posterior sites over time; as time progresses, the posterior asymmetry favouring the left hemisphere fades, while at anterior sites an opposite asymmetry becomes more pronounced.

6.8. Summary

The magnitude analyses revealed that the positive-going shifts present in the ERPs elicited by visual and auditory hits were reliable from around 400 ms onwards. During the final 1600–1944 ms interval these effects were reduced in magnitude, but remained statistically reliable at lateral anterior and posterior sites. The positive shift in the ERPs to visual hits was larger than that for the ERPs to auditory hits. There was no evidence for encoding-dependent differences in the topography of the ERP cued recall effects.

7. Discussion

The probability of correctly completing a stem and of recognising the completion as a studied item was some 11% higher for items that were seen rather than heard at study, echoing the findings of Craik et al. [5]. The conditional probability of recognition was also higher for items which were seen at study, but by only 2%. Thus, in contrast to Experiment 1, the encoding manipulation in the present experiment influenced primarily the probability of completing a stem with a stu-
were associated with qualitatively different patterns of encoding conditions. By this argument, the effect of modality on correct completions is a direct reflection of the sensitivity of explicit memory to this variable during word stem cued recall. Since, according to this account, the same memory processes that support the completion response also contribute heavily to the subsequent recognition judgement, it is unsurprising that the conditional probability of recognition should be high and affected only minimally by the modality manipulation.

An alternative possibility is that the effect of modality may have arisen mainly from the influence of perceptual priming. By this argument [13], a primed completion was more likely when study and test modalities matched, thereby accounting for the higher completion rate for the visually studied items. Once generated however, studied items were recognised with ease in both encoding conditions, by virtue of the ‘deep’ encoding to which they had been subjected. The small effect of modality on conditional recognition may reflect the additional influence of ‘fluency’ or ease of generation on recognition judgements, arising because completions with same modality items came to mind more easily than did those for across modality items (see [15] for discussion of the influence of fluency on memory judgements). By this argument, therefore, the encoding manipulation primarily influenced the probability of implicit rather than explicit retrieval of studied items.

The ERP cued recall effects observed in the present experiment were very similar to those observed in Experiment 1. This close resemblance was confirmed by additional across-experiment ANOVAs, directly contrasting the topography of the cued recall effects from each experiment during each of the latency regions shown in Figs. 2 and 5. No significant effects involving the factor of experiment were observed, indicating that the effects obtained in each experiment were statistically equivalent throughout their entire time course.

The scalp topographies of the cued recall ERP effects for the visually and auditorily studied items were statistically equivalent. Thus, again echoing the findings of Experiment 1, the present experiment failed to find evidence that different encoding conditions were associated with qualitatively different patterns of neural activity at retrieval. Finally, and once more in agreement with the findings of Experiment 1, there was a shift in the scalp topography of the ERP cued recall effects over time, indicating that the effects reflect the activity of more than one generator population.

The absence of topographic differences in the cued recall ERP effects observed here has a parallel in the results of Wilding et al. [37]. In two experiments, Wilding et al. intermixed visual and auditory items at study, and subsequently required recognition judgements to be made on these items, employing either visual (Experiment 1) or auditory (Experiment 2) test items. In neither experiment was there any evidence for differences in the scalp topography of the ERP ‘old/new’ effects elicited by old test items as a function of their study modality. While the limited number of electrode sites and the short recording epochs employed in Wilding et al.’s study signal the need for caution when considering their null effects, their findings none the less add weight to those described here.

The cued recall ERP effects were, however, larger in magnitude when elicited by stems that were completed by study items that had been presented visually rather than auditorily, a finding analogous to that obtained with the depth of processing manipulation in Experiment 1 (i.e. the more memorable items were associated with the larger cued-recall ERP effects). However, the magnitude differences in the present experiment cannot be attributed to the differential probability with which study items in each encoding condition received conceptual processing. The implications of this finding are dealt with in the General Discussion.

8. General discussion

In two experiments, we investigated ERP cued recall effects elicited by word stems cuing the retrieval of items that had been studied under different encoding conditions. In Experiment 1, encoding was either ‘shallow’ or ‘deep’, and in Experiment 2 the cognitive operations required at study were held constant, but the sensory modality of the study items was varied. In each case, the principal question was whether the neural correlates of the explicit retrieval of study items would vary qualitatively according to encoding condition, as predicted by what has been termed the ‘consensus view’ of the functional anatomy of long term memory [31]. The results were consistent across the two experiments. Robust ERP cued recall effects were observed for stems completed with explicitly retrieved items. These effects varied in their magnitude, such that they were largest when elicited by the more memorable class of items. Within each experiment, the scalp distributions of the effects associated with each
encoding condition were statistically equivalent. Additional across-experiment ANOVAs showed that the topographies of the cued recall effects obtained in each experiment were essentially equivalent throughout their entire time courses.

The absence of differences in scalp distribution in response to the two kinds of encoding manipulation employed here could have arisen for a number of reasons. One of these reasons — that items which were recollected had all been subjected to common encoding operations — has already been discussed in relation to the findings of Experiment 1. While still a viable account of the findings of that experiment, it cannot apply to the findings from Experiment 2, when the encoding manipulation involved an intrinsic attribute of each study item. Other reasons for the negative topographic findings, equally applicable to both experiments, include the possibilities (i) that the encoding manipulations were not sufficiently extreme, such that the neural processing associated with each class of study item largely overlapped, (ii) that the neural activity detected by scalp recorded ERPs is insensitive to the activity representing retrieved information, and (iii) that the 'consensus view' of memory retrieval requires modification.

At present, it is not possible to choose between these various alternatives that, in any case, are not all mutually exclusive. Regardless of which alternative turns out to be correct, the present findings suggest that explicit cued recall is associated with what might be described as a 'core' set of neural correlates, as represented by the ERP cued recall effects. These effects were largely invariant in their temporal and their spatial characteristics, both within and across the present experiments, but were largest in magnitude when elicited by the more memorable class of study items in each experiment. These findings allow a number of conclusions to be drawn about the neural and functional bases of explicit retrieval.

One conclusion concerns whether the process of explicit retrieval, as reflected by the ERP cued recall effect, is associated with a voluntary or an involuntary retrieval strategy. This issue arises from a position advocated by Richardson-Klavehn et al. [27–29], who have proposed that conscious awareness of a past event is dissociable from retrieval volition, and that voluntary and involuntary retrieval processes are themselves functionally dissociable. Critically, some of the empirical evidence advanced to support their position comes from studies of depth of processing and modality effects on stem cued recall. On the basis of these studies, Richardson-Klavehn et al. have proposed that voluntary, or controlled, retrieval processing is affected by depth of processing at study, while involuntary or automatic retrieval is sensitive to overlap in study-test modality (see especially [27], along with [5], for related findings). Because we have shown in the present two experiments that the magnitude of the ERP cued recall effect is sensitive to both of these encoding manipulations, it cannot be the case that the explicit retrieval processes reflected by the effect are specific to either a voluntary or an involuntary retrieval strategy. The present findings thus support Richardson-Klavehn and colleagues' view that retrieval volition and memorial awareness are functionally dissociable.

Various accounts of the magnitude differences in the cued recall ERP effects were considered in discussion of Experiment 1, leading to the proposal that depth of processing may have affected the proportion of correct completions recognised by virtue of the retrieval of their study episode. By this argument (see Discussion, Experiment 1), the recognition of deeply studied items was based more often upon episodic retrieval than was the recognition of shallowly studied items. This in turn led to the dilution of the ERP cued recall effect for shallowly studied items. The foregoing explanation has difficulty however in accounting for the findings from Experiment 2, unless we suppose that the recollection of past episodes involves processes that are sensitive to overlap in the presentation modality of retrieved information and the retrieval cue. This supposition fits well with the transfer appropriate processing (TAP) approach [24,30] which may provide a framework that accounts for the findings of both of the present experiments.

According to the TAP approach, the probability of successful memory retrieval is affected by the level of overlap between the cognitive operations performed at study and those performed at test. The reasons why, within this framework, modality manipulations might influence retrieval are obvious. In the case of depth of processing, the benefit of 'deep' encoding could be attributed to the view that, left to their own devices, participants in direct tests of memory tend to process retrieval cues conceptually [30], that is, in a manner more compatible with deep than with shallow encoding conditions. To account for the present findings within the foregoing framework, it is necessary to assume that study-test compatibility influences not only the probability of successful retrieval, but also properties of what is recollected. According to this assumption, even when retrieval is successful, the 'completeness' or 'amount' of the retrieved information can vary according to the degree of overlap that exists between processing carried out at study and test. And it is these attributes of the retrieved information that are reflected in the magnitude of ERP cued recall effects.

According to this argument, therefore, and as has been proposed for the ERP correlates of recognition memory [34], the ERP cued recall effect is a graded phenomenon, with a magnitude proportional to the amount or quality of retrieved information available.
to consciousness. This argument fits well with the finding that the magnitude, but not the scalp topography, of the cued recall effect varies with the amount of contextual information that can be retrieved for a recalled item [3]. But how does this argument relate to the consensus view of episodic memory?

As mentioned in the Introduction, the consensus view of episodic memory incorporates a core system, centered upon the hippocampal formation, that is involved in the recovery of recently experienced episodes by virtue of cortico-hippocampal interactions that occur during retrieval [35]. Furthermore, it has been proposed that scalp-recorded ERP effects associated with episodic retrieval may reflect changes in neocortical activity caused by such cortico-hippocampal interactions [4,35]. The present findings add to such proposals because they suggest that during the retrieval of different classes of episode a common set of processes are engaged, albeit to different extents (as indicated by the differences in the magnitude of the ERP cued recall effects). The exact contribution made by these processes to retrieval remains to be clarified.

It is possible, for example, that the ERP cued recall effect reflects the activity of neocortical regions that act in conjunction with the core system to reinstatement neural activity in other parts of the neocortex responsible for representing an episode. It seems reasonable to assume, further, that changes in the processes responsible for reinstating encoding activity will affect the amount or quality of the information that can be retrieved. This interpretation accounts both for the graded nature of the effect observed when elicited by classes of stimuli that differ in their memorability. The merits of this interpretation need to be contrasted against an alternative, alluded to above, that the encoding manipulations were not sufficiently extreme, and allowed a common form of encoding to be carried out for each class of episode employed in both of the present experiments, which was subsequently reinstated during retrieval.

Finally, a consistent finding across experiments was a shift with time in the scalp topography of the ERP cued recall effects. For the first two latency regions analysed, the effects displayed reliable asymmetries (left > right) over the temporo-parietal scalp, which subsequently gave way to a slightly right-sided fronto-central distribution. The early, left-sided effect is reminiscent of the so-called 'left parietal old/new effect' described in numerous studies of recognition memory (for reviews see [4,32]), and thought to be an electrophysiological correlate of episodic retrieval. The later, right-sided distribution of the cued recall effects resembles previous findings from studies employing recognition tasks, some of which have described a late, sustained positive wave (the 'right frontal old/new effect') which is maximal over right frontal scalp and may be correlated with the post-retrieval monitoring or evaluation of retrieved episodic information [4,8,9,38].

Thus, the present findings suggest that ERP cued recall effects receive a contribution from the generators of both the left parietal and right frontal effects that have been described in studies employing 'copy' retrieval cues. The findings of a previous study [2] also showed that cued recall ERP effects shift over time to a slightly right-sided fronto-central distribution. In that study, however, as in that of Allan, Doyle and Rugg [1], the cued recall ERP effects were initially distributed asymmetrically over the temporo-parietal scalp, rather than asymmetrically as here. Even in the present experiments, however, the scalp distribution of the ERP cued recall effects was markedly more diffuse than that typically observed in recognition memory. The present findings add weight to the proposal (see also [3]) that ERP cued recall effects may include a contribution from the generators of the same memory effects that are elicited during tests of recognition, but that they also reflect the activity of generators that are not engaged during recognition (for further discussion of this issue, see [4]).

In sum, the present experiments have demonstrated robust electrophysiological correlates of explicit word stem cued recall, and shown that these correlates reflect the activity of multiple neural generators with different time-courses. There was no evidence that the pattern over the scalp of the correlates of cued memory retrieval varied according to the encoding history of the retrieved information, and thus no evidence to support the view that episodic retrieval involves the literal reinstatement of qualitatively different processes engaged during encoding. It remains to be determined whether these negative findings reflect a limitation of the present experimental procedures, the method used to detect the neural correlates of memory retrieval, or whether instead they point to an inadequacy of current views of memory retrieval.

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References


