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Research Report

The effect of encoding manipulation on word-stem cued recall: An event-related potential study

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Abstract

The purpose of the present study was to find out whether the neural correlates of explicit retrieval from episodic memory would vary according to conditions at encoding when the words were presented in separate study/test blocks. Event-related potentials (ERPs) were recorded while participants performed a word-stem cued-recall task. Deeply (semantically) studied words were associated with higher levels of recall and faster response times than shallowly (lexically) studied words. Robust ERP old/new effects were observed for each encoding condition. They varied in magnitude, being largest in the semantic condition. As expected, scalp distributions also differed: for deeply studied words, the old/new effect resembled that found in previous ERP studies of word-stem cued-recall tasks (parietal and right frontal effects, between 400–800 and 800–1100 ms post-stimulus), whereas for shallowly studied words, the parietal old/new effect was absent in the latter latency window. These results can be interpreted as reflecting access to different kinds of memory representation depending on the nature of the processing engaged during encoding. Furthermore, differences in the ERPs elicited by new items indicate that subjects adopted different processing strategies in the test blocks following each encoding condition.

Theme: Neural basis of behavior
Topic: Cognition

Keywords: Explicit memory; ERP; Old/new effect; Depth of processing; Word-stem cued recall

1. Introduction

Explicit memory tests are those which require "intentional or conscious recollection of previous experiences" ([43] p. 159). One test that has received much attention is the word-stem cued-recall task. In this type of explicit memory task, as used in the present experiment, participants first learn a list of words. Three-letter strings (e.g., SOL____) are then used as retrieval cues for the previously memorized words (e.g., SOLDAT: French for soldier). Participants are instructed to try to complete each stem with a studied item or with any other suitable word if a studied item cannot be recalled. To distinguish between completions made with and without explicit memory, participants are required to make an overt recognition ("old/new") judgment for each completion. A similar cued-recall task has been used in previous behavioral studies [30,31] as well as in electrophysiological studies [1–3,5,6].

Allan, Doyle, and Rugg [3] identified an ERP "cued recall effect" (or ERP "old/new effect") in which ERPs elicited by stems attracting explicit retrieval of study items were modulated by a sustained positive-going shift compared to ERPs elicited by stems completed with unstudied words. This ERP cued-recall effect had an onset latency of

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around 300–400 ms post-stimulus. It persisted for around 1–1.5 s and was largest at anterior electrodes. The scalp topography of the effects changed over time, signaling that it reflected the activity of multiple neural generators [1,2,5,6]. Allan et al. [3] also demonstrated that this ERP cued-recall effect was associated selectively with explicit retrieval and was insensitive to the process responsible for the implicit completion of stems with studied items (studied items unrecognized). They concluded that these findings were consistent with the idea that the cued-recall ERP effect reflects processes that either contribute to or are contingent upon explicit memory.

Whether an episodic retrieval attempt is successful or not is influenced by numerous factors, not least the way the event is initially encoded in memory: deep study (or semantic) processing typically produces a strong and significant performance advantage over shallow study (perceptual or lexical) processing [12]. A recent study using event-related functional MRI has suggested that successful episodic encoding during a shallow study task relies on a subset of the regions engaged during successful encoding in a deep task [28]. The cues available and the processes engaged during the retrieval attempt are also important. The importance of retrieval cues and how they are processed is emphasized in the principle of "transfer appropriate processing" [27], which suggests that memory performance is a function of the degree to which cognitive operations engaged at encoding are recapitulated at retrieval. A similar notion is enshrined in the principle of "encoding specificity" [47]. Subsequent models of episodic memory have suggested that retrieval involves the reinstatement of the neural activity patterns of the study episode [13,14,25,26,46]. Hence, it is possible that the neural correlates of episodic retrieval, as reflected by ERPs, vary qualitatively according to the nature of the information that has been encoded. Allan et al. ([3,5] experiment 1) attempted to verify this hypothesis in two studies using event-related potential correlates of word-stem cued recall for items studied under different encoding conditions. The "shallow" task involved judging whether the vowels in each word were in alphabetic order, and the "deep" task was to judge whether the meaning of the word was pleasant or unpleasant. The rationale of this procedure was that the attributes preferentially encoded in episodic memory could be varied by having participants focus their attention on either superficial or conceptual attributes of studied items. According to Allan et al. [5], ERP effects with different topographies could reflect differences either in the loci of the effect generators, or in the relative levels of activation of multiple neural generators common to each condition. However, both studies failed to find any differences in the scalp distribution of the retrieval ERP effects between the two encoding conditions. In Allan et al.'s study [3], there was weak evidence to suggest that ERPs were sensitive to depth of processing, and in the most recent study [5], the cued-recall effects only varied in magnitude, being largest when elicited by the more memorable class of items (deeply encoded items). Allan et al. [3,5] concluded that, as far as can be detected with ERPs, the neural correlates of cued memory retrieval do not vary qualitatively according to whether study items are encoded in terms of their surface or conceptual attributes. Another possible explanation for this lack of difference could be that the method employed may not have allowed participants to reinstate at retrieval the cognitive operations engaged at encoding. Indeed, in both studies, the encoding task was a randomized rather than a blocked variable. Consequently, during the test phase participants were required to complete the stems of a mixture of new words, old words subjected to deep study, and old words subjected to shallow study, making the reinstatement of appropriate cognitive operations for each completion difficult, and probably diluting the encoding-task effects.

In the present experiment, depth of processing was manipulated using separate trial blocks for each encoding condition. ERPs were recorded during six word-stem cued recall test blocks, preceded by either a "shallow" (lexical) study task or a "deep" (semantic) study task. In this way, studying the retrieval of shallowly and deeply encoded words in separate study/test blocks should allow participants to adopt and maintain retrieval strategies specific to each encoding task during each test phase. Consequently, encoding differences in both magnitude and topography of the ERP cued-recall effects were expected. If episodic retrieval requires the reinstatement of neural activity engaged at the time of study, ERPs associated with episodic retrieval would differ qualitatively as a function of the encoding history of the retrieved information.

Another argument supporting this hypothesis can be found in a study conducted by Rugg, Allan, and Birch [41]. These authors showed differences between ERPs elicited by correctly classified old and new words (old/new effects) in two recognition memory test blocks, preceded in one case by a "shallow" study task and in the other by a "deep" task. The effects for deeply studied words resembled those found in previous ERP studies of recognition memory (left parietal and frontal old/new effects; for a review, see Ref. [35]), whereas old/new effects for shallowly studied words were confined to a late-onsetting, right frontal positivity. In addition, it can be noted that in Rugg et al.'s study [41], ERPs elicited by the new words also varied as a function of the encoding task. This comparison is important because it enables investigation of retrieval effort or orientation rather than retrieval success [37]. This result suggests that subjects adopt different processing strategies in the test blocks for following each encoding condition. According to Hornberger, Morcon, and Rugg [19], ERP retrieval orientation effects reflect differences in the processing necessary to maximize overlap between cue and memory representations.

The present study also addresses the question of whether ERPs elicited by new words in a word-stem cued-recall task vary according to the study history of the corresponding old words. Such an effect would represent the need to access different kinds of memory representation according to the nature of the processing engaged during encoding. Allan et al. [3,5] could not investigate this point because, with their randomized depth of processing manipulation, ERP correlates of shallowly and deeply studied words were assessed with respect to a single new-word "baseline".

Allan et al. [3] interpreted the cued-recall effect in terms of retrieval processes associated with explicit memory, but they also proposed an alternative interpretation, namely that "the effect may reflect differential engagement of working memory" (p. 260). As participants were instructed to withhold their responses until a signal was displayed on the monitor, this interpretation could fit their study in two plausible ways. On the one hand, recognized studied items may be retrieved relatively quickly, in which case the retrieved item would have to be maintained in working memory prior to the response cue. In this case, the cued-recall effect is best characterized as an enhanced positive shift in old ERPs compared to new ERPs, reflecting the maintenance of retrieved information in working memory prior to the onset of the cue to respond. On the other hand, working memory processes may be more crucial for the prolongation of a lexical/semantic memory search for possible completions to stems which cannot be completed rapidly with a recognizable studied item. In this case, the effect is best characterized as a negative shift in ERPs for stems completed with unstudied and unrecognized studied items, reflecting a continuing memory search for studied items. Our experiment may contribute to distinguishing between these two equally plausible interpretations, as participants were instructed to press a button as soon as they were able to answer, before saying their response out loud. Thus, retrieved items would not have to be maintained in working memory for a long time. If the ERP cued-recall effect reflects the maintenance of retrieved information in working memory prior to the onset of the cue to respond, this effect would be attenuated in our study. By contrast, if the cued-recall effect reflects a continuing memory search for studied items, the old/new effect of the present study would be characterized by a negative shift in ERPs to stems completed with unstudied and unrecognized studied items. The introduction of a motor response in the experimental protocol also allowed response times to be recorded. These measures could provide additional evidence for the prolongation of a lexical/semantic memory search for old items when stems cannot be completed with a recognizable studied item: old completions would be shorter than new completions.

In summary, the present ERP study used word stems as retrieval cues for words previously studied either lexically or semantically. The main purpose of the present work was to find out whether the neural correlates of explicit retrieval from episodic memory (ERP cued-recall effects or ERP old/new effects) differ qualitatively according to encoding conditions, when the words are presented in separate study/test blocks. In addition, this study allowed investigation of whether the ERPs elicited by new words vary according to the study history of the corresponding old words.

2. Materials and methods

2.1. Participants

Participants were 14 young adults. All were right-handed, native French speakers with normal or corrected-to-normal vision. The data from two of these 14 participants could not be used because they participated in too few ERP trials in critical conditions. The mean age of the remaining participants (8 females, 4 males) was 25.3 years (range 22–33 years).

2.2. Experimental design and stimuli

The experiment included one within-participant factor (encoding task: lexical and semantic) and consisted of six study/test blocks. Successive iterations of study/test phases were carried out in order to obtain enough events to allow for the averaging of event-related potentials (ERPs). The stimuli were drawn from a pool of 360 French words. Items were six- to ten-letter singular nouns presented visually. The first three letters, or stem, of each word were never the same, and each stem could be completed with at least five different words (the target was never the most frequent response to each stem). The 360-item pool was used to form six lists of 60 critical items for the six study/test blocks of the experiment. On average, the frequency of occurrence for words of each list was comparable (M = 116.58, SD = 93.13 per 100 million; according to Brulex, database for French language [11]). Each list of 60 items was divided into three lists of 20 words (also comparable in terms of mean frequency of occurrence). Two of these three lists were presented during the study phase and the third was used to produce a mean baseline completion rate (the list that served as baseline was counterbalanced). Thus, each study list consisted of 40 critical items. 24 additional items were chosen, of which two were presented at the beginning and end of each study list as primacy and recency buffers. Three of the six study lists were studied with one encoding task and three with the other. The task order was alternated so that participants never did the same encoding task in two successive study/test blocks. Half of the participants started with the lexical task and the other half with the semantic task, so that each word was presented equally often in each encoding condition. The test list consisted of 60 word stems, 20 corresponding to items drawn from the unstudied word pool, and the remaining 40 to the 40 items presented for study. All stimuli appeared in white on a black background in upper case on a computer monitor.

Each encoding task (Fig. 1a) started with a 1000-ms presentation of a fixation cross, followed immediately by a

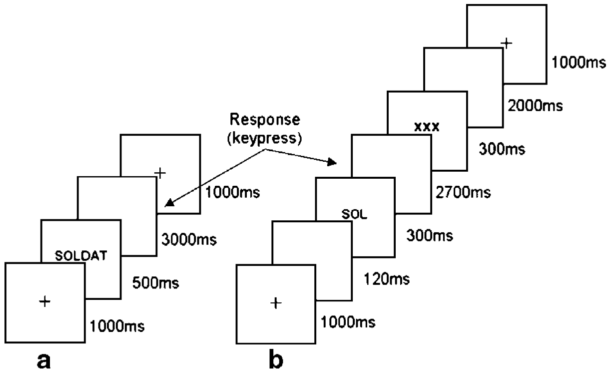

Fig. 1. Diagram showing the sequence of events in each trial during the study phase (a) and the test phase (b).

word presented in the center of the screen for 500 ms. A period of 3000 ms was allocated for answering before the start of the next trial. The retrieval task (Fig. 1b) also started with presentation of a fixation cross for 1000 ms. The screen was then blanked for 120 ms, after which a word stem was displayed for 300 ms, centered on the position occupied by the fixation cue. The screen was then blanked for 2700 ms to allow for the response, after which a signal (xxx) was displayed for 300 ms to indicate that the trial was finished. After a 2000-ms interval, the fixation cross reappeared to begin the next trial.

2.3. Procedure

Once the electrode cap had been fitted, participants were seated comfortably in a chair in front of the stimulus presentation monitor. They were informed that they were about to take part in an experiment to assess their memory. To familiarize them with the experimental procedure, there was a practice phase consisting of ten trials (as in the test phase, see Fig. 1b). In each trial, a single stem was presented on the monitor. The participants were instructed to complete each stem with the first name of a city that came to mind. As soon as they were able to provide an answer, they were to press a button with the right thumb just before saying aloud their response.

Once the practice phase had been successfully completed, the first study/test block began. Participants were given an encoding task consisting of 44 stimuli. Each word was studied using the same study task: the "shallow" (lexical) task involved counting the syllables of each word and the "deep" (semantic) task was to judge whether the meaning of the word was pleasant, neutral, or unpleasant. Participants were instructed to press a button before saying their judgment out loud. The duration of each study phase was 3 min 18 s, followed by a 1-min rest interval before the test phase which lasted about 7 min. 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 to complete each stem with a studied item. If this was not possible, then the stem should be completed with the first suitable word that came to mind. They were instructed to press a button as soon as they had found a completion for the stem. This simultaneously put a marker on the EEG track, which, with the stimulus onset, allowed the response time to be computed. Two verbal responses were then required: first a completion for the stem and second to say "old" if the completion was a studied item and "new" if not. When subjects did not provide an immediate verbal response after the key press, the trial was excluded from the average.

Participants were asked to remain as relaxed as possible during the test phase trials to minimize EEG artifacts due to head and body movements. They were also instructed to refrain from blinking between the display of the fixation cross and the button press, in order to minimize the effect of oculomotor artifacts on the EEG.

2.4. ERP recording and analysis

The EEG activity was recorded with electrodes embedded in an elastic cap (Electro-cap International) from 62 scalp sites of the extended 10–20 system. Electrode labeling was based on the standard nomenclature. The vertical electrooculogram (EOG) was recorded from electrodes located above and below the director eye, and the horizontal EOG from electrodes at the outer canthus of each eye. All scalp electrodes were off-line referenced to both earlobes. EEG and EOG were recorded continuously within a band pass from 0.16 to 170 Hz and were A–D converted with 16 bit resolution at a sampling rate of 512 Hz.

In the test phase, ERPs were computed for each participant at all recording sites with epochs extending from 200 ms before onset of word presentation to 3000 ms after onset. For each encoding condition, ERP correlates of explicit retrieval were analyzed by contrasting ERPs for two conditions: stems correctly completed and recognized (termed old) and stems completed with unstudied items given a correct recognition judgment (termed new). Instances in which a new word was produced when a study word could be recalled were not included. The mean number of trials contributing to ERPs for the "old" and "new" conditions was, respectively, 25 (range = 18–35) and 43 (32–52) in the lexical condition, and 44 (33–54) and 43 (35–50) in the semantic condition.

The average potential in the 200-ms preceding stimulus presentation served as a baseline. Prior to averaging, each epoch was scanned for EOG and other artifacts. The EEG epochs were visually scanned for further artifacts. The averages were low-pass filtered below 12 Hz in order to increase the signal-to-noise ratio by eliminating those frequencies that were irrelevant to the measurements of interest. Because some of the ERP components were not clearly apparent as peaks at all electrode sites, mean amplitude measurements were taken as they were more reliable for component scoring than peak measurements.

A selected subset of the full electrode montage was chosen to allow the magnitude of differences between conditions to be assessed as a function of the anterior/posterior and hemisphere location of the electrode sites. ANOVAs were conducted on averages of paired electrodes. The selected sites were located at anterior (left: F3, FC3; midline: FZ, FCZ; right: F4, FC4) and posterior (left: P5, P3; midline: PZ, POZ; right: P4, P6) locations. Separate ANOVAs were conducted on the ERPs from the 2 midline sites, the 2 lateral anterior sites, and the 2 lateral posterior sites. These ANOVAs employed factors of both item type (old vs. new) and encoding condition (lexical vs. semantic). In addition, ANOVAs conducted on ERPs from the two midline sites included the factor of location (anterior vs. posterior), and those conducted on ERPs from the lateral sites included the factor of hemisphere (left vs. right). Topographic analyses were also conducted after normalization [24]. ANOVAs on normalized ERP values were reported when initial interactions involving electrode position were significant. Only effects that involved the factor of item type (old/new effect) were reported.

These ANOVAs were carried out at selected latency ranges. The intervals were chosen on the basis of visual inspection of the waveforms. In addition, ERPs were subjected to preliminary analysis by ANOVAs of mean amplitude of consecutive 100 ms latency ranges. From 400 ms post-stimulus, these ANOVAs gave rise to a consistent pattern of highly significant old/new effects at midline and lateral sites. On the basis of these analyses, two broad latency regions, 400–800 ms and 800–1100 ms post-stimulus (the shortest mean response time being 1121 ms post-stimulus), were selected for the analyses. These latency regions encompass the intervals employed in previous studies of word-stem cued recall [1,2,5]. All post hoc tests used the Newman–Keuls method, with a significance level of $P < 0.05$.

3. Results

3.1. Behavioral data

These data have been described in detail by Fay et al. [15]. Trials from the study and test conditions in which participants failed to give a response within 3500 ms (study) and 3000 ms (test) after stimulus onset were removed from subsequent analyses. Reaction time was defined as the interval between the occurrence of the test item (stem) and the participant's key press. The behavioral data are summarized in Table 1.

The completion rate represents the percentage of correct completions for stems belonging to studied items (pooled across recognition decision). Participants correctly recalled 31.1% and 41.7% of the words in the lexical and semantic conditions, respectively. Baseline completion was estimated for each participant by analysis of the responses to the stems belonging to the set of 120 critical items that had not been presented at study. The baseline rate is an estimate of the probability that the stem of a critical word will be completed with that word in the absence of prior study. This estimate could thus be used to determine whether completion rates for studied words were significantly higher than chance. The correct completion rates for stems of shallowly and deeply studied items were corrected by subtracting the baseline completion rate of 5.7%. These corrected completion rates were both significantly greater than zero (lexical: $t(11) = 13.95$, $P < 0.001$; and semantic: $t(11) = 35.97$, $P < 0.001$), but more correct completions were made for semantically than for lexically studied items ($t(11) = 5.54$, $P < 0.001$). The false-alarm rate was defined as the percentage of completions with unstudied items that were falsely judged to be old. Both false-alarm rates were significantly greater than zero (lexical: $t(11) = 6.48$, $P < 0.001$; and semantic: $t(11) = 7.42$, $P < 0.001$), but more false alarms were made for lexically than for semantically studied items ($t(11) = 4.49$, $P < 0.001$). The recognition rate was defined as the mean percentage of correct completions which were also correctly recognized. Recognition scores for studied words were corrected for guessing by subtracting the false-alarm rate. The corrected recognition scores for both lexically and semantically studied words were significantly greater than zero (lexical: $t(11) = 9.68$, $P < 0.001$; and semantic: $t(11) = 25.38$, $P < 0.001$), but more recognitions were made for semantically than lexically studied items ($t(11) = 10.84$, $P < 0.001$). Finally, the conditional probabilities of recognition given correct completion also differed significantly as a function of the encoding variable, the rate for semantically studied items

Table 1
Behavioral data*

	Completion rate (%)	False-alarm rate (%), F.A.	Recognition rate (%), old	Conditional probability of recognition	New completion rate (%), new
Lexical	31.1 (6.78)	4.2 (2.23)	23.3 (6.50)	0.74 (0.08)	80.0 (7.00)
Semantic	41.7 (4.48)	1.9 (0.86)	40.6 (5.19)	0.97 (0.05)	80.6 (6.21)
Baseline	5.7 (2.33)	–	–	–	–

* Column 1: percentage of correct completions for stems belonging to studied items (pooled across recognition decision) and percentage of baseline completions for unstudied items; column 2: percentage of false recognition of completions; column 3: mean percentage of correct completions which were also correctly recognized; column 4: conditional probability of correct recognition for correctly completed stems; column 5: mean percentage of new completions for stems belonging to unstudied items. SDs are shown in parentheses.

Table 2
Response times (RT) to produce old and new words in word-stem cued recall as a function of encoding condition

	RT/ms	
	Old words	New words*
Lexical	1225 (317)	1562 (441)
Semantic	1121 (173)	1590 (420)
Overall	1156 (220)	1577 (428)

SDs are shown in parentheses.
* New completions arise from stems belonging to unstudied items.

being higher ($t(11) = 10.48$, $P < 0.001$). Regarding the new completion rate, new words occurred when participants could not complete a word stem to form a study word, but produced a word anyway, which was also correctly recognized as new. Proportions of new completions did not differ between the two encoding conditions (lexical vs. semantic, $t(11) = 0.25$).

Mean response times for the two main types of completions (old vs. new) are presented in Table 2. An ANOVA on these data between type of produced words (old vs. new) and encoding task (lexical vs. semantic) revealed no significant effect of encoding condition [$F(1,11) = 1.55$]. The effect of type of words was significant, indicating slower response times for new words [$F(1,11) = 40.04$, $P < 0.001$]. The data also revealed a significant interaction between type of words produced and encoding condition [$F(1,11) = 6.22$, $P < 0.05$], showing that response times to produce old words in the semantic condition were faster than in the lexical condition [$P < 0.05$], whereas there was no significant encoding effect on the time taken to produce new words [NS].

3.2. Event-related potentials

Inspection of the waveforms (Fig. 2) suggests that ERPs evoked by stems completed with studied words differed from those evoked by stems completed with unstudied items. In each encoding condition, this difference took the form of increased negativity for new words, maximal at fronto-central electrode sites, which began around 400 ms after stem onset and was sustained for 700 ms. In line with response-time data, the return to the baseline occurred later for new words than old words.

The ERP data were subjected to three sets of analyses. The first set focused on the overall old/new effect; the second investigated whether the ERP old/new effect (reflecting retrieval success) was modulated by the encoding task, and the third set examined whether ERPs elicited by new completions (reflecting retrieval orientation) varied according to the encoding manipulation. ERPs elicited by old words are ill suited for addressing this

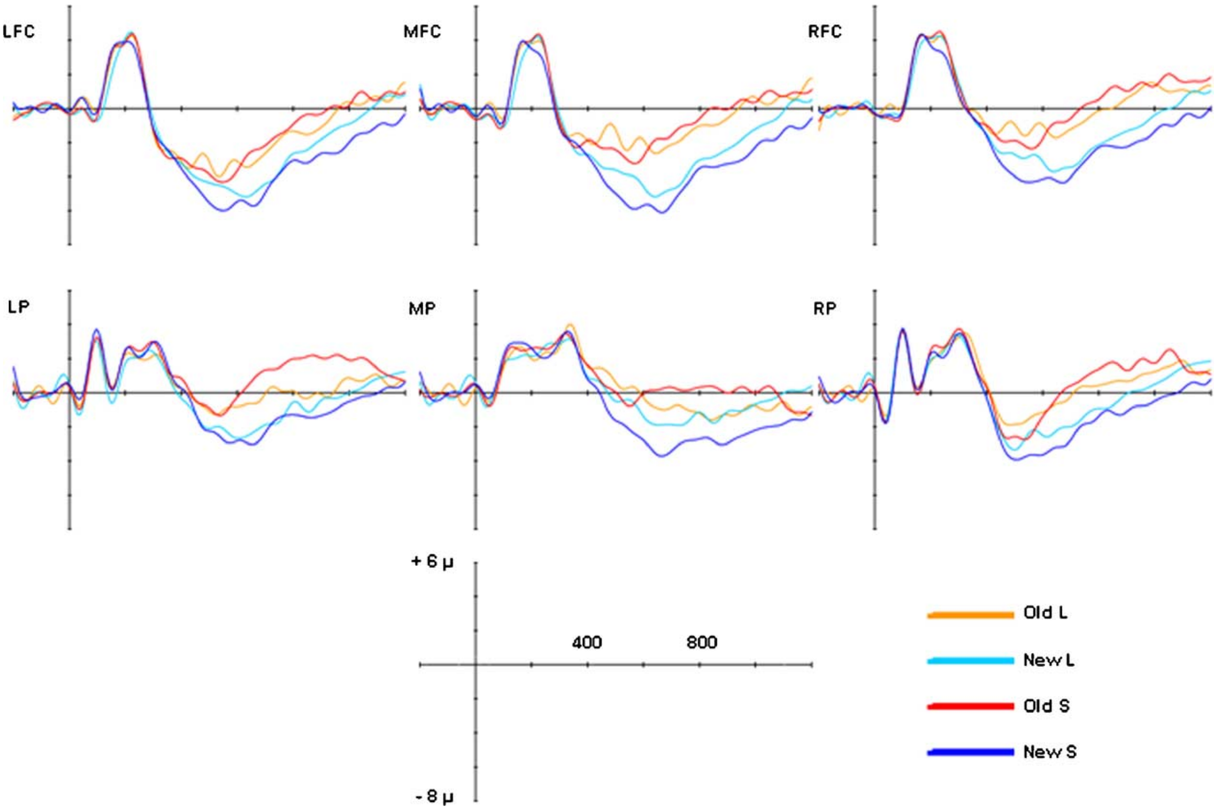

Fig. 2. Grand average ERPs evoked by stems correctly completed with recognized studied items (old), along with ERPs evoked by stems completed with unstudied items which are correctly rejected (new) as a function of the encoding condition (L: lexical vs. S: semantic). Abbreviations: MFC, midline fronto-central (FZ, FCZ); MP: midline parietal (PZ, POZ); LFC: left fronto-central (F3, FC3); RFC: right fronto-central (F4, FC4); LP: left parietal (P5, P3); RP: right parietal (P4, P6).

issue because the waveforms also contain effects associated with retrieval success.

3.2.1. The overall ERP old/new effect

The ANOVAs carried out on data from the midline and lateral sites in the 400–800 ms and 800–1100 ms latency regions gave rise to main effects of item type (400–800 ms: midline [$F(1,11) = 29.72$, $P < 0.001$], lateral anterior [$F(1,11) = 27.18$, $P < 0.001$], lateral posterior location [$F(1,11) = 23.52$, $P < 0.001$]; 800–1100 ms: midline [$F(1,11) = 11.68$, $P < 0.01$], lateral anterior [$F(1,11) = 18.72$, $P < 0.001$], and lateral posterior location [$F(1,11) = 9.17$, $P < 0.05$]). ERP old/new effects were observed, with a greater negativity of ERPs elicited by stems completed with an unstudied item compared to those elicited by recalled items. This old/new effect was qualified by several interactions. Data from midline sites gave rise to significant item-type by location interaction for the 400–800 ms latency region [$F(1,11) = 6.50$, $P < 0.05$], approaching significance for the 800–1100 ms latency region [$F(1,11) = 4.23$, $P = 0.06$]. Post hoc analyses revealed that these interactions reflect the fact that the old/new effect was larger at fronto-central (anterior) electrode sites than at parieto-occipital (posterior) sites. After normalization, topographic analyses indicated that the old/new effect was prominent over frontal electrodes only in the 800–1100 ms latency region (400–800 ms: [$F(1,11) = 3.01$], 800–1100 ms: [$F(1,11) = 17.59$, $P < 0.01$]. Moreover, analyses of the data from the anterior lateral sites in both latency regions gave rise to a significant item-type by hemisphere interaction [$F(1,11) = 5.84$, $P < 0.05$ and $F(1,11) = 4.63$, $P = 0.05$, for the 400–800 ms and the 800–1100 ms latency regions, respectively], indicating that the old/new effect was larger over right fronto-central electrode sites than over left sites. This result was confirmed after normalization in both the 400–800 ms [$F(1,11) = 9.56$, $P < 0.01$] and the 800–1100 ms [$F(1,11) = 11.15$, $P < 0.01$] time windows. By contrast, data from the posterior lateral sites did not reveal such an interaction, suggesting that the parietal ERP old/new effect was not lateralized (400–800 ms: [$F(1,11) = 0.34$]; 800–1100 ms: [$F(1,11) = 0.00$]).

3.2.2. ERP old/new effect as a function of the encoding task

Fig. 3 depicts the topography of the lexical and semantic old/new effects at 700 and 900 ms post-stimulus (for each latency region). The old/new effect appears to be larger and more widespread in the semantic than the lexical condition. Moreover, during the 800–1100 ms latency region, the posterior old/new effect observed in the semantic condition was absent in the lexical condition. Data from the midline and lateral sites in the 400–800 ms latency region indicate that the ERP old/new effect did not differ as a function of the encoding condition (midline [$F(1,11) = 1.15$], lateral anterior [$F(1,11) = 0.60$], lateral posterior [$F(1,11) = 0.69$]). By contrast, during the 800–1100 ms latency region, ANOVAs of the data from midline sites revealed a tendency for interaction between item type and encoding condition [$F(1,11) = 4.28$, $P = 0.06$], the ERP old/new effect being larger in the semantic than in the lexical condition. At lateral anterior sites, the interaction between item type and encoding condition was not significant in the 800–1100 latency region [$F(1,11) = 2.28$], suggesting that the lexical old/new effect did not differ from the semantic old/new effect. However, at lateral posterior sites, this interaction was significant [$F(1,11) = 7.05$, $P < 0.05$]. Post hoc analyses revealed that only the semantic ERP old/new effect was significant ($P < 0.01$).

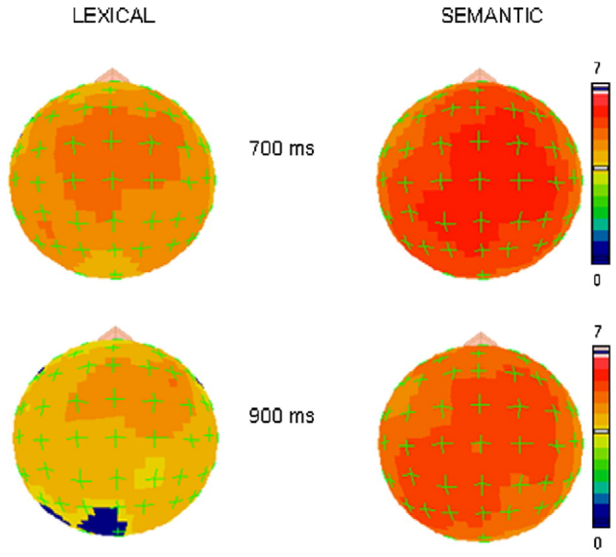

Fig. 3. Topographic voltage maps for the lexical and semantic old/new effects, showing the relative amplitude of the differences between the ERPs elicited by old words and the ERPs elicited by new words (old minus new), at 700 and 900 ms post-stimulus.

Analyses of data from the midline sites indicated that the three-way interactions between the factors of item type, encoding condition and location were not significant [400–800 ms: $F(1,11) = 0.78$; 800–1100: $F(1,11) = 2.47$]. Data from the lateral sites also showed that the three-way interactions between item type, encoding condition and hemisphere were not significant (400–800 ms: lateral anterior [$F(1,11) = 0.09$], lateral posterior [$F(1,11) = 0.67$]; 800–1100 ms: lateral anterior [$F(1,11) = 0.12$], and lateral posterior [$F(1,11) = 2.45$]).

3.2.3. Encoding effect on ERPs elicited by new words

Additional ANOVAs were conducted on the ERPs elicited by new words in order to investigate whether participants adopted different “retrieval sets” when attempting to retrieve studied items (memory search operations). Only effects that involved the factor of encoding condition are reported.

Data from the midline sites in the 400–800 ms latency region indicated that the main effect of encoding condition was significant [$F(1,11) = 5.39$, $P < 0.05$], semantic ERPs being more negative than lexical ones. This factor did not interact with location [$F(1,11) = 0.30$], indicating that differences between lexical and semantic ERPs were of the same order at midline anterior and posterior sites. In the 800–1100 ms latency region, neither the encoding effect [$F(1,11) = 3.16$] nor the interaction between encoding condition and location [$F(1,11) = 0.01$] was significant.

Data from the lateral sites showed that the main effect of encoding condition was not significant (400–800 ms: anterior [$F(1,11) = 0.22$], posterior [$F(1,11) = 1.39$]; 800–1100 ms: anterior [$F(1,11) = 1.22$], posterior [$F(1,11) = 1.68$]). The interaction between encoding condition and hemisphere was not significant (400–800 ms: anterior [$F(1,11) = 0.43$]; 800–1100 ms: anterior [$F(1,11) = 0.32$], posterior [$F(1,11) = 0.73$]), except between 400 and 800 ms post-stimulus at posterior lateral sites [$F(1,11) = 4.87$, $P < 0.05$]. Post hoc analysis revealed that semantic ERPs were more negative than lexical ERPs at right posterior sites ($P < 0.01$), whereas at left posterior sites they did not differ. This interaction was not confirmed after normalization [$F(1,11) = 1.62$].

4. Discussion

4.1. Behavioral results

This experiment consisted in an explicit memory task in which participants actively retrieved recently presented study words by using word stems as cues. Participants were instructed to try to complete each stem with a studied item or with any other suitable completion if a studied item could not be recalled. In addition, participants were required to judge whether or not the completion was present on the study list. This test procedure was intended to ensure that only completions that were explicitly remembered contributed to the "old" ERPs. Memory performances were compared under two encoding conditions (lexical vs. semantic). As expected, the depth of processing manipulation had a significant effect on cued-recall performance, with higher levels of correct completion for semantically than lexically studied items (Table 1). In line with Allan et al.'s results [3,5], depth of processing had a strong effect on subsequent recognition judgment: stems completed with semantically studied items were much more likely to be correctly judged old than those completed with words from the lexical task. In addition, semantically studied words were produced more quickly than lexically studied ones (Table 2). Thus, in the word-stem cued-recall task, semantic encoding increased the recall and recognition rates, while it decreased the time to access the "enriched" memory trace. Participants took longer on average to produce new words than old (studied) words. Presumably, participants first tried to generate a word from the earlier study list. If the memory search was successful, the word was produced relatively quickly. If the participant could not produce a study-list word, the memory search was abandoned, and participants completed the stem cue with an appropriate word that they could generate.

4.2. ERP results

4.2.1. The overall ERP old/new effect

ERPs evoked by stems completed with studied (old) words differed from those evoked by stems completed with unstudied (new) items. This difference took the form of increased negativity for new words (Fig. 2). The ERP old/new effect had an onset latency of around 400 ms post-stimulus and persisted for at least 700 ms. In line with the findings of previous studies [1–3,5,6], a firm conclusion can be drawn from this result about the time course of word-stem cue processing, notably that it takes no more than about 400 ms for such a cue to engage differential processing predictive of the nature of a subsequent memory judgment. The ERP old/new effect was fronto-central and parietal, but the differences were more marked at anterior than at posterior electrode sites. Moreover, at fronto-central electrode sites, the old/new effect was more pronounced over the right than left hemisphere, whereas at parietal electrode sites, the old/new effect was symmetrical.

Allan et al. ([1,2]; see also Refs. [3,5,6]) found that ERPs elicited by stems attracting explicit retrieval of studied items were modulated by a sustained positive-going shift compared to those elicited by stems completed with unstudied words. In the present study, the whole deflection was negative in both cases (for old and new ERPs), probably due to either motor preparation or CNV-like activity. Nevertheless, with regard to the old/new effect, our results are consistent with those of Allan et al. [1–3,5,6], since potentials were less negative for old than for new items. Allan et al. [3] interpreted this old/new effect (or cued-recall effect) as retrieval processes associated with explicit memory. However, they also proposed an alternative interpretation, namely that the effect may reflect a differential engagement of working memory, either (a) for the maintenance of the retrieved item, or (b) for the prolongation of a lexical/semantic search. The protocol of the present experiment made it possible to identify the most plausible of these explanations. Given that participants were instructed to press a button as soon as they were able to give a response, the retrieved item did not have to be maintained in working memory for a long time. Consequently, the robust ERP cued-recall effect that we observed could not come from an enhanced positive shift in old ERPs compared to new ERPs (a). Instead, the old/new effect is best characterized as a negative shift in ERPs elicited by stems completed with unstudied and unrecognized studied items. This suggests that working memory processes are more crucial for the prolongation of a lexical/semantic memory search for potential completions to stems which cannot be completed rapidly with a recognizable studied item (b). This explanation is supported here by response-time and electrophysiological data: participants took longer to produce new than old words, and the return to baseline occurred later for new than for old words. These findings suggest that participants were attempting to retrieve a word from memory for a longer time in the new than in the old condition. In sum, the cued-recall effect appears to reflect retrieval processes associated with explicit memory and/or differential engagement of working memory, such that the increased negative potential for new words is a sign of a continuing memory search for studied items.

The majority of studies investigating ERP correlates of explicit memory have employed a direct test of recognition (see Refs. [21,34,35] for reviews). Wilding and Rugg [51] indicated that the old/new effect can be separated into at least two components. In their study, ERPs evoked by correctly recognized items were contrasted according to whether the items were correctly or incorrectly assigned to their study context (gender of speaker). Compared to ERPs elicited by new items, those evoked by items associated with incorrect contextual judgment exhibited an asymmetrical (left > right), centro-parietally distributed positivity. The ERPs evoked by items attracting a correct contextual judgment also showed a sustained frontally distributed positive shift, which tended to be greater over the right hemisphere. Wilding and Rugg [51] linked the left parietal effect with the retrieval of item and contextual information from memory, operations supported by the “medial temporal lobe memory system” [45]. They also linked the right frontal effect with processing the products of successful retrieval (“post-retrieval” operation), operations dependent on the prefrontal cortex (see Ref. [36] for a detailed discussion of functional interpretations based on ERP data). These hypotheses have also received support from the findings of positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) studies, which have consistently demonstrated activation of these regions during episodic retrieval tasks (for reviews, see Refs. [7–9,16,42]).

The present experiment has shown that the cued-recall effect was greater at anterior than at posterior electrode sites, thus replicating previous studies [1–3,5]. In addition, our data indicate that these frontally distributed differences between old and new ERPs were significantly larger over the right than over the left hemisphere. This result, suggesting the existence of a right hemisphere contribution to cued recall, is consistent with a study using the divided visual field technique [23], in which word-stem cues gave rise to more accurate recall when presented to the right than to the left hemisphere. The right frontal cued-recall effect is also supported by the hemispheric encoding/retrieval asymmetry model of prefrontal involvement in encoding and retrieval of episodic memory [48]. According to this model, right prefrontal cortical regions are more involved in episodic memory retrieval than the left prefrontal cortical regions.

In the present study, it was found that the cued-recall effect was not lateralized in the parietal regions. Other studies using a word-stem cued-recall task [1,3] also failed to find an asymmetric parietally distributed difference between ERPs evoked by correctly identified old and new words. Apparently, such topographic distribution is task dependent: Allan and Rugg [1], contrasting word-stem cued-recall and recognition tasks, showed that the scalp distribution of the ERP cued-recall effects appears markedly more diffuse than that typically observed in recognition memory.

4.2.2. ERP old/new effect as a function of the encoding task

The retrieval processes reflected by the ERP old/new effects were dependent on the conditions under which the retrieved information was encoded. In the 400–800 ms latency region, the old/new effects associated with each encoding condition were statistically equivalent. By contrast, in the 800–1100 ms latency region, there were differences in both the magnitude and the scalp topography of the effects, according to whether the completions had been subjected to lexical or semantic processing at study (Fig. 3). At midline electrode sites, the old/new effect tended to be greatest when elicited by semantically studied items. These differences in magnitude corroborate Allan et al.’s results [5], in which old/new effects varied in magnitude, being largest when elicited by the more memorable class of study item (see also Ref. [40] for a similar result in a recognition task). As proposed for the ERP correlates of recognition memory [39], the ERP old/new effect is a graded phenomenon, with a magnitude proportional to the amount or quality of retrieved information available to consciousness [5]. Thus, it is not surprising that the magnitude of the old/new effect was larger in the semantic than in the lexical condition. In line with this idea, several studies have indicated that the old/new effect is sensitive to the amount of contextual information retrieved, in as much as ERP memory effects are larger when successful item memory is accompanied by accurate rather than inaccurate source memory [2,49,51]. Consequently, it has been proposed (see Ref. [35] for a review) that the old/new ERP effect is closely associated with recognition based on recollection rather than on familiarity: in recollection, the retrieved memory contains contextual information about the learning episode [20], and deep encoding is known to increase the probability of recollection [17].

Contrary to Allan et al.’s studies [3,5] which failed to find any evidence for differences in scalp topography, our results showed that between 800 and 1100 ms post-stimulus there was a significant old/new effect at lateral posterior electrode sites in the semantic condition only. ERPs associated with episodic retrieval differed qualitatively as a function of the encoding history of the retrieved information. Such differences were not observed in Allan et al.’s studies. This was probably due to their encoding manipulation (a randomized variable), whereas in the present experiment, the encoding manipulation was a blocked variable. Thus, participants may have adopted more obvious retrieval strategies specific to each class of item during each test block. In a recognition task, Rugg et al. [41] also found that old/new effects varied with the encoding condition. Interestingly, the left parietal effect elicited by deeply studied recognized words was absent in the waveforms elicited by shallowly studied items, consistent with the view that the effect is a correlate of recollection. These findings, showing an encoding effect mainly on the parietal old/new effect, are congruent with the idea that the "parietal old/new effect" is a brain potential correlate of episodic retrieval (e.g., recollection, for review see Ref. [4]), whereas the frontally distributed old/new effect reflects processes that operate selectively on the products of retrieval.

In sum, the main results of this study are the temporal and topographic differences between old/new effects for shallowly and deeply encoded words, when the words are presented in separate study/test blocks. Thus, in a word-stem cued recall task, the nature of the reinstated information during the retrieval phase, and hence its neural basis, varies from one episode to another according to what is encoded. In contrast to those of Allan et al. [3,5], our data are thus in agreement with models of episodic memory which suggest that retrieval involves the reinstatement of patterns of neural activity representing an episode while it was first experienced [13,14,25,26,46]. However, ERPs were not recorded at encoding in the present experiment and thus could not be directly compared with those at retrieval.

4.2.3. Encoding effect on new words

The encoding manipulation also gave rise to differences between the ERPs elicited by new words in each test block. Differences in the ERPs elicited by new items show that subjects adopted different processing strategies in the test blocks for each encoding condition. This comparison is important because it allows investigation of retrieval effort or orientation rather than retrieval success. The effect of the encoding condition was evident between approximately 400 and 800 ms post-stimulus. The differences took the form of greater negativity in the ERPs elicited by new items in the semantic condition than in the lexical condition, these differences being maximal over anterior and posterior midline electrode sites and right posterior electrode sites. This last effect must be interpreted with caution because no significant encoding × hemisphere interaction emerged at posterior electrode sites after normalization.

Rugg et al. [41] found that ERPs elicited by new words in the shallow condition of a recognition task were more positive, and that this effect tended to be greater over the right than the left hemisphere at posterior central sites between 600 and 1000 ms. The slightly right-sided distribution of this effect resembles the distribution which is often found for the modulation of the "N400" component by the nature of the processing dedicated to the word. Compared to tasks in which words are processed according to their semantic attributes, the N400 is attenuated when elicited in tasks where processing is confined to surface attributes of a word [10,38]. Rugg et al. [41] interpreted the right central/posterior retrieval set effect as reflecting qualitative differences in the processing of test items in the two encoding conditions. Since encoding and test tasks were blocked in their study, as in the present experiment, subjects were able to adjust their processing strategies at test to match the conditions under which items had been encoded at study. This result reinforces the hypothesis according to which explicit retrieval requires the reinstatement of neural activity engaged at the time of encoding. The encoding effect on ERPs to new words would indicate an aspect of retrieval orientation, namely, whether test items are subjected to conceptually or data-driven processing [33]. This effect represents a further example of the modulation of ERP waveforms by the manipulation of variables influencing the manner in which retrieval cues are processed [18,19,22,29,32,41,44,49,50].

5. Conclusion

Robust ERP cued-recall effects were observed for stems completed with explicitly retrieved items. These effects varied in magnitude, being larger when elicited in the deep encoding condition. While replicating the findings of a previous study [5], the present results also reveal that scalp topography of the effects varies according to whether study items are encoded in terms of their surface or conceptual attributes. Thus, depth of processing manipulation at encoding may give rise to different patterns of neural activity during retrieval when the items are presented in separate study/test blocks. Furthermore, differences in the ERPs elicited by new items show that subjects adopt different processing strategies in the test blocks following each encoding condition. Overall, the present results add to evidence suggesting that depth of processing acts on two types of retrieval-related neural activity, one associated with retrieval success (old/new effect), the other with memory search operations (retrieval orientation).

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