Brain Potentials during Memory Retrieval Provide Neurophysiological Support for the Distinction between Conscious Recollection and Priming

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Abstract

■ Event-related brain potentials were recorded from subjects as they attempted to identify words displayed tachistoscopically. Words that had also been presented a few minutes earlier in a different context were identified more often than were words that had not been presented before. This priming effect was observed for words initially seen in an imagery task requiring size estimations as well as for words initially seen in an orthographic task requiring letter counting. Unlike priming, recall and recognition were much better for words repeated from the imagery task than from the orthographic task. Brain potentials elicited during word identification also differed as a function of task. Based on these differences, a potential from 500 to 800 msec was interpreted as an index of recollection processes. Earlier potentials may have indexed processing related to priming. These effects thus provide measures of the hypothetical processes underlying memory performance and demonstrate that recollection and priming are associated with distinct neural events. ■

INTRODUCTION

The subjective experience of remembering, *conscious recollection*, can be thought of as an outcome of retrieval processes such as those engaged in recall and recognition tests. In contrast, some types of memory need not be associated with conscious recollection. This theoretical distinction not only draws attention to an important characteristic of human memory, but also may promote a better understanding of conscious recollection itself, through investigations of the ways in which recall and recognition differ from other types of memory.

In particular, it can be useful to juxtapose conscious recollection and *priming*. Whereas recollection is typically assessed in explicit memory tests, priming can be assessed using a number of different implicit memory tests, classified as such because the subject is asked to engage in an activity other than deliberate memory retrieval. In the word-identification test, for example, subjects are asked to read words that are flashed so briefly that only a subset of the words can be identified correctly. Priming is demonstrated when prior study leads to an increase in the number of correct identification responses or a decrease in the exposure time required for correct identification (e.g., Feustel, Shiffrin, & Salasoo, 1983; Jacoby, 1983; Jacoby & Dallas, 1981; Murrell & Morton, 1974; Salasoo, Shiffrin, & Feustel, 1985). Demonstrations that recollection and priming effects of this sort are differentially influenced by a wide variety of experimental manipulations (e.g., only the former is influenced by the extent to which meaning is processed at acquisition) have been used to support the idea that recollection and priming are subserved by fundamentally different psychological processes (for reviews see Richardson-Klavehn & Bjork, 1988; Roediger, 1990; Schacter, 1987; Shimamura, 1986; Squire, 1986; Tulving & Schacter, 1990). This view is further supported by findings that amnesic patients with severe impairments in recall and recognition show normal priming effects on tests of (1) word identification (e.g., Cermak, Talbot, Chandler, & Wolbarst, 1985; Haist, Musen, & Squire, 1991; Paller, Mayes, McDermott, Pickering, & Meudell, 1991), (2) stem completion (e.g., Graf, Squire, & Mandler, 1984; Shimamura & Squire, 1984; Warrington & Weiskrantz, 1970), (3) homophone spelling (Jacoby & Witherspoon, 1982), (4) face matching (Paller, Mayes, Thompson, Young, Roberts, & Meudell, 1992), (5) duration judgments (Paller et al., 1991), (6) object decisions (Schacter, Cooper, Tharan, & Rubens, 1991), and (7) lexical decisions (Glass & Butters, 1985; Moscovitch, 1985). Indeed, the evidence from amnesia suggests that recollection depends on critical functions normally mediated in specific brain areas such as the hippocampus and associated regions, and that these functions are not required for priming.

A goal for cognitive neuroscience, then, is to determine how the processes that give rise to recollection and priming are instantiated by distinctive neural machinery. A recent positron-emission tomographic study, for example, provided some insights on this question (Squire, Ojemann, Miezin, Petersen, & Raichle, 1992). Regional cerebral blood flow was measured in normal subjects using ^{15}O-labeled water, and comparisons were made among several different conditions in a stem-completion paradigm that required subjects to view three-letter stems, some of which matched the beginnings of previously studied words (Graf, Mandler, & Haden, 1982; Warrington & Weiskrantz, 1968). In the "priming" condition, subjects attempted to complete stems with the first word to come to mind. In the "memory" condition, subjects attempted to complete stems with a previously studied word. Systematic changes in blood flow in the area of the right hippocampus suggested that this region was engaged during the memory condition and, to a significantly lesser extent, during the priming condition.

Further advances in characterizing the anatomy of human memory are likely to result from functional imaging studies of this sort, in addition to studies of patients with memory impairments. Physiological measures with greater temporal resolution, in addition, may provide complementary evidence essential for a more complete understanding of the processes in question. The results of the present experiment show how measures of brain electrical activity can be enlisted toward this end.

Event-Related Brain Potentials and Memory

A number of studies have attempted to apply event-related potential (ERP) techniques to the study of human memory (see review by Kutas, 1988). ERPs reflect the summation of electrical activity generated in various brain regions and can be obtained by applying signal averaging techniques to electroencephalographic recordings from scalp electrodes. Some ERPs (often called *cognitive* ERPs) have been shown to vary reliably as a function of psychological manipulations (for reviews see Hillyard & Kutas, 1983; Hillyard & Picton, 1987).

In one early experiment involving recognition memory, ERPs were recorded while subjects viewed color slides depicting a variety of people, places, and paintings (Neville, Snyder, Woods, & Galambos, 1982). Subsequently, subjects were shown each slide again and asked to indicate whether or not they had recognized it on its initial exposure. An average of 11% of the slides fell into this category. Positive ERPs elicited during the initial recording phase showed a considerably greater amplitude for these slides than for the remaining slides, particularly at around 400 msec. The authors interpreted this effect as a modulation of the P3 component, which is an ERP typically elicited by rare target events embedded in highly repetitive stimulus sequences (see reviews by Johnson, 1986; Pritchard, 1981; Verleger, 1988).

More recently, many investigators have examined ERPs as a function of recognition in verbal learning paradigms (e.g., Bentin & Moscovitch, 1990; Friedman, 1990; Johnson, Pfefferbaum, & Kopell, 1985; Karis, Fabiani, & Donchin, 1984; Neville, Kutas, Chesney, & Schmidt, 1986; Paller, Kutas, & Mayes, 1987; Rugg & Nagy, 1989; Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980; Smith & Halgren, 1989). A consistent finding in these experiments was that ERPs to recognized words were more positive than ERPs to words that had not been presented previously. Again, these effects were often interpreted as modulations of the P3 component, although some authors have argued that the effects were due in part to modulations of other components such as the N400, an ERP studied extensively in language contexts (see review by Kutas & Van Petten, 1988).

A separate issue concerns whether these ERP effects reflect particular aspects of the recognition process. Several features of the recognition paradigm cloud this issue. First, the requirement that subjects detect recognized words may call into play target-detection operations that differ for old and new items, in that only the former are targets. Second, the confidence with which a recognition judgment is made may differ considerably between old and new items. Third, the latency to recognize a previously studied word is generally shorter than the latency to detect a new word. Fourth, subjects may develop expectations about which type of item is more likely to occur in the sequence, or, in other words, the subjective probability of old and new items may vary. Ample evidence in the literature suggests that each of these factors can influence ERP amplitudes. Therefore, without suitable control conditions or additional empirical information, it is difficult to distinguish electrophysiological effects unique to the recognition process from effects due to such nonspecific factors.

Moreover, simple comparisons between old and new items in a recognition paradigm provide no straightforward way of isolating the separate processes that, according to two-process theories of recognition (e.g., Mandler, 1980, 1991), contribute to recognition decisions. The stem-completion paradigm is advantageous in this regard because it can reveal dissociations between recollection and priming while only the instructions are varied. For example, ERPs to word stems can be compared in two conditions, one in which subjects complete each stem with the first word to come to mind and another in which subjects attempt to recall previously studied words. Recordings made under such conditions (Paller, Wood, & McCarthy, unpublished findings) yielded an ERP effect similar to that observed in recognition paradigms: the amplitude of ERPs from 400 to 700 msec was more positive in the recall condition than in the completion condition. While tantalizing, this ERP effect cannot unequivocally be ascribed to recollection because subjects' success in generating responses and their confidence in these responses also differed between the recall and completion conditions.

Our strategy in the present experiment, while not sufficient to surmount all of these confounds, does make significant headway toward isolating processes related to recollection and to priming. We used the word-identification paradigm and employed two strategically selected study tasks in an incidental learning procedure. The *image study task* required subjects to visualize the referent of each word and compare its size to that of a reference object. The *letter study task* required subjects to count the number of *E*s contained in each word. Although these tasks obviously differed on several dimensions, it is likely that the extent to which the meaning of each word was processed was greater for the image task than for the letter task. Previous results suggested that recall and recognition would be better for words from the image task than for words from the letter task, but that these two tasks would yield priming effects of identical magnitude (Jacoby & Dallas, 1981, Experiment 1). Based on this predicted pattern of behavioral results, we planned to adopt the working hypothesis (discussed further below) that the underlying processes responsible for the priming effects did not differ between the two study tasks. Accordingly, if the repeated words in the identification test elicited ERPs that did not differ between the two study tasks, the ERP effects due to repetition could reasonably be interpreted as reflections of priming-related processes. On the other hand, different ERP responses as a function of study task could be used as indications of memory processes beyond those responsible for priming. In fact, we will argue that ERPs we recorded can indeed be interpreted as reflections of the brain activity underlying recollection.

RESULTS

Study Task Performance

Nearly all of the study task responses were scored as correct (90% in the image study task and 95% in the letter study task). For correct trials, the mean reaction time was 843 msec ($SE = 37$) in the image study task and 809 msec ($SE = 40$) in the letter study task. A two-way repeated-measures analysis of variance (ANOVA) showed that reaction times did not differ significantly as a function of task [$F(1,11) = 2.78$], but did tend to be slower (54 msec on average) for incorrect trials than for correct trials [$F(1,11) = 4.48, p = 0.058$].

Identification Performance

Identification scores are shown in Table 1, along with recall and recognition scores. The average priming effect across tasks was about 10%. Priming was confirmed by the results of an ANOVA with two factors: Condition (image/letter/unstudied) and Frequency (low/middle/high, based on norms for frequency of usage, Francis and Kučera, 1982). The main effect of Condition was significant [$F(2,22) = 28.78, p < 0.001$] and a Tukey test indicated that identification scores for words from the two study tasks did not differ significantly from each other, whereas both were larger than the score for unstudied words. The main effect of Frequency was also significant [$F(2,22) = 27.33, p < 0.001$], as identification performance was better for middle- and high-frequency words that for low-frequency words (see Table 2). The Condition by Frequency interaction was nonsignificant [$F(4,44) = 0.99$].

Free Recall Performance

Recall scores were greater for words from the image task than for words from the letter task [$F(1,11) = 51.95, p < 0.001$]. For words from the image task, recall varied as a function of frequency [$F(1,11) = 5.13, p = 0.015$] in that scores were greater for high-frequency words (18.0%) than for either middle- (12.0%) or low-frequency words (11.8%). Recall did not differ significantly as a function of frequency for words from the letter task [$F(1,11) = 0.02$].

Recognition Performance

Recognition scores were greater for words from the image task than for words from the letter task [$F(1,11) = 85.57, p < 0.001$]. The mean false alarm rate was 4.3% ($SE = 1.2$). For words from the image task, recognition varied as a function of frequency [$F(1,11) = 6.67, p = 0.005$] in that scores were greater for low-frequency words (65.3%) than for either middle- (57.8%) or high-frequency words (55.1%). Recognition did not differ significantly as a function of frequency for words from the letter task [$F(1,11) = 2.47$].

Carryover Effects

Given that the identification test could have functioned as an additional study opportunity, it is not surprising that recall and recognition were better for identified words than for unidentified words. Free recall performance averaged 11.0% for identified words and 3.8% for unidentified words; recognition performance averaged 55.8% for identified words and 29.4% for unidentified words. These effects were apparent both in the image task recall, [$F(1,11) = 17.40, p = 0.002$; recognition, $F(1,11) = 41.29, p < 0.001$] and the letter task [recall, $F(1,11) = 20.01, p = 0.001$; recognition, $F(1,11) = 40.63, p < 0.001$].

Note that the interpretive limitations imposed by these carryover effects can be less relevant when dissociations are found (as is also the case with respect to ERP results described below). For example, the recognition advantage for low-frequency words (which replicates previous findings, e.g., Mandler, Goodman, & Wilkes-Gibbs, 1982) cannot be explained as an indirect consequence of interposed identification testing, given that the frequency

Table 1. Performance in each Memory Test as a Function of Study Task (mean percent correct, with *SE* Shown in Parentheses)

Condition	*Test*					
	Identification		*Recall*		*Recognition*	
Words from image task	64.8	(2.5)	13.8	(1.4)	59.6	(4.5)
Words from letter task	60.9	(2.6)	3.0	(0.3)	32.4	(3.4)
Unstudied words	52.1	(3.0)			4.3	(1.2)

Table 2. Identification Scores as a Function of Study Task and Word Frequency (mean percent correct, with *SE* Shown in Parentheses)

Condition	*Frequency of usage*					
	Low		*Middle*		*High*	
Words from image task	60.2	(3.6)	66.2	(4.1)	68.5	(2.2)
Words from letter task	52.3	(2.7)	66.1	(3.2)	64.3	(3.5)
Unstudied words	45.3	(3.5)	55.5	(3.1)	57.3	(3.0)

effect on identification was in the opposite direction. In contrast, word length had similar effects in all three tests, in that scores were higher for longer words than for shorter words. This outcome suggests the possibility that the findings for recall and recognition may have resulted from the interposed identification test. However, the length effects for recall and recognition were upheld even when the analysis was restricted to words that had not been identified correctly in the identification test.

ERPs Elicited during the Identification Test

ERPs elicited while the word and mask were displayed included certain phasic deflections in the first 200 msec after word onset that are characteristic of early ERPs to visual stimuli. The sustained positivity that followed, and the manner in which it differed across experimental conditions, will be the primary focus here. In particular, we will report on differences between ERPs to studied and unstudied words, and their dependence on the processing required by the study task.

In Figure 1, ERPs to words seen earlier in the context of the image task are compared to ERPs to unstudied words, which were not previously presented to the subject in this experiment. The particular words comprising these two categories were counterbalanced across subjects, such that the observed effects cannot be ascribed to material-specific influences. An initial analysis contrasted the mean potential amplitudes over consecutive 100-msec latency intervals for recordings from the three midline electrodes (Fz, Cz, and Pz). These measurements are presented in Table 3, along with results from 2-way ANOVAs (Priming × Electrode) conducted on data from each of the nine intervals. ERP amplitudes were significantly more positive for studied words than for unstudied words between 400 and 800 msec. These effects did not differ across the three electrodes [$Fs < 2$]. A similar analysis for recordings at lateral electrode pairs showed the same pattern of effects from 400 to 800 msec [Priming × Hemisphere × Electrode ANOVA, $Fs(1,11) \geq 10.14, ps \leq 0.009$]. There were indications that the ERP differences started earlier at some anterior electrode locations, as there were significant Priming by Electrode interactions from 300 to 600 msec [$Fs(4,44) \geq 4.28, ps \leq 0.03$]. In the 300 to 400 msec latency range, the Priming effect was significant at the F3/F4 electrode pair [$F(1,11) = 11.28, p = 0.006$], but not at the other electrode pairs [$Fs < 1$ except for C3/C4, $F(1,11) = 4.19, p = 0.065$]. Furthermore, the ERP priming effect was larger over the left than over the right hemisphere, especially late in the epoch [Priming by Hemisphere interaction for 700–800 msec, $F(1,11) = 4.23, p = 0.064$, and for 800–900 msec, $F(1,11) = 4.83, p = 0.05$].

ERPs to words presented earlier during the letter study task are compared to ERPs to unstudied words in Figure 2. The analyses for midline electrodes showed two main effects of priming (200–300 and 400–500 msec, see Table 3), neither of which varied in amplitude along the midline [$Fs \leq 1.44$]. Similar priming effects were observed in ERPs at the lateral electrodes [200–300 ms, $F(1,11) = 27.38, p < 0.001$; 400–500 msec, $F(1,11) = 13.36, p = 0.004$]. These effects did not differ in either the anterior–posterior or left–right dimensions [$Fs < 1$], and although the main effect of Priming approached significance in two intervals [500–600 msec, $F(1,11) = 4.50, p = 0.057$; 600–700 msec, $F(1,11) = 4.14$, $p = 0.067$], no other effects involving Priming were significant [$Fs < 2.32$].

The ERP differences in Figures 1 and 2 are depicted

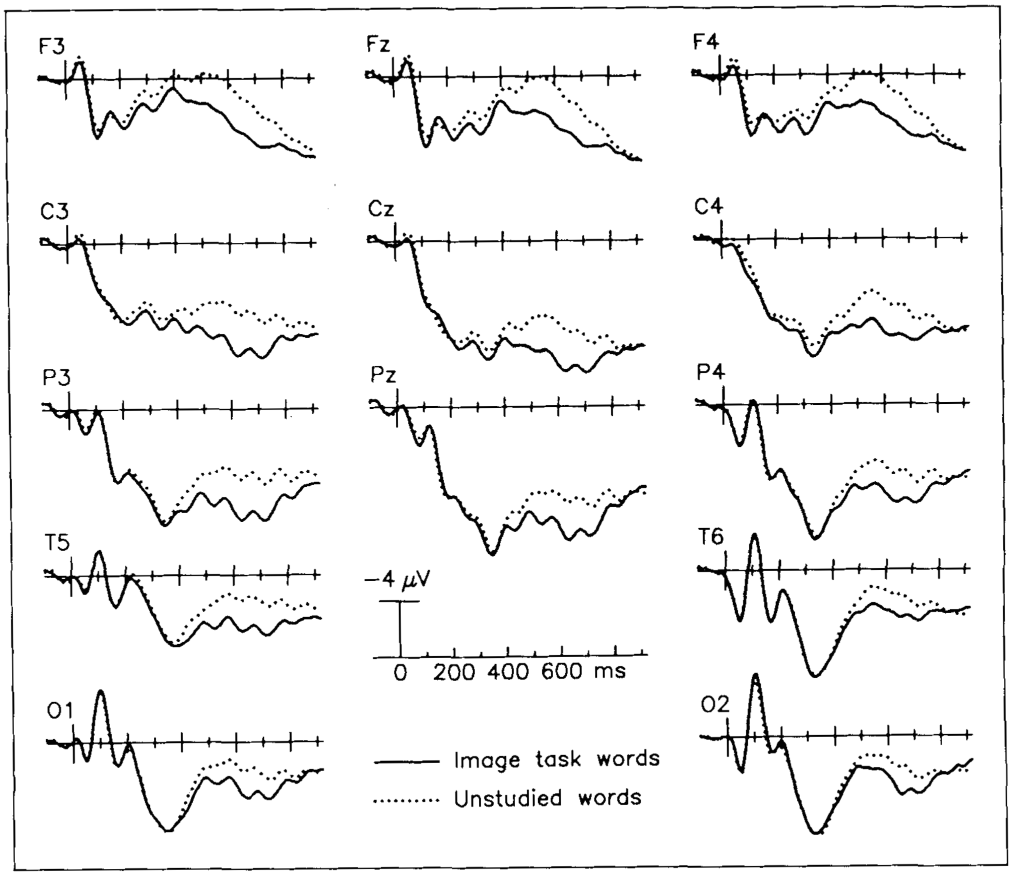


Figure 1. ERPs elicited during the test phase by correctly identified words. The image study effect is the difference between ERPs to words studied in the image task (solid line) and ERPs to unstudied words (dotted line). ERPs are arranged in a topographic manner, with left and right columns representing the left and right sides of the head, respectively.

Table 3. Mean ERP Amplitudes for Consecutive 100-msec Intervals, Averaged across the Three Midline Electrodes (in μV, with *SE* Shown in Parentheses) and Corresponding ANOVA Results

	Beginning latency								
Condition	*0*	*100*	*200*	*300*	*400*	*500*	*600*	*700*	*800*
Words from image task	0.8	4.4	6.3	7.0	6.1	6.4	7.5	7.4	6.8
	(0.3)	(0.6)	(0.7)	(0.8)	(0.9)	(0.9)	(0.7)	(0.6)	(0.5)
Words from letter task	1.0	4.9	6.5	6.4	5.7	4.6	5.3	5.8	5.9
	(0.3)	(0.6)	(0.7)	(0.8)	(0.9)	(0.9)	(0.7)	(0.6)	(0.5)
Unstudied words	0.5	4.5	5.8	6.4	4.8	4.0	4.9	5.8	6.5
	(0.3)	(0.6)	(0.7)	(0.8)	(0.8)	(0.8)	(0.7)	(0.6)	(0.5)
Comparison									
Image vs. unstudied					*	*	*	*	
$F(1,11)$	3.67	0.13	3.26	3.64	15.41	17.72	27.03	7.05	0.34
p	0.082		0.099	0.083	0.002	0.002	0.001	0.022	
Letter vs. unstudied			*		*				
$F(1,11)$	2.53	1.39	9.86	0.00	11.53	2.68	1.30	0.03	1.54
p			0.009		0.006				

*p values lower than 0.05; p values greater than 0.1 are not listed.

Figure 2. ERPs elicited during the test phase by correctly identified words. The letter study effect is the difference between ERPs to words studied in the letter task (solid line) and ERPs to unstudied words (dotted line).

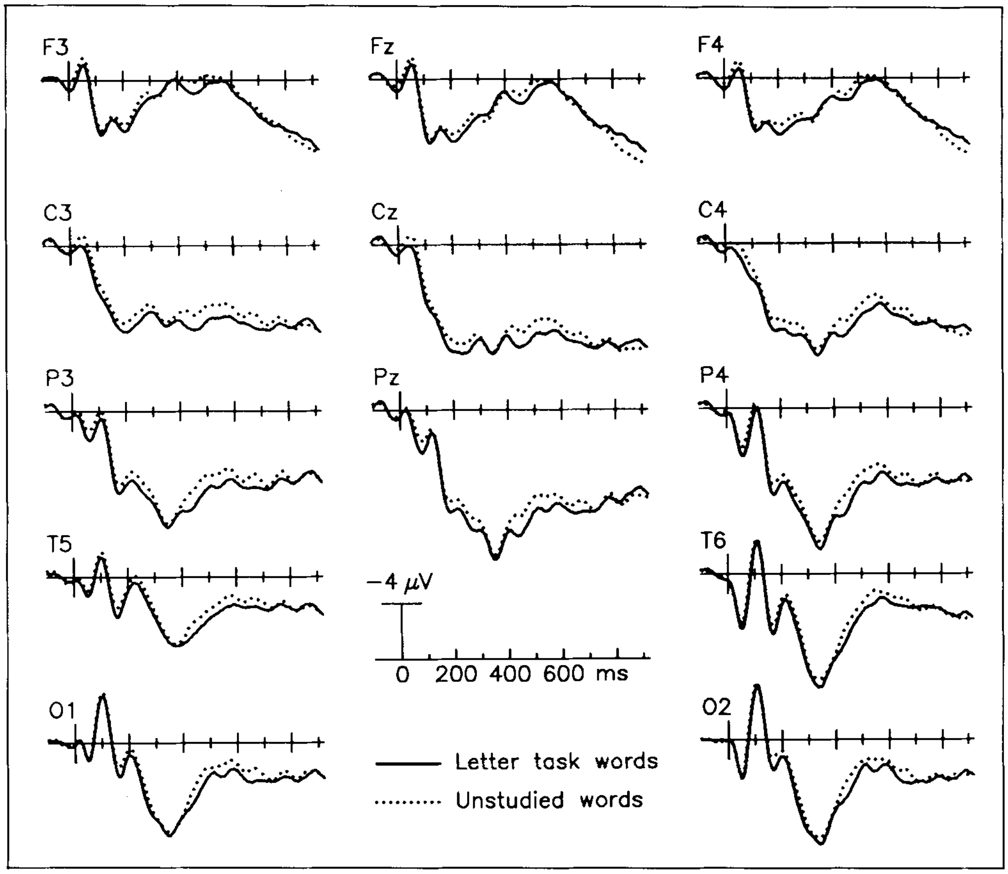
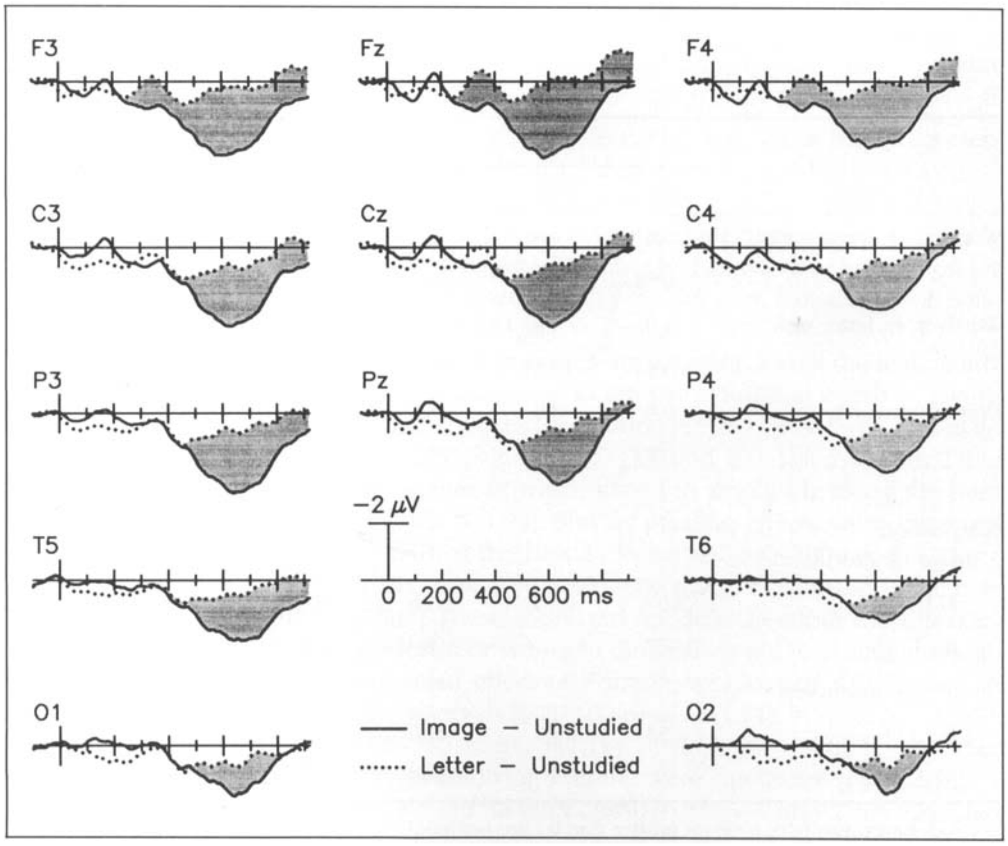


Figure 3. Difference ERPs from the test phase (correctly identified words only) computed by subtracting ERPs to unstudied word from ERPs to studied words for the image task (solid line) and letter task (dotted line).



as difference waves in Figure 3. ANOVAs comparing these two difference waves in each latency window revealed significant differences from 500 to 800 msec at midline and lateral electrodes, where the difference wave associated with the image task was consistently larger than that for the letter task [$Fs \geq 8.08, ps \leq 0.016$]. In addition, there were significant Condition by Electrode interactions for the three intervals beginning at 300 msec [$F(2,22) = 4.92, p = 0.044$; $F(2,22) = 6.45, p = 0.024$; $F(2,22) = 4.88, p = 0.044$; respectively], reflecting the fact that differences between conditions tended to be larger at frontal electrodes. A parallel result obtained for ERPs from lateral electrodes: from 300 to 500 msec ERPs differed only at frontal electrodes and from 500 to 800 msec ERPs differed at all lateral electrodes. Hemispheric laterality effects were apparent only late in the epoch as the difference waves from the image task tended to be larger over the left hemisphere [Task by Hemisphere interaction for 600–700 msec, $F(1,11) = 3.61, p = 0.084$; for 700–800 msec, $F(1,11) = 3.50, p = 0.088$; for 800–900 msec, $F(1,11) = 8.42, p = 0.014$].

Test ERPs Averaged as a Function of Identification, Recognition, and Frequency

Whereas the preceding analyses focused on ERPs to words that were identified correctly in the identification test, Figure 4 shows that ERPs were influenced by the different study conditions only when identification performance was accurate. For words that were not identified correctly, none of the differences between conditions was significant when measured over consecutive 100-msec intervals. Thus, the ERP effects of prior study cannot be attributed to repetition per se. (When collapsed across the three study conditions, ERPs to identified words were more positive than those to unidentified words over the 200–400 msec range.)

ERPs to words that were identified correctly were also averaged according to the accuracy of subsequent recognition judgments. A 3-way ANOVA (Task × Recognition × Electrode) on mean amplitudes from 400 to 800 msec showed a significant task effect at the midline electrodes, consistent with the previous analyses [$F(1,11) = 8.80, p = 0.013$]. The Task effect for words that were subsequently recognized was similar to that for words that were not recognized [Task by Recognition interaction, $F(1,11) = 0.03$; Task by Recognition by Electrode interaction, $F(2,22) = 2.66, p > 0.1$]. Also, the main effect of Recognition was nonsignificant [$F(1,11) = 0.72$]. However, the small number of words in some conditions may have limited the power of this analysis. An additional analysis in which data were collapsed across tasks showed that ERPs to words that were subsequently recognized were more positive than ERPs to words that were subsequently unrecognized (see Fig. 5).

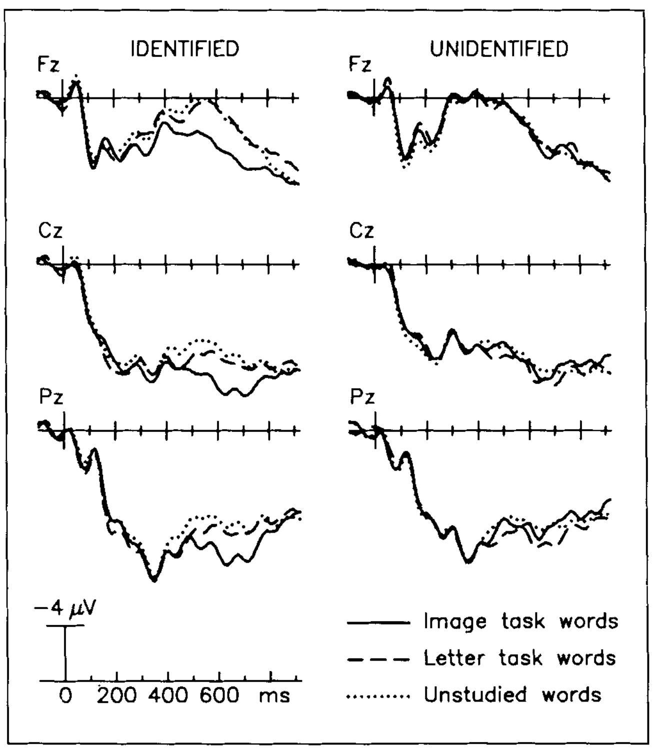


Figure 4. ERPs elicited during the test phase by identified words and unidentified words.

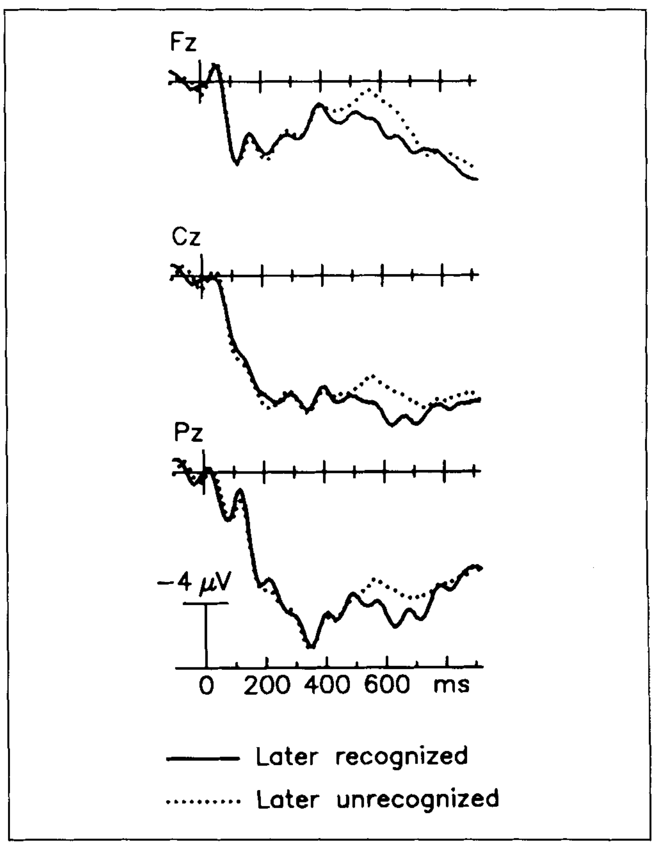


Figure 5. ERPs elicited during the test phase by identified words that were later recognized (solid line) or unrecognized (dotted line).

ERPs were also averaged separately for the three categories of words grouped on the basis of frequency of usage. To determine whether the effects of prior study on test ERPs were influenced by word frequency (see Fig. 6), mean amplitude measurements were made over the latency ranges within which significant study effects had been found. For the image task, all interactions involving frequency were nonsignificant [Fs $\leq$ 1.70]. Similarly, for the letter task, all interactions involving frequency were nonsignificant [Fs $\leq$ 2.05], with the exception of a significant Frequency by Electrode interaction for mean amplitudes over the 400 to 500 msec range [$F(4,44) = 7.06$, $p = 0.004$], reflecting the fact that frequency reliably influenced the ERPs at frontal midline sites. The absence of significant Priming by Frequency interactions indicates that the ERP repetition effects were not reliably affected by frequency. Likewise, ERPs recorded during the study tasks differed minimally as a function of word frequency.

ERPs Elicited during the Study Phase

ERPs elicited from the central midline site during the two study tasks are shown in Figure 7A. In general, words in the letter task elicited a larger positivity between 300 and 700 msec than did words in the image task. In further analyses, ERPs were averaged as a function of performance on subsequent identification, recognition, and recall tests. The corresponding ERP differences will be referred to as *Dm* (after Paller, Kutas, & Mayes, 1987). For words from the letter task, these differences were generally nonsignificant and will not be discussed further. ERPs depicted in Figure 7B were averaged on the basis of subsequent performance in the word-identification test, and no significant differences were found [Fs $\leq$ 2.69, using mean amplitude measurements from 200–400, 400–600, and 600–800 msec, following Paller, 1990].

Because recognition performance was influenced by prior identification, two separate analyses of Dm for recognition were conducted. For unidentified words, Dm for recognition is shown in Figure 7C and measures of this difference approached significance. In particular, ERPs between 600 and 800 msec were more positive for recognized words than for unrecognized words [midline electrodes, $F(1,11) = 3.95$, $p = 0.073$; for lateral electrodes, $F(1,11) = 4.81$, $p = 0.051$]. For identified words, Dm for recognition was nonsignificant. Thus, identification testing apparently altered recognition performance such that Dm for recognition was evident only for unidentified words.

The analysis of Dm for recall was hampered by the small number of recalled words, which precluded a separate analysis of ERPs for identified and unidentified words. When collapsed across these two conditions, ERPs to recalled words nonetheless showed a tendency to be more positive than ERPs to unrecalled words (Fig. 7D). At Cz, for example, the mean amplitude from 600 to 800 msec was 3.4 μV for recalled words and 2.4 μV for unrecalled words.

DISCUSSION

Isolating ERP Effects Associated with Recollection

The principal finding of this experiment was that masked words that were named correctly in the identification test elicited ERPs that differed as a function of prior exposure, and that these differences depended on the task in which the words were originally presented. Our interpretations of this ERP finding are predicated on two facts: (1) scores on the explicit memory tests were better for words from the image task, and (2) priming, defined as greater identification accuracy for words that had been studied than for words that had not been studied, did not differ between the image task and the letter task.

The recall and recognition results conformed with expectations based on the levels-of-processing literature (e.g., Craik & Tulving, 1975). The visual imagery requirements of the image task presumably engendered encoding processes that were conducive to later recollection.

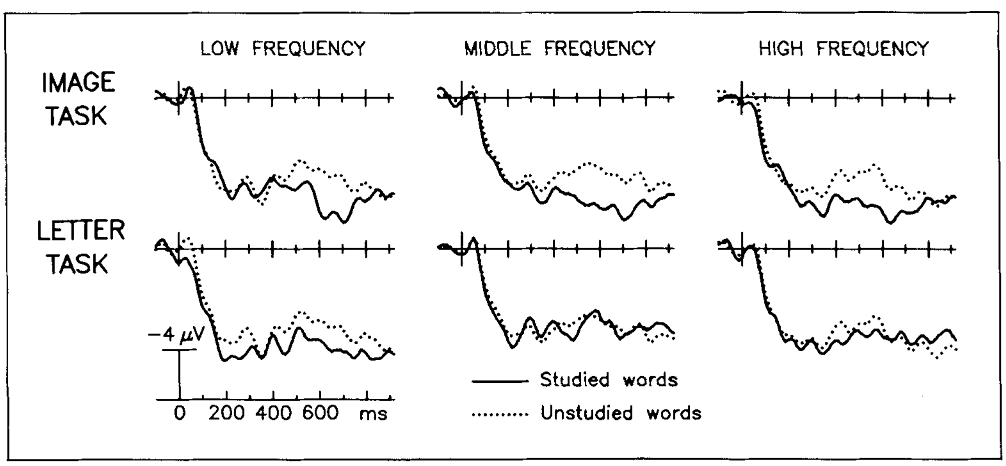


Figure 6. ERPs elicited during the test phase by identified words divided into three groups on the basis of norms for frequency of usage. ERPs are shown for the central midline electrode only.

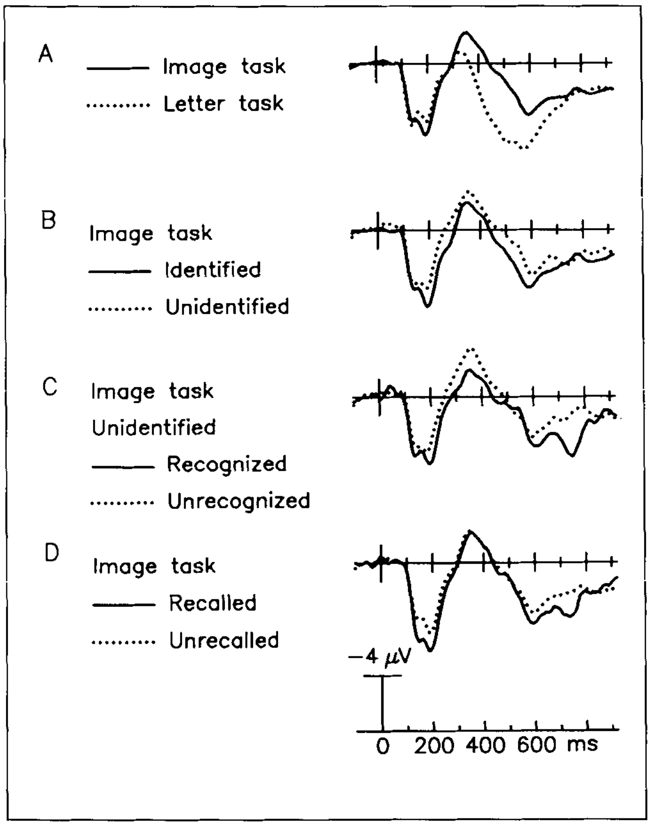


Figure 7. ERPs elicited during the study phase and averaged separately as a function of study task and later memory performance. ERPs are shown for the central midline electrode only. (A) ERPs from the two study tasks; (B) ERPs to words in the image task, averaged as a function of later identification performance; (C) ERPs to words in the image task that were not identified in the identification test, averaged as a function of later recognition performance; (D) ERPs to words in the image task, averaged as a function of later recall performance.

Despite the long retention delay for the recognition test, we assume that recognition memory would have been better for words from the image task than for words from the letter task even at the time of the identification test. Further, we postulate that subjects, while taking the identification test, consciously recollected many of the studied words, especially words from the image task. This recollection was not necessarily the result of deliberate retrieval. Anecdotal evidence from previous experiments suggests that under such conditions, subjects may notice that some words were presented previously (Paller & Mayes, 1992). This spontaneous recollection may not influence identification performance. A similar phenomenon has been shown to occur during the stem-completion test, without influencing measures of priming (Bowers & Schacter, 1990).

In any event, the design of the present experiment allowed us to compare ERPs between conditions that differed in both recollection and priming, as well as between conditions that differed in recollection but did not differ in priming. A subtraction methodology was used to yield separate assessments of ERPs associated with these processes.[1] The procedure resembles finding a solution to two algebraic equations:

$$\text{Image study effect} = R_1 + P \qquad (1)$$

$$\text{Letter study effect} = R_2 + P \qquad (2)$$

where R_1 represents recollection for words from the image task, R_2 represents recollection for words from the letter task, and P represents priming, which is the same for both tasks. The two study effects are shown by the difference waves in Figure 3. We assume that no other factors besides recollection and priming contributed to the study effects. Another difference wave can be obtained by the subtraction of Eq. (2) from Eq. (1):

$$\text{Image study effect} - \text{Letter study effect} = R_1 - R_2 \qquad (3)$$

and can be visualized as the shaded area in Figure 3. This effect takes the form of a positive deflection beginning at 250 msec at frontal locations or at 500 msec at other locations, and it has a widespread distribution across the scalp with a predominance at anterior locations and a left-greater-than-right asymmetry. We propose that this difference wave reflects the differential recollection between the two tasks, with no contribution from priming. In other words, this ERP can be considered a "recollection template"—hypothetically, this waveform would be elicited by any group of words in proportion to how much those words elicited recollection of the study episode.

By this reasoning, one can inquire about the extent to which the recollection template appears in the letter study effect. Even though the recollection template was formed by taking the difference between the image study effect and the letter study effect, two extreme answers to this question are logically possible: (1) the letter study effect includes a positive potential from 500 to 800 msec, or (2) the letter study effect does not include such a potential. Also, it should be noted that recognition scores for words from the letter study effect were above chance levels. Nevertheless, no portion of the letter study effect (Fig. 2) appears to resemble the recollection template. This outcome suggests that recollective processes may have only been minimally engaged for these words when they were presented during the identification test.

Given that recollection is defined as a subjective experience, the hypothesis that the shaded ERP difference in Figure 3 is associated with recollection cannot be readily accepted but rather should be tested in future experiments. Another possibility, for example, is that the recollection template originated not from recollection itself but from cognitive processes that occurred as a consequence of recollection or that for various reasons were correlated with recollection. Nevertheless, we offer this hypothesis as a testable alternative that may function as a guide for future research, which may support or refute its various assumptions.

Further Issues Pertaining to Priming

One criticism of the foregoing account would be to question the premise that priming did not differ between the two tasks. Indeed, there was a nonsignificant tendency for identification scores to be greater for words from the image task than for words from the letter task. Previous reports have suggested that effects of study are greater for low-frequency words in many priming tests (e.g., Jacoby & Dallas, 1981; but for an exception see Humphreys, Besner, & Quinlan, 1988). Indeed, word identification did differ as a function of frequency (Table 2), in that a post hoc analysis showed that scores for the two tasks differed significantly for low-frequency words [$F(1,11) = 10.19$, $p = 0.009$], but not for middle- [$F(1,11) = 0.00$], or high-frequency words [$F(1,11) = 1.20$]. This could either have been due to a direct influence on priming, or identification performance for some of the low-frequency words may have been influenced by recollection in the following manner. Subjects, although encouraged to guess, still did not make a response on every trial, and may have censored their responses when their confidence in identification was especially low. This tendency may have been greater for unusual or orthographically distinctive words (Hunt & Toth, 1990). Conscious recollection, however, would mitigate against this tendency to a greater extent for words from the image task.

A related counterargument against the criticism that priming differences between the two tasks tainted our results also involves word frequency. Priming scores for middle- and high-frequency words did not differ between the two tasks. And yet, the pattern of ERP effects for these two subsets of words (Fig. 6) closely matched that for the entire set of words. Indeed, it is intriguing that the letter study effect for low-frequency words, though not statistically reliable, appeared to include a component in the 500- to 800-msec latency range (which supports the foregoing account attributing the effect of task on identification of low-frequency words to recollection). In any event, the results from the frequency analysis show that the ERP effects in the two tasks were not artifacts of a subtle difference between the priming effects.

Another question remaining is whether some part of the ERP study effect reflects priming. Some early ERP differences due to prior study were evident (see Table 3), but under the measuring protocols used, most of these differences were not sufficiently reliable to warrant interpretation. Furthermore, none of these effects was maximal at posterior electrodes, as might be expected if early visual processing in the occipital lobe were responsble (cf. Squire et al., 1992; Tulving & Schacter, 1990). Perceptual priming mechanisms may have been operative here but not produced measureable ERP correlates. Alternatively, such effects could have been masked by processing related to deliberate retrieval or to other priming mechanisms. Repetition-sensitive mechanisms beyond those that contribute to word-identification priming may not be identical for the two study tasks. However, most priming effects appear to remain unchanged under similar manipulations of levels of processing (Richardson-Klavehn & Bjork, 1988). The most parsimonious outcome, therefore, would be for ERP indices of priming to be identical in the two tasks. Accordingly, the ERP difference between 400 and 500 msec is a candidate, as it preceded the recollection template and appeared in both study effects. This deflection was slightly larger over posterior than anterior locations in the letter—unstudied difference wave (Fig. 3), but the latency of this effect is longer than expected for a priming mechanism. Another speculation is that this difference reflects retrieval attempts that are necessary but not sufficient for recollection.[2] These retrieval attempts could have occurred for words from both tasks, but been far more successful for words from the image task.

ERPs and Memory Retrieval

As outlined in the Introduction, some evidence is suggestive of the notion that the processes underlying recognition can be monitored by ERPs elicited during recognition tests. In a progression from the earliest studies (e.g., Sanquist et al., 1980, Rubin & McAdam, 1972; Warren, 1980) there have been repeated demonstrations using both study-test and continuous recognition designs that ERPs to studied words are more positive than ERPs to new words. These findings of *old/new* ERP differences—in concert with parallel observations with nonverbal stimuli such as common objects (Friedman & Sutton, 1987), color patterns (Paller, Roessler, & McCarthy, 1990), and faces (Barrett, Rugg, & Perrett, 1988; Smith & Halgren, 1987)—laid the groundwork for the hypothesis that recollection processes can be indexed via ERPs.

In many recognition studies, however, recollection and the confidence of the recognition decision may have been confounded. That is, the mean confidence level for old items may not have been the same as that for new items. There is good reason to suspect that decision confidence could have influenced the ERPs, given that P3 components are larger when stimuli are more confidently detected (e.g., Hillyard, Squires, Bauer, & Lindsay, 1971; Ruchkin & Sutton, 1978). More direct evidence also exists from ERPs averaged separately according to confidence measures in a recognition paradigm (Paller, Kutas, & Mayes, unpublished findings, see Paller et al., 1987, which emphasized data from the study phase of the same experiment). Subjects viewed a series of old and new words and registered a level of confidence for each recognition decision. Greater positivity was elicited by correctly recognized old words than by unrecognized old words or new words of either category (correct rejections and false alarms), replicating results first reported by Sanquist et al. (1980). Within categories, furthermore, ERPs were more positive for words categorized with high confidence than with low confidence. By extension, any old/new ERP differences would be increased to the extent that responses to old words were made more confidently than responses to new words, which could happen often. Collecting confidence ratings could help in this regard, but the problem is not easily surmounted because subjects may use different criteria for rating confidence for old and new items.

By this reasoning, the ERP difference observed in the present experiment between the image study effect and the letter study effect may reflect higher decision confidence for words from the image task than for words from the letter task. Our design may have minimized the confounding influence of recognition confidence, as recognition was not queried at the time ERPs were recorded, but identification confidence may still be relevant. However, a likely reason why identification responses may have been more confident for words from the image task is that these words tended to be consciously remembered. This explanation then is closely tied to the interpretation given above emphasizing recollection.

Other investigators have also postulated that ERPs are sensitive to recollective processes. In one report, Smith and Halgren (1989) hypothesized that old/new ERP differences in their recognition paradigm reflected contextual retrieval (i.e., recollection), one of two processes postulated to determine recognition judgments. ERPs were elicited from epileptic patients who had undergone unilateral anterior temporal lobectomies and from control subjects during a recognition test in which a set of 10 words appeared repeatedly in a series of lists. ERP differences between repeated and unrepeated words were attenuated in the left anterior temporal lobectomy patients. Across lists, recognition accuracy increased for control subjects as well as for patients, whereas overall recognition scores were slightly lower for patients with left-hemisphere excisions. The authors speculated that these patients were impaired in their ability to take advantage of contextual retrieval and so based their judgments more on other factors (e.g., perceptual fluency).

Another study of ERPs in epileptic patients lends support to some of these conclusions (Rugg, Roberts, Potter, Pickles, & Nagy, 1991). In this study, old/new ERP effects were abnormally small in patients with anterior temporal lobectomies on either the left or the right side.[3] This finding held for words repeated with a lag of six intervening items in a continuous recognition task, but ERPs were normal in a second task in which words repeated immediately while subjects were required to detect nonwords. Performance measures from the recognition test were not abnormal in the patients, although the left lobectomy group did show a verbal memory deficit in a paired-associate learning test. These dissociations between memory performance and the ERP effects, in addition to dissociations in normal subjects (Rugg & Nagy, 1989), led Rugg and colleagues to conclude that the processes reflected by the old/new ERP differences were not causally related to the ability to make recognition judgments. Although this conclusion was made with respect to the early portion of old/new ERP differences, it is difficult in practice to perform a well-grounded separation between early and late portions of the effect (possibly identifiable with N400 and P3 components, respectively). This difficulty arises because the relative contributions of the two effects to the overall ERP difference varies with subject and task parameters, and because the two (or more) effects overlap in time. One possibility for future investigation, however, is that these overlapping effects can be isolated using study-task manipulations as in the present experiment.

In contrast to their account of early old/new ERP differences, Rugg and colleagues have argued that the later portion of these effects do, in fact, reflect processes underlying recognition judgments, but that they reflect *relative familiarity* rather than recollection. In one experiment, for example, injections of the anticholinergic agent scopolamine were found to produce a decrement in recognition performance along with an increase in the old/new ERP differences (Potter, Pickles, Roberts, & Rugg, 1992). The authors suggested that the drug had a detrimental effect on recollection that functioned to increase the extent to which recognition judgments were based on relative familiarity, as indexed by the ERP effect. Along the same lines, evidence from other experiments showed that old/new ERP differences occurred for low-frequency words but not for high-frequency words (Rugg, 1990; Rugg & Doyle, 1992). The authors proposed that a major portion of this ERP effect reflected the discrepancy between perceived familiarity and expected familiarity (cf. Jacoby & Dallas, 1981; Jacoby & Kelley, 1992; Mandler, 1980), and that this relative familiarity factor was responsible for the recognition advantage for low-frequency words. An alternative explanation for the ERP results, however, is that recognized low-frequency words tend to engage more recollection.

The ambiguity of these results might be diminished by including a manipulation that *differentially* affected recollection and priming. Such manipulations may also yield insights in related research, such as that involving ERP repetition effects for nonwords (e.g., Rugg & Nagy, 1987). As another example of this sort of manipulation, a change of presentation modality from study to test generally has robust effects on priming, but small or no effects on recall and recognition (Graf, Shimamura, & Squire, 1985; Jacoby & Dallas, 1981). To the extent that ERP repetition effects reflect priming, they might be expected to be smaller when modality was changed from study to test compared to when modality was held constant. In one experiment, however, similar ERP repetition effects were found both within and between modalities (Domalski, Smith, & Halgren, 1991). Although this design was not ideal due to possible order effects, confounding physical stimulus differences, and the lack of behavioral measures of priming, the results cast additional doubt on the relative-familiarity account of old/new ERP differences.

A different experimental procedure that purports to separate the two hypothetical components of recognition memory has recently been used to obtain results in accord with the present findings (Smith, 1992). In this modified recognition procedure (introduced by Tulving, 1985) subjects were instructed to introspect about their own subjective experiences during attempted retrieval and to rate them as to whether they were rich and included details of the learning episode ("remember") or whether they did not include such details but merely the gut-level feeling that an item was old ("know"). This procedure rests on the tenuous assumption that subjects are able to give veridical reports in this regard, but the assumption has received empirical support (e.g., Gardiner, 1988). Smith's (1992) findings were that ERPs associated with "remember" responses were more positive than ERPs associated with "know" responses, and so this ERP difference may be analogous to the recollection template derived from ERPs in the present experiment.

Previous experiments that have examined ERPs as a function of study task manipulations have generally not done so in ways that permitted the critical comparisons to be made (e.g., Bashore, Karis, Fabiani, & Donchin, cited by Donchin, 1981; Bentin & Peled, 1990; Bentin & Moscovitch, 1990; Berman, Friedman, & Cramer, 1990; Rugg, Furda, & Lorist, 1988). For example, Bentin and Moscovitch (1990) examined ERPs and priming effects in lexical decision and recognition tests while also varying the number of repetitions and the retention delay. The authors concluded that the ERP repetition effects they found reflected "processes common to both explicit and implicit tests of memory" (p. 351). The experimental manipulations used, however, did not offer a decisive means for dissociating ERP effects related to different types of memory. A manipulation that differentially influences two types of memory is needed, along with behavioral measures that confirm these influences.

In sum, the preceding discussion underscores the difficulty of mapping ERPs elicited during recognition paradigms onto the processes underlying recognition performance. Although ERPs may be sensitive to processing underlying recognition, the various decision- and response-related processes complicate this endeavor. Furthermore, it is striking that the literature includes such divergent hypotheses, ascribing similar ERP effects to (1) conscious recollection (e.g., Smith & Halgren, 1989), (2) a relative familiarity factor associated with some types of priming (Potter et al., 1992; Rugg, 1990; Rugg & Doyle, 1992), and (3) processes that do not contribute to verbal memory performance (Rugg & Nagy, 1989; Rugg et al., 1991). Clearly a more rigorous procedure for associating ERP effects differentially with recollection and priming is needed. We recommend for this purpose the use of behavioral manipulations that dissociate recollection and priming, of which our study task manipulation is but one example.

ERPs and Memory Encoding

The results from ERPs recorded during the study phase and averaged according to subsequent memory performance replicated and extended previous findings. Numerous studies have shown that ERPs can be predictive of performance on explicit memory tests (e.g., Fabiani, Karis, & Donchin, 1986; Friedman, 1990; Münte, Heinze, Scholz, & Künkel, 1988; Neville et al., 1986; Paller, McCarthy, & Wood, 1988; Sanquist et al., 1980). In general, ERPs to remembered words are more positive than ERPs to forgotten words at latencies of about 400 to 800 msec. This ERP difference (Dm) has been found for recall tests as well as for recognition tests. Evidence of these effects in the present experiment for words studied in the image task is consistent with previous evidence showing Dm in association with semantic but not nonsemantic study tasks (Paller et al., 1987). In one study that included both implicit and explicit memory tests, ERPs differed as a function of later recall, but ERPs did not differ as a function of later stem completion (Paller, 1990). This could suggest that Dm reflects processing that is more important for recollection than for priming (e.g., elaborative processing). The present results from study phase ERPs averaged as a function of later memory replicated this pattern of results; ERPs were predictive of later recall and recognition but did not differ as a function of later word identification. In both studies, however, the priming effects were smaller than the recall and recognition effects when compared to their respective baselines (i.e., estimates of the contribution of guessing). This last observation is inconclusive, but it suggests the possibility that the absence of a significant Dm for priming stems from less sensitivity. Nevertheless, the present pattern of results with word identification adds to the prior evidence from stem completion (Paller, 1990) in supporting the generalization that ERPs tend to be predictive of later performance on explicit memory tests but not implicit memory tests.

Relationships to Established ERP Components

It is of interest to question whether any of our experimental effects can be identified with previously studied ERP components. If any effects can be viewed as specific modulations of one or more known ERP components, it might be possible to derive insights from what is known about these components to interpret the present results. This endeavor, however, is limited by the difficulty of rigorously identifying an ERP component across experimental paradigms that differ in the cognitive operations they engender. Moreover, these components may occur in overlapping latency intervals such that identifying them across different paradigms is an ill-founded problem. Whereas it is reasonable to suppose that P3 and N400 components were elicited by words in the present paradigm, it is difficult to know whether the ERP effects across experimental conditions were due to modulations of particular components without relying on additional manipulations known to effect those components. In the absence of such manipulations, this endeavor is highly speculative (see Bentin & Peled, 1990; Besson, Kutas, & Van Petten, 1992; Friedman, 1990; Paller et al., 1987; Rugg et al., 1988; Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991). Nevertheless, we hold that useful conclusions can be drawn from the present results even though the component identification problem prevents us from knowing the extent to which our effects arose from the modulation of ERP components that have been previously studied.

SUMMARY

A study task manipulation was used to dissociate effects of recollection from effects of priming. We hypothesized that ERPs elicited during the word-identification test were sensitive to recollective processes, and that the difference between the respective old/new ERP differences from the two study tasks (shown as the shaded region in Fig. 3) describes the ERP correlate of recollection in this experiment. The suggestion that subjects engaged in recollection during a test in which they were instructed only to attempt to read tachistoscopically presented words can only be based on indirect evidence. Similarly, Squire et al. (1992) hypothesized that in the "priming" condition of their experiment, subjects became aware of the fact that some stems corresponded to previously studied words, and that this awareness was associated with increased blood flow in the hippocampus. The present experiment provided a way to monitor this phenomenon with high temporal resolution. It would be premature to speculate whether the ERPs interpreted as indications of recollection are related to the ERP differences based on later memory performance that were recorded during the study phase. However, the results do show that ERPs are sensitive to the hypothetical processes underlying human memory, both at acquisition and at retrieval, and as such this electrophysiological evidence supplements other evidence derived from behavioral measures to show that recollection and priming reflect different ways in which the brain makes use of learned information.

METHODS

Subjects

A group of 12 native English-speaking adults (six men and six women) aged 19–29 years (mean = 22) were run in a single experimental session. Each subject completed the Edinburgh Inventory to determine hand preferences for various activities (Oldfield, 1975). Scores ranged from 0.60 to 1.00 (mean = 0.85) on a scale from −1.00 to 1.00 where 1.00 is the maximum score for right handedness. Thus, all subjects were strongly right-handed, and nine subjects indicated that all of the members of their immediate family were right-handed.

Stimuli

A group of 480 concrete nouns were selected as critical words. Each critical word contained 5–8 letters, including no more than two *E*s. These words were classified according to frequency of usage (using the norms of Francis and Kučera, 1982) into the following three groups (with the number of words in each group shown in parentheses): *low* = frequency less than 7 occurrences/million (183), *middle* = frequency between 7 and 24 occurrences/million (146), and *high* = frequency greater than 24 occurrences/million (151). The critical words were also categorized on the basis of length into the following three groups: five-letter words (201), six-letter words (151), and seven- and eight-letter words (128). Another 296 words were selected for use as fillers in the identification test, foils in the recognition test, and practice words.

Words were presented in upper case letters (vertical visual angle = 0.6°) in the center of a monitor within a white rectangular frame (4.2° by 1.2°). Proportional spacing was used. During the study phase, the presentation rate was one word every 1500 msec and the stimulus duration was 300 msec. The white rectangle appeared 3 sec prior to the first word in each list. After the final word in each list, the word "relax" was presented in lower-case blue letters for 6 sec, and then the screen was blanked. In the letter study task, on average, 56 words contained 1 *E*, 10 words contained 2 *E*s, and 54 words contained no *E*s. In the image study task, on average, 63 words represented small objects and 57 words represented large objects, based on size judgments made by the experimenter.

The mask stimulus used during the test phase was constructed to resemble a collage of letter-parts randomly arranged within the rectangular frame. The presentation rate during the test phase was controlled by the experimenter, who waited for EEG artifacts to abate before presenting each item. First the white rectangle appeared for 1500 msec, followed by the mask, which appeared for 50 msec. Next, a word appeared for either 33 or 50 msec followed immediately by the mask, which persisted for 1000 msec, when the screen was blanked.

The recognition test form was constructed by intermixing 240 studied words with 240 foils that had not been presented in any other phase of the experiment. The order of words from the study lists was maintained except that words from the two study tasks were intermixed. These 480 words were printed in 11 columns on a single sheet of paper.

General Procedure

Subjects were tested individually and all were naive to the experimental objectives. Subjects were told that the goals of the experiment were to measure their brain activity while they read words and created visual images in their mind. This subterfuge served to disguise the incidental learning procedure.

The subject was first led into a sound-attenuating chamber to determine stimulus parameters for the identification test. The subject sat in a comfortable chair at a viewing distance of 100 cm from the video monitor. A list of 28 words that were not presented in any other phase of the experiment was used. These words were presented under masking conditions as described above (except that 100 msec was the initial stimulus onset asynchrony or SOA, the time from the onset of the word until the onset of the mask). The experimenter manipulated the SOA and the intensity of the mask and of the word to determine which parameters would most likely yield threshold-level identification performance. An SOA setting for the word and intensity levels for the word and for the mask (high or low) were ultimately selected. These parameters were later altered for six subjects during the initial portion of the experiment to avoid ceiling and floor effects. The final SOA setting was 33 msec for half of the subjects and 50 msec for the other half.

Next, an electrode cap and additional electrodes (as described below) were positioned. To increase the signal-to-noise ratio of the recordings, subjects were instructed to minimize muscle tension, eye movements, and blinking. Also, a period of guided relaxation was included, and additional relaxation periods were interposed when necessary.

Next, subjects were introduced to the two study tasks and practiced each task with a separate list of 9 words that were not shown in any other phase of the experiment. For each task, a card was provided to show how the two response choices mapped onto the left and right buttons. In the *image study task*, subjects decided whether each object was smaller or larger than the video monitor on which the words were presented (left=smaller, right=larger). Subjects were instructed to visualize each object in its typical size and to imagine whether it would fit within the space occupied by the monitor. Responses were later scored as correct if they agreed with judgments made by the experimenter. In the *letter study task*, subjects decided whether each word contained 1, 2, or no *E*s (left=1, right=0 or 2). Subjects were instructed to read each word silently and to visualize the letters of each word in order to make their decision.

The experiment included four study-test blocks separated by short breaks, and required a total time of 93 min. In each block, 30 words were studied with the image task and another 30 words were studied with the letter task. The order of tasks was switched for each new block and the initial order of tasks was counterbalanced across subjects. The mean time required for the study phase was about 3 min. Across the four blocks, a total of 120 words were studied in each task. However, the particular words used as study words were counterbalanced across subjects such that each word occurred equally often as a study word and as an unstudied word, and furthermore, each word occurred equally often in the image task and in the letter task.

Within 30 sec of the end of the study phase, the test phase began. In the identification test, 60 unstudied words were mixed with 60 words that had just been studied. Words from the image study list alternated with words from the letter study list. Furthermore, a pseudorandom order was used such that words in the first half of the study lists occurred in the first half of the test phase. All subjects were shown the same words in the same order in lists of 60. Each list began with a filler word. Subjects were encouraged to guess in this test, as they were advised that people sometimes see a word without realizing that they saw it. Thus, subjects were asked to give as a response any word that happened to come to mind, or to say "I don't know" if no word came to mind. Subjects were also advised that some of the words in the test would be the same as words shown earlier, but that their task was simply to read what they saw and to make their response immediately when the screen went blank (i.e., 1000 msec after word onset). Responses were delayed in this manner to minimize speech-related artifacts in the recordings. The experimenter monitored the subject's verbal responses (which were amplified via a microphone suspended from the ceiling of the chamber) and scored each response using a printed sheet that listed each word. The mean time required for the test phase was 16 min.

Two explicit memory tests were administered after the fourth block. For the free recall test, the subject was given a blank sheet of paper and a pen and asked to produce words from either of the two study tasks. The mean time for the free recall test was 10 min. In the subsequent recognition test, the subject was given the appropriate form and a highlighter and instructed to mark each word that had been presented in the study phase. The mean time for the recognition test was 11 min.

Electrophysiological Recordings

Tin electrodes embedded in an elastic cap were used to make recordings from 13 scalp locations of the International 10–20 System (Jasper, 1958): namely, the midline frontal (Fz), central (Cz), and parietal (Pz) sites and lateral pairs at frontal (F3/F4), central (C3/C4), parietal (P3/P4), posterior temporal (T5/T6), and occipital (O1/O2) sites. An electrode over the mastoid process was used as the reference (the right side for half of the subjects and the left side for the remaining subjects). The reference for all subjects was later changed to the numerical average of left and right mastoid recordings (by subtracting one-half of the ERP recorded between the two mastoids from each ERP). Recordings between electrodes placed lateral to each eye monitored horizontal eye movements. Recordings between an electrode below the right eye and the reference monitored vertical eye movements and blinks. These electrooculographic recordings were used to eliminate artifactually contaminated trials, which amounted to roughly 12% of the total number of trials.

The electrical activity, amplified with a bandpass of 0.1–100 Hz, was digitized at a rate of 4 msec/sample and written to magnetic tape. ERPs were computed for epochs extending from 100 msec before word onset to 924 msec after word onset. Mean amplitude measurements were made over designated latency ranges relative to the baseline amplitude during the 100 msec prior to word onset. These measurements were submitted to repeated-measures ANOVAs, with Geisser–Greenhouse corrections applied. The Tukey Test was used for all post hoc comparisons.

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Notes

1. This procedure can be conceived of as a variation of the subtraction methodology advocated by Jacoby and Kelley (1992), with the following differences. (1) Their procedure attempts to disentangle recollection and familiarity, two independent bases for making recognition judgments, by using a testing condition in which the two bases are put into opposition. In the present procedure, the study effects are thought to derive from a recollection factor and a priming factor, which apply to additive ERP effects, not recognition probabilities. (2) The factors are not put into opposition because our interest is in measuring the underlying neural processes, not just the behavioral responses. The opposition manipulation does not change recollection itself; it changes which behavioral response follows recollection. (3) Familiarity, in the formulation advocated by Jacoby and Kelley, is regarded as an automatic attribution resulting from cues such as fluent processing. Similarly, recollection can be seen as a construction based on inferences. We agree with the gist of this view but prefer to use the term *priming* in our equations rather than the term *familiarity*. Amnesic patients can demonstrate normal priming effects for material that fails to evoke the subjective experience of familiarity, and further, they appear to be able to use fluency to make normal attributions in other realms (Paller et al., 1991). Thus, familiarity is not a necessary consequence of fluency alone.

2. We thank Michael Smith for suggesting this alternative.

3. The reason why Smith and Halgren (1989) found differences only in their right lobectomy group but Rugg et al. (1991) found differences in both right and left lobectomy groups is unclear, but it could reflect differences between the studies in subject selection or in task parameters.

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Erratum: This is a reprint of figure 2 from Marcia K. Johnson's article, "MEM: Mechanisms of Recollection", that appeared in the *Journal of Cognitive Neuroscience*, 4:3. Because of a printing error the shaded cones did not reproduce. Here is the corrected version.

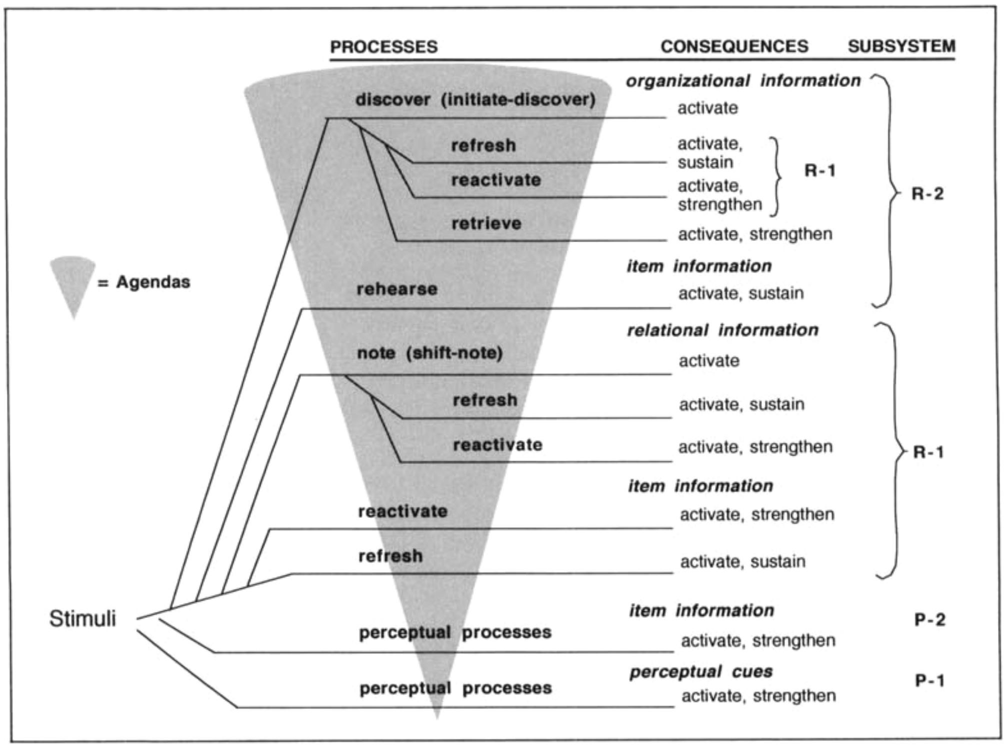

Figure 2. Schematic representation of reflective component processes in MEM and their consequences. Agendas (shaded cone) recruit processes that activate, sustain, and strengthen both item and relational information.