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Recall and Stem-Completion Priming Have Different Electrophysiological Correlates and Are Modified Differentially by Directed Forgetting

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The notion that different aspects of memory are assessed by explicit and implicit memory tests was supported by behavioral and electrophysiological results. In a study-test procedure, 24 subjects were instructed to remember some words and to forget other words. Free recall and cued recall were better for words associated with the remember instruction, whereas directed forgetting did not influence stem completion (an implicit memory test). Event-related brain potentials elicited during study differed as a function of subsequent memory performance for free recall and cued recall, but not for stem completion. These results implicate encoding differences in the distinction between the 2 types of memory test. Factors governing whether explicit retrieval affects performance on an implicit memory test, mechanisms that may underlie directed-forgetting effects, and the importance of electrophysiological correlates of memory are also discussed.

New hopes for progress in understanding the conscious recollection of prior events have sprung from the recent experimental use of memory tests that do not refer to prior learning episodes. Comparisons of these implicit memory tests and traditional recall or recognition tests have demonstrated several robust dissociations between the two types of test[1] (see reviews by Richardson-Klavehn & Bjork, 1988; Schacter, 1987). Demonstrations that the performance of amnesic patients on explicit memory tests can be severely impaired while performance on implicit memory tests is intact have become particularly important for understanding the organization of memory (Shimamura, 1986). Amnesics studied by Graf, Squire, and Mandler (1984), for example, exhibited impaired scores on a cued-recall test but normal scores on a stem-completion priming test. These two tests differed only in the instructions given. In both tests, subjects were shown three-letter stems, such as MOT___. In the priming test, subjects were told to complete each stem with the first word to come to mind; in the cued-recall test, subjects were told to use the stems to aid their attempts at recall. The stem-completion priming test directs subjects away from the memory aspects of the test, but performance is strongly influenced by recent presentation of possible completions (Graf & Mandler, 1984; Graf, Mandler, & Haden, 1982). Spared memory in amnesia also has been demonstrated with other priming tests, including homophone spelling (Jacoby & Witherspoon, 1982), perceptual identification of briefly flashed words (Cermak, Talbot, Chandler, & Wolbarst, 1985), perceptual identification of degraded words (Warrington & Weiskrantz, 1970), naming category exemplars (Gardner, Boller, Moreines, & Butters, 1973; Graf, Shimamura, & Squire, 1985), word association (Schacter, 1985; Shimamura & Squire, 1984), lexical decision (Moscovitch, 1984), and affective preferences (M. K. Johnson, Kim, & Risse, 1985). Although priming effects found in these different tests are often lumped together, this must be done with caution because differences among tests may prove to be important.

In normal subjects, one factor that, like amnesia, influences performance in explicit memory tests but does not influence priming is the level of processing during encoding. Priming measures in several different tests were not higher for semantically processed words than for phonemically or orthographically processed words (e.g., Carroll, Byrne, & Kirsner, 1985; Graf & Mandler, 1984; Graf et al., 1982; Jacoby & Dallas, 1981). Similarly, priming levels were not changed by manipulations of elaborative processing during acquisition (Graf & Schacter, 1985; Schacter & Graf, 1986), of intention to learn (Greene, 1986), or of rehearsal duration (Greene, 1986; Jacoby & Dallas, 1981; Seamon, Marsh, & Brody, 1984). On the other hand, all of these encoding manipulations had robust effects on recall and recognition.

Two types of theoretical positions have been advanced to account for these empirical dissociations between different

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[1] The terms *explicit* and *implicit* are used to refer to the two types of memory test and not to theoretical forms of memory (e.g., *declarative* and *nondeclarative* memory). The objection to using an identical term to refer to both a type of test and a type of memory (Richardson-Klavehn & Bjork, 1988) is thus avoided.

memory tests. Many theories invoke multiple memory systems that store different types of information. The fact that amnesia can be limited to specific types of memory implies that certain critical brain areas are necessary for that type of memory, whereas these brain areas are not needed for other types of memory. At the same time, the evidence does not imply that different types of memory are *mutually* independent. Several different formulations for characterizing distinctions between memory systems have been given (e.g., Cohen & Squire, 1980; Graf & Schacter, 1985; Halgren, 1984; Mishkin, 1982; O'Keefe & Nadel, 1978; Tulving, 1987; Warrington & Weiskrantz, 1982). The procedural–declarative distinction used by Squire and Cohen (1984) has been adopted by many authors. *Declarative memory* refers to memory for facts and episodes subject to conscious recollection. As an alternative to the term *procedural memory*, I use the term *nondeclarative memory* to subsume various phenomena that are grouped together primarily by exclusion. These nondeclarative phenomena include motor skills, cognitive skills, simple classical conditioning, perceptual aftereffects, immediate memory, and priming. Declarative memory abilities apply to many realms of information and so may be implemented through interactions between processing in brain areas specialized to analyze a particular sort of information and processing in the brain areas critical for declarative memory. The declarative system is thus thought to be superimposed on other processing systems rather than being independent of them.

Theories of multiple memory systems can be contrasted with views that instead emphasize a unitary memory system (e.g., Craik, 1983; Jacoby, 1983a; Kolers & Roediger, 1984). In particular, Jacoby (1983a, 1984) hypothesized that different aspects of the same episodic memories are relied on in both explicit memory tests and implicit memory tests. Jacoby (1984) argued against postulating separate memory stores and instead used a distinction between incidental and intentional retrieval. According to this view, differences between explicit and implicit tests arise from differing retrieval strategies called into play by the information provided by the test. Other authors have also emphasized retrieval processes rather than separate memory systems (e.g., Ratcliff & McKoon, 1988; Roediger, Weldon, & Challis, 1989).

Unitary memory theories tend to marshal support from experimental manipulations that affect performance on the two types of test in the same way. The effects of repetition on perceptual identification and stem completion, for example, parallel those on recognition (Feustel, Shiffrin, & Salasoo, 1983; Graf & Mandler, 1984; Jacoby & Dallas, 1981). Other factors leading to parallel effects include context during learning (Graf & Schacter, 1985, 1987; MacLeod, 1989b; Schacter & Graf, 1986), the focus of selective attention in dichotic listening paradigms (Eich, 1984; Seamon, Brody, & Kauff, 1983), and directed forgetting (MacLeod, 1989a).

Adding an evolutionary perspective on the problem, Sherry and Schacter (1987) suggested that hypothetical memory systems can be justified convincingly if the systems are shown to be unique in the functional properties each contributes. Nevertheless, they concluded that "there are no entirely satisfactory criteria for determining whether experimentally observed dissociations among memory tasks support a distinction between memory systems or should be interpreted as evidence for different processes within the same system" (Sherry & Schacter, 1987, p. 449). Additional perspectives on this problem could also be useful. Analyses of electrical activity recorded from the brain, for example, could lead to a way to monitor directly the processes in question rather than relying on behavioral measures obtained later.

MacLeod (1989a) recently elaborated on the contrast between dissociating and parallel effects by hypothesizing that whereas encoding manipulations influence performance in explicit memory tests but not in implicit memory tests, "retrieval manipulations may affect the two classes of memory tests similarly" (p. 14). Supporting evidence was obtained by comparing directed-forgetting effects in two explicit memory tests (recall and recognition) and two implicit memory tests (fragment completion and lexical-decision priming). Each word was presented with either an instruction to remember or an instruction to forget. In all four tests, better memory scores were found for words associated with the remember instruction than for words associated with the forget instruction. However, whether these effects were truly parallel is unclear, given the small magnitude of the effects on the implicit memory tests and the difficulty of comparing different response measures. The particular tests used did not allow a straightforward comparison between the magnitude of directed-forgetting effects in implicit memory tests and that in explicit memory tests. A more suitable pair of tests for answering this question would be the cued-recall test and the stem-completion priming test because identical test forms can be used and the overall levels of performance are similar. In the present experiment, directed-forgetting effects were examined using these two tests, and furthermore, modifications were added to make the priming test less subject to contamination from explicit retrieval, as discussed later.

A further procedural change—supplementing the behavioral evidence with neurophysiological evidence from brain potentials (for reviews, see Hillyard & Kutas, 1983; Kutas, 1988)—has been added in an attempt to enrich the evidence that might constrain theories about the processes underlying memory performance. Event-related potentials (ERPs) reflect electrical activity from within the brain and can be recorded noninvasively from electrodes on the scalp. Signal-averaging techniques applied to the electroencephalogram reveal that electrical changes are correlated with sensory, cognitive, and motor events. The visual presentation of a stimulus, such as a word, evokes a series of ERP deflections related to the sensory processing of the stimulus, as well as ERPs that are strongly influenced by manipulations of psychological variables. Previous studies have demonstrated that the ERP elicited by a stimulus can be predictive of later recall or recognition of that stimulus (Fabiani, Karis, & Donchin, 1985, 1986; Friedman, & Sutton, 1987; R. Johnson, Pfefferbaum, & Kopell, 1985; Karis, Fabiani, & Donchin, 1984; Münte, Heinze, Scholz, & Künkel, 1988; Neville, Kutas, Chesney, & Schmidt, 1986; Paller, Kutas, & Mayes, 1987; Paller, McCarthy, & Wood, 1988b; Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980). In general, ERPs to stimuli that were remembered later were more positive than ERPs to stimuli that were not remembered later, especially 400–800 ms after the onset of the stimulus. These ERP differences related to subsequent memory performance were found using several experimental paradigms; such effects are labeled *Dm* because they are ERP differences based on memory. Results from a levels-of-processing manipulation (Paller, Kutas, & Mayes, 1987) suggested that semantic processing was important for the recognition Dm elicited in that experiment, although the effect could not be explained simply by a contrast between words processed at a semantic level and words processed at a nonsemantic level.

ERP analyses were used in this study to determine whether the two types of memory test differ in their association with Dm. To obtain an adequate signal-to-noise ratio for these measures, the comparisons between memory tests were made in separate groups of subjects. A third test, free recall, was used in both groups. A strong interpretation of the view that retrieval strategies account entirely for the differences between performance on explicit and implicit memory tests would predict that Dm should not differ between the two tests. On the other hand, if Dm for cued recall differed from Dm for priming, this finding would suggest that differences in processing at the time of encoding contribute to the distinction between the two memory tests.

Method

Subjects

A group of 24 right-handed adults (10 men and 14 women) between 18 and 35 years of age (mean age = 25 years) participated in the experimental session. Subjects were randomly assigned to either the cued-recall group ($n = 12$) or the priming group ($n = 12$). All subjects stated that English was their native language.

Procedure

Subjects were tested individually and did not know the experimental objectives. After electrodes were attached (see later text), each subject reclined on a bed and faced the monitor, which was on a table over the bed. Subjects were instructed on limiting artifacts derived from head movements, muscle tension, eye movements, and blinks. These behavioral requirements, especially refraining from blinking, constituted secondary tasks. Relaxation periods were interposed when necessary.

Subjects were assigned two primary tasks to perform while words were presented, (a) to remember some words and forget others, and (b) to detect occasional target words. Subjects were informed that words would be shown either in red letters or in green letters. Half of the subjects were told that later, their memory for the red words would be tested in a recall test and that a monetary reward could be earned for scoring well. Therefore, they were advised to pay special attention to the red words, to try to memorize each one when shown, and to forget the green words. In a parallel fashion, the other subjects were instructed to remember the green words and to forget the red words.

The target-detection task was assigned to require a semantic analysis of each word, regardless of its color. Subjects were asked to press a button each time a word from the target category, color names, was presented. The six target words were listed, and subjects were informed that these were the only color names that would be used.

Five lists of words were presented, which required a total time of approximately 15 min, including breaks between lists. After the final list, subjects were asked to count backward by threes for 1 min, to interfere with rehearsal. Within 2 min after the fifth list ended, each subject was given either the cued-recall test or the priming test, after which the free-recall test was given. The mean time for the cued-recall test was 18 min. The mean time for the priming test was 8 min. The mean time for the free-recall test was 17 min.

For the cued-recall test, subjects were informed that each stem on the test form began one of the words they might have seen on the screen, either in red or in green. Subjects were instructed to use each stem as a clue for verbally recalling a word, but if a word could not be recalled after 5 s, they were to skip to the next stem. Responses were monitored by the experimenter.

For the priming test, subjects were given the same test form but different instructions. Subjects were told that they would next work on a word puzzle and that the recall test would be given later. Subjects were told that each stem could be used to begin several different English words. The task was to add any number of letters to the end of each stem to make a word (avoiding proper names) and to say this word aloud. Instructions stressed that "the first word to come to mind" should be used and that the task should be completed as quickly as possible. Responses, which were given at rates as fast as several completions per second, were monitored by the experimenter.

The baseline score for these two tests was estimated in two ways. The priming tests were given to 12 subjects who did not previously view the critical words. The mean percentage of critical words completed was 9%. In addition, comparable word lists had been used previously (Paller, Kutas, Shimamura, & Squire, 1987; Paller, McCarthy, & Wood, 1988a), and in these experiments the chance likelihood of completing a stem with a critical word was estimated to be 11%.

For the free-recall test, subjects were given a blank sheet of paper and a pencil. A monetary reward was promised for the subject who recalled the most words, including words that had been shown in red and words that had been shown in green.

Stimuli

The 210 critical words (listed in the Appendix) were selected according to four criteria. First, the initial three letters of each word (the stem) began at least 5 different words. Second, each stem differed from that associated with every other word presented to the subject. Third, each word was a relatively concrete noun. And fourth, each word contained from four to nine letters. The critical words were randomly organized into five lists. At the beginning and end of each list, 2 filler words were added to minimize the influence of primacy and recency effects on the learning of critical words. Also, 3 target words were interspersed into each list. The target words were *red*, *blue*, *violet*, *yellow*, *orange*, and *pink*. Thus, a total of 245 words were presented in the same order to each subject.

Words were presented in the center of a high-resolution color monitor at the rate of one word every 1,500 ms. Stimulus duration was 200 ms. The letters of each word (0.5° by 0.8°) were shown in either red or green on a white rectangle (11.4° by 1.5°) surrounded by black. A pseudorandom sequence was used to assign a color to each critical word, with the constraint that four words in the same color never occurred consecutively. The color assignments were reversed for half of the subjects, such that each word was shown in red to 12 subjects and in green to the other 12 subjects. From each of these groups of 12 subjects, 6 subjects were instructed to remember the red words, and 6 subjects were instructed to remember the green words, as described earlier. Filler words were all shown in the color associated with the remember instruction. Nine target words were also shown in this color, and the other six target words were shown in the other color.

The test forms, which were identical for the cued-recall test and the priming test, consisted of a list of stems followed by blanks (e.g., MOT____). One stem was taken from each of the 210 critical words, and stems were arranged in centered columns on 10 sheets of paper. Two random orders were used.

ERP Recordings

Recordings were made with an electrocap system from 12 scalp locations of the International 10–20 System: Fz, Cz, Pz, Oz, O1, O2, P3, P4, T3, T4, T5, and T6 (Jasper, 1958). Fz, Cz, Pz, and Oz sites designate locations spaced along the midline between nasion and inion skull landmarks over frontal, central, parietal, and occipital areas, respectively; odd-numbered sites are on the left side; even-numbered sites are on the right side. The electroencephalogram was recorded with a bandpass of 0.1–100 Hz from each electrode referred to an electrode on the mastoid process (the right side for half of the subjects and the left side for the remaining subjects). Horizontal and vertical electrooculograms were recorded with electrodes lateral to each eye and above and below the right eye. The root mean square voltage of the electrooculograms was computed for the epoch associated with each word and was used to eliminate trials contaminated by ocular artifacts. For critical words, an average of 12% of the trials were thus eliminated, although the behavioral results reported are for all trials. Electrode impedances were maintained below 5 KΩ.

Data were digitized at a rate of 4 ms per sample and written to tape. ERPs were computed for epochs extending from 100 ms before word onset to 924 ms after word onset. For critical words, the chief criteria for averaging trials were the instructions (remember or forget) and later memory performance on each of the three tests. ERPs were measured over three consecutive latency ranges for mean amplitude measurements (200–400, 400–600, and 600–800 ms) and over various other latency ranges for peak amplitude and latency measurements. Topographic maps were computed by two-dimensional linear interpolation.

Results

Behavior

Memory scores for each of the three tests were computed separately for critical words associated with the remember instruction (R words) and for critical words associated with the forget instruction (F words) and are shown in Figure 1. In the free-recall test, performance was significantly better for R words than for F words, $F(1, 23) = 33.70$, $MS_e = 29.92$, $p < .0001$. In the cued-recall test, performance was also significantly better for R words than for F words, $F(1, 23) = 13.92$, $MS_e = 23.98$, $p < .0033$. In contrast, performance in the priming test for R words was not different from that for F words, $F(1, 23) = 0.01$, $MS_e = 36.95$. In fact, the mean scores for the two types of words were nearly identical, and the individual scores were greater for R words for 6 subjects and greater for F words for the other 6 subjects.

In support of this contrast between cued recall and priming, the 2 × 2 analysis of variance (ANOVA; cued recall or priming by R words or F words) showed a significant interaction term, $F(1, 11) = 5.53$, $MS_e = 32.18$, $p < .0384$. Note that the tests also differed in the extent to which critical words were produced by chance. The baseline performance level for the priming test was about 10%, whereas subjects often failed to

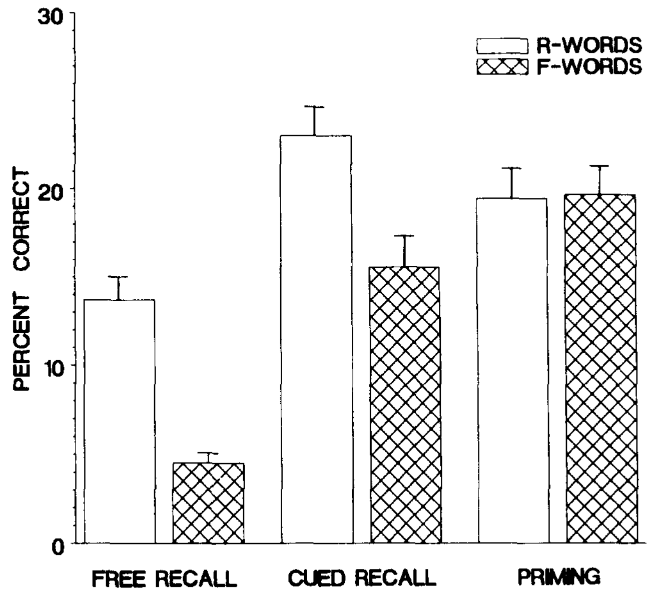

Figure 1. Mean scores (with standard errors) on each of the three memory tests for words associated with the remember instruction (R-WORDS) and for words associated with the forget instruction (F-WORDS).

respond to stems in the cued-recall test, so the baseline would be substantially lower. More guessing in the cued-recall test presumably would have raised scores equally for R words and F words and, for the associated ERPs, decreased the signal-to-noise ratio.

Performance in the free-recall test did not differ significantly between the group tested on cued recall (9.6% correct) and the group tested on priming (8.7% correct), $F(1, 11) = 0.56$, $MS_e = 8.91$. Similarly, free-recall performance did not differ between the group told to remember the red words and the group told to remember the green words (8.5% correct vs. 9.8% correct, respectively), $F(1, 11) = 0.69$, $MS_e = 14.97$. These last two groups also did not differ in their cued-recall scores (21.0% vs. 17.5%), $F(1, 5) = 1.38$, $MS_e = 26.56$, or in their priming scores (19.3% vs. 19.8%), $F(1, 5) = 0.08$, $MS_e = 11.22$.

As expected, performance in the free-recall test was biased according to behavioral responses in the prior memory test. For critical words that were remembered in the cued-recall test, free-recall performance was higher than it was for critical words that were forgotten (31.5% vs. 4.7%), $F(1, 11) = 65.93$, $MS_e = 65.16$, $p < .0001$. Similarly, critical words that were given as completions in the priming test were recalled more often than were critical words not given as completions (17.6% vs. 6.3%), $F(1, 11) = 12.04$, $MS_e = 62.76$, $p < .0052$.

For the target-detection task, subjects responded to 91% of the target words ($SE = 2$). The mean reaction time for target detection was 727 ms ($SE = 18$).

ERPs

ERPs elicited by words included two early deflections, a negative deflection at a latency of about 100 ms and a positive deflection at a latency of about 160 ms. For the remainder of the recording epoch, the waveforms were positive relative to the baseline, and for most of this period, the ERPs elicited by target words were more positive than the ERPs elicited by critical words. Figure 2 shows ERPs recorded from the Pz electrode averaged across subjects for these two conditions. Target words elicited enhanced positivity at all electrodes, but the highest amplitude was reached at Pz.

The electrophysiological effects of greatest interest involve ERPs to critical words averaged on the basis of subsequent memory performance. With respect to free recall, for example, ERPs to recalled words were more positive than ERPs to unrecalled words. This difference, Dm for free recall, was most apparent between 200 and 800 ms after word onset, as shown at the top of Figure 3. The difference was evident at all electrode locations, although to a lesser extent at the temporal locations. Along the midline, Dm for free recall (measured as a mean amplitude between 200 and 800 ms) averaged 2.7 μV at Fz, 3.8 μV at Cz, 3.4 μV at Pz, and 1.5 μV at Oz.

To assess the statistical significance of the ERP differences, mean amplitude measurements from three latency ranges were used. For the Pz electrode, these measurements are shown in Table 1. The statistical results from a one-way ANOVA on Pz measurements and from a two-way ANOVA on measurements from all midline electrodes are shown in Table 2. ERPs differed significantly as a function of later free-recall performance in the first two latency ranges. Dm for free recall in subjects given the cued-recall test was similar to that in subjects given the priming test (e.g., at Pz the mean amplitude between 200 and 800 ms averaged 3.5 μV for the former group and 3.3 μV for the latter group).

ERP differences based on later performance in the cued-recall test were similar to those for free recall (Figure 3, middle panel). ERPs to remembered words were generally positive relative to ERPs to forgotten words. Dm for cued recall was smaller and later than Dm for free recall. The differences associated with cued-recall performance (as measured between 200 and 800 ms) averaged 2.5 μV at Fz, 2.4 μV at Cz, 1.5 μV at Pz, and 0.2 μV at Oz. Measurements were significantly different for the 400- to 600-ms latency range, as shown in Tables 1 and 2. At Pz, the difference began at about 300 ms and ended at about 750 ms.

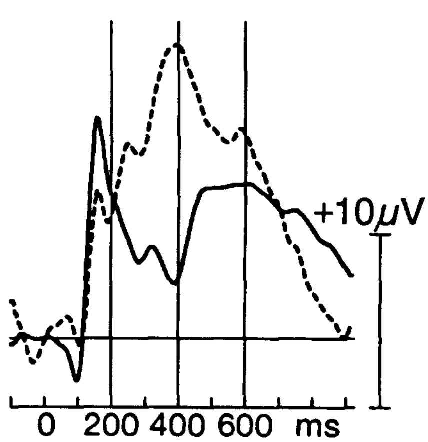

Figure 2. The event-related potential elicited from the Pz electrode by critical words (solid trace) and by detected target words (dashed trace).

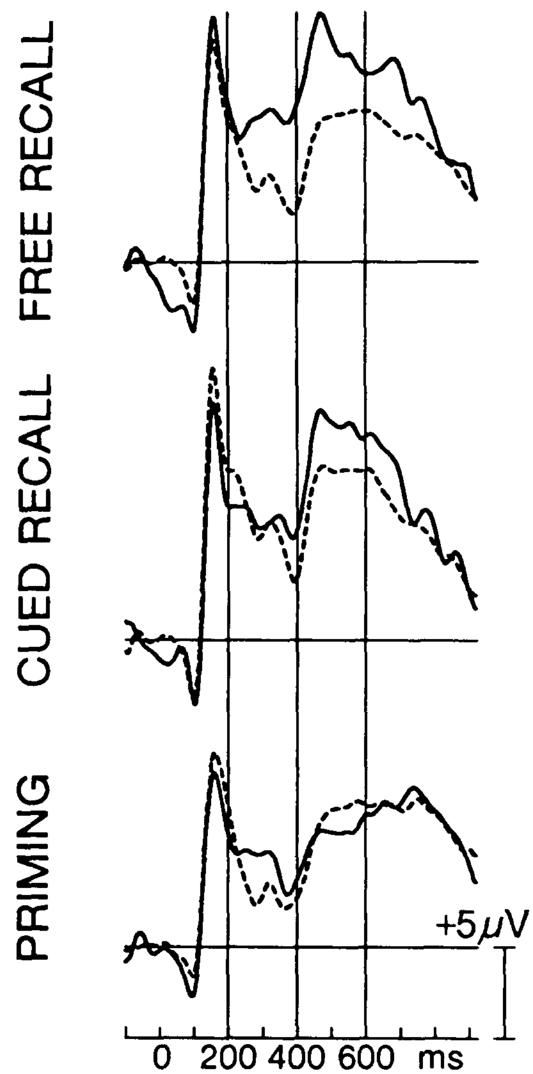

Figure 3. Event-related potentials elicited from the Pz electrode by critical words, averaged on the basis of performance on subsequent memory tests. (Solid traces show ERPs to critical words later recalled [for free recall] and critical words later given as a response to the corresponding stem [for cued recall and stem-completion priming]; dashed traces show ERPs to critical words not produced in the corresponding memory test.)

ERP differences based on later performance in the priming test were relatively small (Figure 3, bottom panel). There was a tendency for ERPs to words given as completions to be more positive than words not given as completions between 250 and 450 ms; a trend in the opposite polarity was apparent over the interval from 450 to 650 ms. Measurements made over consecutive 200-ms intervals failed to reveal any significant differences (see Tables 1 and 2).

ERPs were also analyzed separately for R words and F words. In general, R words elicited greater positivity from 250 to 600 ms, and F words elicited greater positivity from 600 ms to the end of the epoch. ERP differences based on later

Table 1
Event-Related Potential Measurements in μV

Condition	200–400 ms	400–600 ms	600–800 ms
Free recall			
+	8.2 *	12.1 *	10.4
−	5.0	7.5	7.8
Cued recall			
+	7.0	11.4 *	9.4
−	6.7	8.7	7.7
Priming			
+	4.8	6.2	8.3
−	3.5	6.8	8.1

Note. Measurements shown are from the Pz electrode for remembered (+) and unremembered (−) words. Significant differences are designated by an asterisk.

memory performance, however, were still apparent for both types of words (Figure 4). Both Dm for free recall and Dm for cued recall appeared somewhat smaller for F words than for R words, but there was more variability for F words because so few were recalled. Dm for stem-completion priming was highly similar for the two types of words. Statistical analyses of these effects were conducted via ANOVA on ERP measurements made over the standard latency ranges mentioned earlier. None of the interactions of R words or F words by Remembered or Unremembered were significant (all Fs < 1). A similar analysis was done to compare ERPs between the group of subjects instructed to remember red words and forget green words and the group of subjects given the opposite instructions. Dm for all three memory tests differed very little across the two groups.

Dm for cued recall and Dm for stem-completion priming can be compared in Figure 5, which shows the distribution of these effects across the scalp. Dm for cued recall was clearest at Fz, Cz, and Pz electrodes and had a scalp distribution centered near Cz. Large effects were also evident at the T4 electrode at 450 ms, shifting the distribution toward the right side. The distribution of Dm for free recall was similar to that of Dm for cued recall. Although the measurements of Dm for priming failed to show any significant differences, it is possible that some of the trends may reflect small effects that might be reliably measured with other techniques. One concern about Dm for priming is that it could be simply a diluted version of Dm for cued recall, because somewhat less than half of the correct responses may have been correct only by chance. There was no evidence for this, however. At Pz, Dm for priming was negative when Dm for cued recall was most positive (Figure 2). Furthermore, the scalp distribution of Dm for cued recall had a central maximum from 350 to 650 ms, whereas Dm for priming showed a strongly posterior scalp maximum (Figure 5). Another concern about Dm for priming is that it could be a version of Dm for recall that occurs only at a short latency, because at 250 and 350 ms, the distribution of Dm for priming appeared largely positive. However, this tendency for Dm for priming to be positive was associated with a distribution most positive at posterior scalp locations. Thus, these early ERP differences based on later priming performance (nonsignificant differences by the measurement techniques used) appeared to differ from Dm for cued recall in scalp topography as well as in latency.

Discussion

This experiment provided several kinds of evidence dissociating cued recall and stem-completion priming. As such, these data are consistent with previous findings that have demonstrated dissociations between explicit and implicit memory tests. Whereas the previous findings have been limited to behavioral measures obtained some time after acquisition (with or without preexisting neurological impairments),

Table 2
Event-Related Potential Statistical Results

Effects	200–400 ms F	200–400 ms MS_e	200–400 ms p	400–600 ms F	400–600 ms MS_e	400–600 ms p	600–800 ms F	600–800 ms MS_e	600–800 ms p
Free recall									
Pz effect	5.18	4.50	.033	6.02	7.64	.022	3.12	4.72	.090
Main effect	5.27	80.52	.031	5.31	119.87	.031	2.95	68.74	.100
Interaction	5.44	2.85	.002	3.30	6.29	.025	<1	7.30	>.1
Cued recall									
Pz effect	<1	0.44	>.1	5.91	3.80	.023	<1	9.09	>.1
Main effect	<1	7.87	>.1	16.87	10.91	.002	1.67	53.63	>.1
Interaction	2.05	2.95	>.1	3.17	3.72	.037	<1	4.36	>.1
Priming									
Pz effect	1.20	3.91	>.1	<1	8.24	>.1	<1	4.13	>.1
Main effect	<1	23.57	>.1	<1	53.61	>.1	<1	38.26	>.1
Interaction	<1	6.15	>.1	<1	5.94	>.1	<1	6.06	>.1

Note. Pz effect refers to the main effect of memory from the one-way analysis of variance (ANOVA) for comparing measurements from the Pz electrode. Main effect and interaction refer to the main effect of memory and the Memory x Electrode interaction from the two-way ANOVA for comparing measurements from all four midline electrodes.

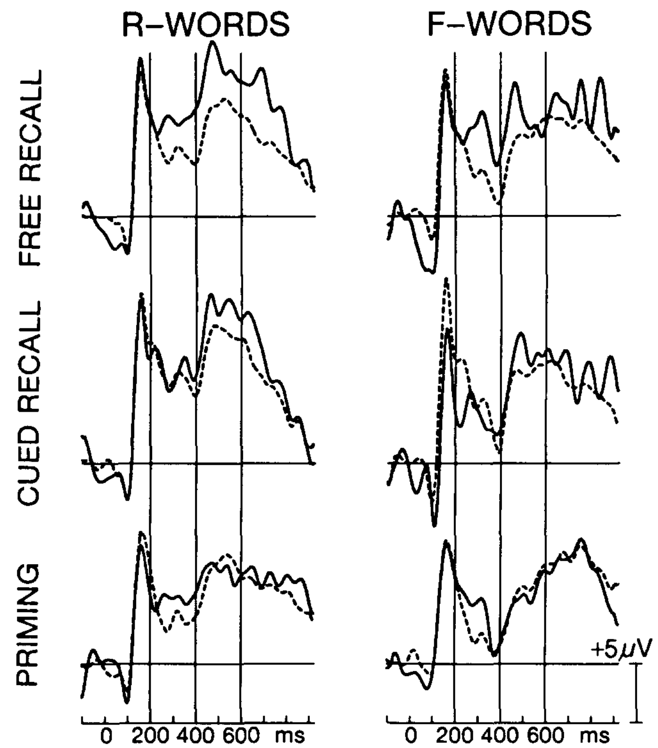

Figure 4. Event-related potentials elicited from the Pz electrode, averaged on the basis of subsequent memory performance for words associated with the remember instruction (R-WORDS) and for words associated with the forget instruction (F-WORDS). (Solid and dashed traces as in Figure 3.)

these findings included electrophysiological measures that were obtained during the encoding stage.

A Behavioral Dissociation

The behavioral data obtained in this experiment conflict with prior results that showed directed-forgetting effects in implicit memory tests (MacLeod, 1989a). There are several ways to reconcile these results. One explanation is that directed-forgetting instructions influenced performance on implicit memory tests via contamination by explicit retrieval, especially for some of the items associated with the remember instruction. MacLeod (1989a) found a significant 12-ms advantage for R words over F words in a lexical-decision task, and he argued that the speeded responses in this task were incompatible with an explicit-retrieval explanation. Nevertheless, it remains possible that explicit retrieval of some R words prior to the speeded response could account for this small effect, although a more rigorous assessment of contamination by explicit retrieval would require comparing performance under a specific manipulation of retrieval strategies.

The interpretation that fragment-completion performance was contaminated by explicit retrieval can be supported by several arguments. Experiments reported by Squire, Shimamura, and Graf (1987) showed that whereas the performance of amnesic patients was impaired on two completion tests (a fragment-completion test and a stem-completion test that was constructed such that each stem had only one possible completion), performance was unimpaired on a stem-completion test that was constructed such that each stem had multiple possible completions, as in this experiment. Explicit retrieval is apparently more likely to influence completion when only one word will complete the stem or fragment. The finding that fragment completion in normal subjects was influenced by level of processing during encoding (Squire et al., 1987) also casts doubt on the idea that fragment completion can measure priming independent of explicit retrieval. Furthermore, the unlimited time allowed for fragment completion in MacLeod's (1989a) study could have increased the likelihood that subjects used explicit retrieval.

In contrast to a priming test in which each fragment presented uniquely specifies a word, each priming cue in this experiment could be completed by at least five words. Also, two modifications of the testing format used by Graf et al. (1984)—extreme time pressure and the oral rather than written response mode—probably functioned to further limit the extent of explicit retrieval. The nature of the tests do not, of course, allow an absolute contrast; there may have been some explicit retrieval in the priming test, and there may have been some relatively automatic responses (not involving explicit retrieval) in the cued-recall test. The dissociations between recall and priming nonetheless attest to the effectiveness of the instructions in distinguishing the tests, presumably by calling into play different retrieval strategies.

Directed Forgetting

Three mechanisms for the directed-forgetting effect have been proposed: selective encoding (and rehearsal), selective grouping or functionally segregating items in memory, and retrieval inhibition, a repressionlike process thought to operate at the time of retrieval for words associated with a forget instruction (Geiselman & Bagheri, 1985; Geiselman, Bjork, & Fishman, 1983). MacLeod (1989a) interpreted his results as implicating the retrieval-inhibition mechanism on the basis of the following reasoning: (a) Manipulations of encoding influence performance on explicit but not implicit memory tests, and (b) directed forgetting influenced performance on both types of test. Therefore, directed forgetting must not have been mediated solely by encoding differences; hence, MacLeod (1989a) argued, retrieval inhibition played a role. Directed forgetting was regarded as a retrieval manipulation, and the parallel effects on explicit and implicit tests were seen to be in accordance with the other examples of parallel effects from retrieval manipulations referred to earlier. The present results undermine this reasoning by demonstrating differential effects of directed forgetting on two tests that differed only in the nature of their instructions. Apparently, the retrieval-inhibition process, if it is operative at all, does not function equivalently in these two tests.

An alternative way to reconcile my results with those of MacLeod (1989a) is to suppose that the divergence reflects the nature of the directed-forgetting manipulation in my experiment. In most other studies of directed forgetting, the

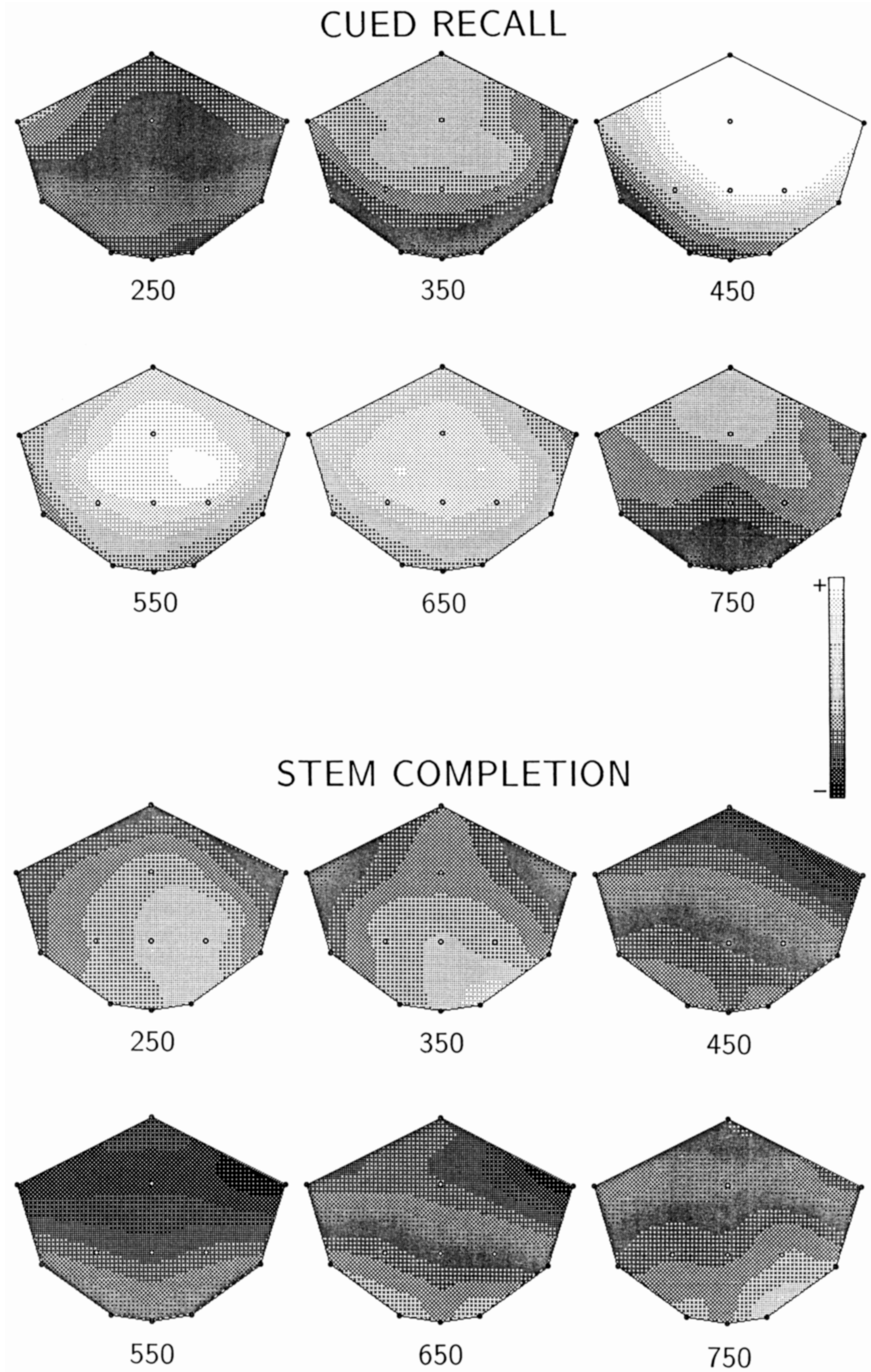

Figure 5. Topographic maps showing the distribution on the scalp of difference waves based on later memory performance (Dm) for cued recall and stem completion. Difference waves were computed by subtracting event-related potentials [ERPs] to unremembered words from ERPs to remembered words and values were interpolated at six latencies [labeled in milliseconds]. Electrode locations are shown as circles, with poterior locations at the bottom of each map. Each pattern represents an area of like potential, as shown on the calibration bar, which covers a 6-μV range centered on 0 μV. White areas represent ERP differences greater than or equal to 2.6 μV.)

instruction to remember or forget was given after each word or after a group of words. In this study, the instruction was presented simultaneously with the associated word and was denoted by the color of the word. Thus, whereas the initial encoding of each word was guaranteed in other paradigms by delaying the instruction to remember or forget, the present paradigm used the target-detection task to necessitate an analysis of the semantic content of each word. The semantic analysis may have occurred in parallel with the color analysis; behavioral, anatomical, and physiological evidence suggests that color information is processed separately from information about visual form (see Damasio, Yamada, Damasio, Corbett, & McKee, 1980; Livingstone & Hubel, 1988). Despite these differences from prior paradigms, the directed-forgetting manipulation in this study was highly effective for both free recall and cued recall.

The present directed-forgetting format would still be suspect if it somehow diminished the role of retrieval inhibition. However, it is more reasonable to suppose that all three of the proposed mechanisms for directed forgetting would have been enhanced because color could provide a salient basis for segregating F words from R words. The differences between ERPs elicited by R words and those elicited by F words indicated that the two types of words were processed differentially as early as 250 ms after word onset. These ERP effects could not have been due to the word color per se because color was balanced across subjects. Rather, the ERP effects are consistent with the idea that directed-forgetting instructions lead to superior encoding for R words, and this differential processing influences recall but not stem completion. The relationship between differential processing to which the ERPs were sensitive and encoding differences that specifically led to superior memory for R words is unclear. The directed-forgetting effects may have been mediated by mechanisms that were not associated with any systematic ERP variations. At any rate, the results cast doubt on the support mustered for the retrieval-inhibition process by MacLeod's (1989a) findings, although other evidence for inhibitory mechanisms in retrieval is plentiful (Bjork, 1989).

To further support the validity of the present manipulation, an additional group of 14 subjects were given directed-forgetting instructions in the format of MacLeod (1989a). Words were displayed for 1 s, followed by a remember or forget instruction ("-RRRR-" or "-FFFF-" in inverse field) displayed for 3 s. One hundred words were presented, half selected from the critical words used in this study and half selected from those used to study fragment completion (MacLeod, 1989a; Tulving, Schacter, & Stark, 1982). After a 2-min delay, a stem-completion test and then a fragment-completion test were given. Again, directed forgetting did not reliably influence stem completion (24% for R words vs. 23% for F words), $F(1, 13) = 0.51$, $MS_e = 40.26$. On the other hand, there was a small effect on fragment completion (48% for R words vs. 40% for F words), $F(1, 13) = 5.66$, $MS_e = 90.90$, $p < .033$, replicating the results of MacLeod (1989a). In sum, the choice of format for delivering the directed-forgetting instructions was not critical because neither of the two formats produced effects on stem completion.

An Electrophysiological Dissociation

The ERP results have further implications for understanding memory mechanisms associated with explicit and implicit tests. Monitoring neural activity at the time of acquisition may lead to insights that are complementary to those obtained via behavioral measures of memory performance. The finding that ERPs differed as a function of later memory implies that this electrical activity reflected encoding or some other process important for later memory. The candidate processes that could have led to Dm might be specific to lexical representations, like processing of perceptual, semantic, or other dimensions, or they might be nonspecific processes that also correlated with later memory performance, such as forms of arousal. The finding that Dm differed across tests limits these candidate processes, in that the processes must also differ across tests. Accordingly, the process in question could be important for free recall and cued recall but less relevant for stem-completion priming, as is elaborative processing.

Several other factors also constrain hypotheses about the processes underlying Dm. The temporal information implies that these processes were operative, on the average, during the interval between about 400 and 700 ms after word onset. Processes that correlated with later memory performance but that did not occur in this time range did not directly contribute to Dm. One example of such a process is the rehearsal of a word during a break because this rehearsal could not have been reflected in the ERP to that word. Similar reasoning could be applied to interitem processing. When the presentation of one word led to an association between that word and a previous word, this associative processing could have contributed to Dm for the second word but not for the first word. In fact, to the extent that memory for the first word was due to this later association and not to processing while the ERP was recorded, Dm would be diminished. In short, any processing displaced from the time immediately after the presentation of a word did not contribute to Dm, and if this processing influenced later memory performance, then it may have been antagonistic toward Dm.

Despite the abundance of factors that logically are antagonistic to Dm, the circumstances of this experiment were suitable for obtaining significant differences with respect to Dm for free recall and Dm for cued recall. The waveform characteristics of these effects replicate similar findings in other paradigms (e.g., Fabiani et al., 1986; Karis et al., 1984; Münte et al., 1988; Paller et al., 1988b).[2] In some experiments, however, ERP amplitudes were not significantly different as a function of later memory (R. Johnson et al., 1985; Paller, Kutas, Shimamura, & Squire, 1987). One factor that could be responsible for a failure to elicit Dm involves the displaced-rehearsal scenario discussed earlier, in that the use of complex

[2] Although close relationships between ERP differences based on subsequent memory performance and particular ERP components are difficult to determine with existing data, the present conclusions are independent of such considerations. For further discussion of possible relationships between Dm and specific ERP components, see Friedman (1990) and Paller, Kutas, and Mayes (1987).

semantic associations (i.e., the creation of mnemonic aids) has been associated with a diminution in Dm (Fabiani et al., 1985; Karis et al., 1984). The signal-to-noise ratio in the recordings is another factor that certainly can influence results. In particular, the study of Paller, Kutas, Shimamura, and Squire (1987) was limited by the fact that 100 words were used for each memory test, yielding an inordinately small number of words for some conditions, depending on how unequally the memory performance of each individual divided the words into two groups. Significant ERP differences as a function of later stem-completion priming were found, but only for high-frequency words and not for low-frequency words. Three subsequent experiments had a very similar design, but with a different orienting task and an added retention-interval manipulation (Paller et al., 1988a). Free recall was studied in one experiment, and ERP differences based on free recall were significant and resembled those reported previously. Recognition was studied in all three experiments, but Dm for recognition was significant in only two of the experiments. Dm for priming was highly variable across experiments and was generally nonsignificant. The present design increased the reliability of the ERP analyses in relying on 210 words for each memory test by virtue of manipulating type of memory test between groups.

In any event, that Dm for cued recall differed from Dm for priming was underscored by the clear differences between the associated ERP topographies. This contrast indicates that (a) processes to which ERPs were sensitive (i.e., a subset of electrophysiological processes active at that time) influenced or otherwise were correlated with later cued-recall performance and (b) these processes were not related to later stem-completion performance in the same way. In other words, the tests were dissociated in their relationships to encoding differences between remembered and unremembered words. This conclusion is incompatible with any conception of the differences between explicit and implicit memory tests that does not recognize a contribution from encoding differences. Whereas several theorists (Jacoby, 1983a, 1984; Ratcliff & McKoon, 1988) have emphasized retrieval differences in mediating the implicit–explicit distinction, the present results argue for emphasis on encoding variability. Such an idea parallels the encoding-specificity principle (Tulving & Thomson, 1973), in that the similarity between stored information and information provided by retrieval cues can be modified by both encoding and retrieval manipulations. An emphasis on encoding variability may thus be consistent with Jacoby's (1983a, 1984) position[3] that different aspects of the same episodic memories are influential for both explicit and implicit memory performance. Delineating different aspects of memory traces that can be mapped onto the differences between memory tested explicitly versus implicitly remains an important endeavor.

[3] Jacoby (1983a, 1984) extended his position further to argue that there is no need to invoke separate memory systems. In a similar manner, Roediger, Weldon, and Challis (1989) championed the idea that the usefulness of encoding processes depends on transfer to the retrieval situation in terms of the distinction between data-driven and conceptually driven processing (Jacoby, 1983b). Clearly, both encoding conditions and memory tests can vary in the relative emphasis on surface features versus meaning. Roediger et al. (1989) have pointed out that the distinction between implicit and explicit memory tests is usually confounded with the distinction between data-driven and conceptually driven processing. Operational definitions were given for the latter distinction (comparing memory performance under study conditions that differentially emphasize either surface features or meaning), but these have not been applied to stem completion and cued recall. Although test materials for these two tests do not differ, cued recall may differ from stem completion in terms of greater reliance on (a) concepts as opposed to surface features, (b) intraitem organization, (c) contextual information, (d) explicit retrieval, or possibly other factors. Thus, it may be premature to reject the sort of distinction outlined earlier between declarative memory and nondeclarative memory. Rather, the operative dimensions on which tests differ need to be determined.

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Appendix

Critical Words

ABODE	CHEESE	FOREST	MEADOW	QUARTER	STOVE
ACCENT	CHICKEN	FRAME	MELON	RADISH	STRAW
ACRE	CHOIR	FREEWAY	MERMAID	RAISIN	STUDIO
ADVISOR	CIRCUS	FRIEND	METEOR	RANSOM	SUCKER
AMBULANCE	CLAY	GALAXY	MILK	REALM	SUMMIT
ANAGRAM	CLERK	GARBAGE	MINK	RECORD	SUPPER
APPLE	CLOVER	GENIUS	MODULE	REFEREE	SURGEON
ATTIC	COLUMN	GLASS	MONSTER	RELIC	SWEATER
AUTUMN	COMB	GLOVE	MORTUARY	REPTILE	SWINE
AWARD	CORK	GRAPE	MOSAIC	RESIN	TACO
BALLOON	COUSIN	GREASE	MOTEL	ROOF	TENT
BANDIT	CREEK	GRIDDLE	MOUNTAIN	ROULETTE	TERMITE
BARREL	CRICKET	GROCERY	MUSTARD	RUST	THIGH
BASEMENT	CURB	HALO	MUTANT	SALMON	THROAT
BATH	DECANTER	HANDLE	NOTCH	SATELLITE	TORNADO
BEARD	DEFENDANT	HARBOR	OBSTACLE	SCALP	TRACK
BELLY	DELICACY	HEAVEN	OCCUPANT	SCOOP	TREASURE
BENCH	DEPUTY	HERRING	OFFICE	SCREW	TRIAL
BLANKET	DESK	HOLIDAY	ORGAN	SENATE	TROUSERS
BLOOD	DIAMOND	HUNTER	PALACE	SERVANT	TRUMPET
BOOZE	DISH	IMMIGRANT	PARTY	SHADOW	TURTLE
BREAD	DRAGON	IMPLEMENT	PASSAGE	SHEEP	TWIG
BRIDE	DUNCE	INCH	PATCH	SHIRT	UNIFORM
BROW	ELEPHANT	INDIAN	PEARL	SHOULDER	VACCINE
BURGLAR	EMBASSY	INSECT	PENCIL	SILK	VALVE
BUTTERFLY	EMPEROR	KING	PERFORMER	SLAVE	VERMOUTH
CABBAGE	ENTITY	LAMP	PICNIC	SOLDIER	VICTIM
CALENDAR	EQUATION	LEAF	PLATE	SOUP	VISITOR
CAMEL	EXCREMENT	LIMERICK	POLKA	SPADE	VOLCANO
CANDY	EXPERT	LOCUST	PORCUPINE	SPEAKER	WEAPON
CAPSULE	FEATHER	LOOT	PRAIRIE	SPIDER	WHEAT
CARPET	FILM	MACARONI	PRESIDENT	SQUARE	WHISKER
CASINO	FINGER	MANAGER	PRIEST	STATUE	WINDOW
CENTAUR	FLASH	MARTINI	PROPHET	STEAM	WORM
CHAIN	FLOWER	MATCH	PURSE	STICK	WRIST

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