Current Trends in Event-Related Potential Research (EEG Suppl. 40)
Editors: R. Johnson, Jr., J.W. Rohrbaugh and R. Parasuraman

Brain Responses to Concrete and Abstract Words Reflect Processes that Correlate with Later Performance on a Test of Stem-Completion Priming*

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Recent applications of electrophysiological techniques to the study of human memory have shown that event-related brain potentials (ERPs) to words can be predictive of subsequent memory performance (Sanquist et al. 1980; Karis et al. 1984; Johnson et al. 1985; Fabiani et al. 1986; Neville et al. 1986; Paller et al. 1987). In these studies, the brain's electrical response to each word was sorted according to whether that word was or was not remembered on subsequent tests of recognition or recall. In general, ERPs to words that were later remembered were more positive (beginning about 400 msec after word onset) than ERPs to words that were not remembered. This difference between responses to remembered and forgotten words (hence referred to as Dm) may be a direct reflection of differential processing that determines how well a word is encoded in memory. It is unclear, however, which aspects of information processing Dm measures, since perceptual processing, semantic processing, and changes in arousal can all influence later memory performance.

Dm might be better understood if this ERP difference could be rigorously identified with specific mechanisms of memory. To this end, one particular theoretical distinction may prove relevant; namely, the distinction between *elaboration,* a process important for later conscious retrieval (e.g., in explicit memory tests), and *activation,* a process that promotes priming (Graf and Mandler 1984). Priming, in this context, occurs when performance (e.g., in implicit memory tests) is biased due to recent experience. For example, if a subject is asked to complete the word stem 'MOT _____' with the first word that comes to mind, the response 'MOTEL' will be more likely if this word had been presented recently (since, we suppose, the mental representation of the word remained activated). Neuropsychological results suggest that this distinction between conscious

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* Supported by NSF Grant BNS83 05525, NIHM Predoctoral Fellowship MH09128 to K.A.P., and Research Scientist Development Award USPHS 1K02 MH00322 to M.K.

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retrieval (or declarative memory) and priming is honored by the nervous system, in that only declarative memory is dependent on the integrity of the brain regions damaged in amnesia (Graf et al. 1984; Shimamura 1986). Priming can be intact when performance on a declarative memory test is at chance levels (Squire et al. 1985). The present experiment used the distinction between implicit and explicit memory tests in an analysis of Dm, the ERP correlate of encoding.

METHOD

An incidental learning paradigm was used in which 12 right-handed subjects (6 of each sex, mean age: 22 years) rated words on a concreteness scale using 4 response keys. Subjects were instructed to distribute their responses equally across the 4 levels of concreteness. Ratings were later collapsed into 2 levels, *concrete* and *abstract*. Based on frequency of usage (Kučera and Francis 1967), each word was also designated either *high frequency* (mean 57 occurrences/million) or *low frequency* (mean 8 occurrences/million). Words were presented on a video terminal for 200 msec at a rate of 1 word every 3 sec. Each word began with a unique, three-letter stem. Ten word lists were presented in the same order to each subject. Each list contained 20 critical words and 6 other words (3 at the beginning and 3 at the end). The critical words (200 in all) were selected such that each stem could be completed to form at least 5 common words.

Within 1 min after the presentation of each list, a priming test was given. For each priming test, subjects were given a sheet of paper with 23 three-letter stems. Of these 23 stems, 10 could be completed to form critical words from the immediately preceding list, 12 were used as unique distractors, and 1 was used to estimate stem-completion baseline (the chance likelihood that a stem is completed with a critical word). Subjects were instructed to complete each stem by saying a word aloud. Instructions stressed that the first completion to come to mind should be used and that these responses should be made as rapidly as possible. In all, 100 of the 200 critical words were tested for priming — 100 for 6 subjects and the other 100 for the other 6 subjects.

After 10 word lists and corresponding priming tests (about 40 min), a counting task was given to prevent rehearsal (1 min). Two explicit memory tests followed. In the free recall test, subjects were allowed 10 min to write down words from the concreteness judgment task. Then, in the cued recall test, 200 word stems were presented. These stems could be completed to form the 200 critical words. Subjects attempted to recall these words with the aid of the stems.

During the concreteness judgment task, ERPs were recorded from 13 Ag/AgCl electrodes affixed to the scalp, each referred to the average of left and right mastoid recordings. Horizontal and vertical EOG were recorded so that trials contaminated by electro-ocular artifact could be rejected. The bandpass was 0.01 – 100 Hz with a digitization rate of 170 Hz. ERPs were averaged beginning 200 msec prior to word onset and continuing for 2800 msec. The present report will focus on ERPs in the first 1500 msec recorded from 3 midline electrodes (Fz, Cz and Pz). Reported measurements were mean amplitudes in the 400 – 800 msec latency range averaged across recordings from these 3 electrodes.

RESULTS

Mean behavioral performance scores in each phase of the experiment are shown in Fig. 1. Published norms for concreteness (Friendly et al. 1982) were highly correlated with subjects' ratings ($r = 0.87$). More words were rated concrete than abstract, especially for low-frequency words. The lower portion of Fig. 1 shows memory scores for the priming test and the cued recall test, as well as a breakdown of these scores as a function of concreteness ratings and as a function of word frequency. Both priming and cued recall scores were better for concrete words than for abstract words, although the difference was statistically significant only for cued recall (F (1/11) = 5.2, $P < 0.045$). On the other hand, priming was relatively better for low-frequency words (F (1/11) = 5.7, $P < 0.036$) whereas cued recall was better for high-frequency words (F (1/11) = 5.2, $P < 0.044$). Free recall performance averaged 6% correct. Results for both recall tests are based only on critical words not tested for stem-completion priming, since words given as completions in this test tended to be remembered more often (60% recalled in cued recall) than words that were not given as completions (15% recalled in cued recall), whereas performance for the remaining 100 words could not be biased in this manner.

ERPs averaged on the basis of subsequent memory performance are shown in Fig. 2. ERPs elicited by words that were later given as completions in the stem-completion priming test (the implicit memory test) were generally more positive than ERPs elicited by words that were not given as completions. This ERP difference, Dm for priming, (measured in the 400 – 800 msec latency range in recordings from 3 midline electrodes) averaged 0.9 μV (S.E.M. = 0.2), a statistically significant difference (F (1/11) = 6.8, $P < 0.024$). ERPs averaged on the basis of performance on the explicit memory tests showed small, non-significant differences between words later recalled and words not recalled. Dm for cued recall averaged 0.3 μV (S.E.M. = 0.3) and Dm for free recall averaged 0.2 μV (S.E.M. = 0.7).

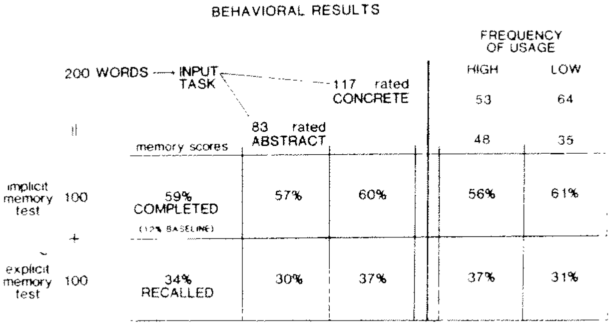

Fig. 1. The upper portion shows the mean number of critical words that were rated abstract or concrete and how these categories mapped on to the 2 categories based on frequency of usage. Below are mean memory scores from the stem-completion priming test and the cued recall test (based on 100 critical words each). Scores are also shown as functions of concreteness ratings and of word frequency.

Dm for priming was also analyzed as a function of concreteness ratings and as a function of word frequency (Fig. 3). Dm for priming was apparent both for abstract words and for concrete words. Also, Dm for priming was large for high-frequency words (2.3 μV, S.E.M. = 0.4), but small for low-frequency words (-0.5 μV, S.E.M. = 0.4), a significant difference ($F(1/11) = 8.9$, $P < 0.012$).

ERPs also varied directly as functions of concreteness ratings and word frequency. First, ERPs to words rated abstract were more positive than ERPs to words rated concrete (1.9 μV, S.E.M. = 0.3). This difference was present for 6 subjects who used the concrete rating much more often than the abstract rating, as well as for the other subjects who used concrete and abstract ratings for a roughly equal number of words. Finally, ERPs to high-frequency words were more positive than ERPs to low-frequency words (1.0 μV, S.E.M. = 0.2), primarily at posterior electrode sites.

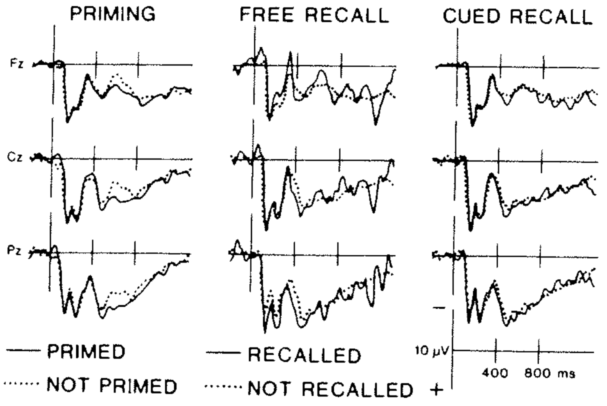

Fig. 2. ERPs recorded from midline electrodes and averaged on the basis of subsequent performance on tests of stem-completion priming, free recall, and cued recall. The difference between overlapping ERPs (Dm) was larger for priming than for either recall test.

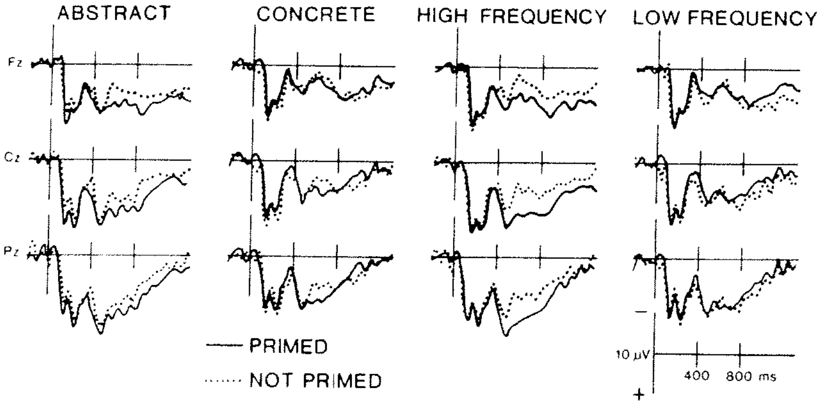

Fig. 3. ERPs averaged on the basis of subsequent priming performance for words rated abstract, words rated concrete, high-frequency words, and low-frequency words.

DISCUSSION

Brain responses to words were highly sensitive to processes that correlated with performance on the implicit memory test (priming). Since Dm for priming was evident both at anterior and at posterior sites, it does not appear to be solely an effect on P3, a positive deflection largest at posterior sites with a peak latency of about 500 msec at Pz. (Paller et al. (1987) discuss similar results dissociating Dm for recognition and P3.)

ERP correlates of explicit memory (cued recall and free recall) were much smaller; there was a non-significant tendency for ERPs to words later recalled to be more positive than ERPs to words not recalled. It is unclear why this Dm for recall was smaller than similar ERP differences in previous experiments. Although the requirement for concreteness judgments may have brought into play different processing strategies, further experiments would be required to demonstrate the relevance of this factor.

The ERP correlate of priming may reflect the process of activation that is thought to underlie stem-completion priming (Graf and Mandler 1984). Furthermore, the differential effects of word frequency on Dm for priming suggest that the priming of high- and low-frequency words may have differed in a fundamental way. Although differences between Dm for priming and Dm for recall were intriguing, the recall tests took place at a longer delay than did the priming test, and fewer words were recalled than were completed. Whereas it is clear that ERPs were sensitive to processes correlated with priming, further research will be required to specify these processes more precisely and to identify and characterize ERP correlates of processes specific to declarative memory.

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