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Event-Related Brain Potentials during Initial Encoding and Recognition Memory of Congruous and Incongruous Words

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Event-related brain potentials (ERPs) were recorded while subjects read statements followed by words that were either semantically congruous or incongruous with the preceding phrase, and during a subsequent recognition test. Congruous words yielded smaller N400s and better memory than did incongruous statements. In addition, the ERPs to correctly recognized old words were characterized by an enhanced late positivity (P650) relative to those elicited by correctly identified new words. A second experiment essentially replicated the results of the first. In addition, the amplitude of the late positive component (P650) elicited by final words on initial exposure was predictive of subsequent recognition; words that would be later recognized were associated with a larger P650 (whether they were incongruous or not) than were words that would not be recognized. These ERP data provide evidence that within 250 ms of the presentation of a congruous word and within 450 ms of an incongruous word, a significant portion of the brain processes which determine whether a word will or will not be recognized some time in the future have taken place.

Over the past decade a large literature has documented the critical relationship between the nature of initial learning or encoding operations and subsequent memory (for review see Craik, 1979). Kolers (1973, 1979) has even proposed that we remember in terms of the encoding operations themselves. A less extreme view holds that the memory trace is a record of the processing performed on a stimulus. This latter view is at the core of the levels of processing theory which assumes that qualitatively different traces result from processing a stimulus in different ways or to different depths (Craik & Lockhart, 1972). It was proposed and found in numerous studies that the meaningful, semantic processing of materials leads to superior performance on a subsequent recall or recognition test relative to shallow, nonsemantic processing.

This levels of processing analysis as originally proposed was found lacking in several respects including failure to account for the observed variation in retention for items processed within a level (Bobrow & Bower, 1969; Baddeley, 1978; Eysenck, 1978; Nelson, 1977; Treisman & Tuxworth, 1974). A depth analysis could not explain why semantically processed items associated with a yes decision were better recollected than similar items followed by a no response. Later formulations proposed that processing differences within a level could be attributed to the degree of elaboration (Craik & Tulving, 1975) or the distinctiveness of the resultant memory traces (Klein & Saltz, 1976; Lockhart, Craik, & Jacoby, 1976). The concept of elaboration refers in general to a process of relating semantic information from the target event to other aspects of the individual's knowledge and, within the levels framework, to the extensiveness or amount of processing that oc-

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curs at any particular level of analysis. The concept of discriminability on the other hand refers to the fact that the memory of a particular event must be discriminable from those of other similar events; this discrimination is based on distinctiveness which can be viewed as an inverse function of the number of features in a trace shared by other to-be-remembered events. A congruous ending is thus assumed to yield superior memory performance to the extent that it forms an integrated unit with its context by virtue of its more elaborate trace.

Indeed a substantial number of studies both within and outside the levels-of-processing framework have demonstrated the utility of refined concepts of elaboration, distinctiveness, and congruity in accounting for variability in retention. Nonetheless, since the impact of these manipulations has been evaluated by means of behavioral measures of the memory performance, their specific interactions with the processes taking place at the time the stimulus is presented remain an open question. Some recent attempts at scrutinizing the memory process online have required subjects to predict their subsequent memory performance (for review see Cavanaugh & Perlmutter, 1982) or have included recordings of various autonomic responses (e.g., heart rate, galvanic skin response) as possible indicants of the differential processing leading to future behavior (e.g., Geiselman, Woodward, & Beatty, 1982).

Another online approach to the investigation of the nature and timing of neural events that occur during learning and memory has been via the analysis of event-related brain potentials (ERPs) recorded from the human scalp (Donchin, Ritter, & McCallum, 1978; Gaillard & Ritter, 1983; Hillyard & Kutas, 1983; Karrer, Cohen, & Tueting, 1984). These potentials are particularly useful in that they can provide a measure of the dynamics of the mnemonic processes accorded events during both learning and recognition.

A number of studies have detailed variations in ERP parameters as a function of mnemonic processing. For example, Chapman, McCrary, and Chapman (1981) reported that the amplitude of a P250 component behaved as if it were a sign of storage in short-term memory (STM). In a different group of subjects, Chapman et al. demonstrated that those very stimuli which would have elicited the largest P250 (by inference from the previous ERP experiment) were also the ones which were best recalled. Friedman, Vaughan, and Erlenmeyer-Kimling (1981) similarly observed that ERPs to numbers in a task requiring matching of successive stimuli contained several late components, some of which (including P250) were correlated with the requirement for STM storage.

Most ERP investigations in learning and memory have focused on amplitude and latency variations of the late positive components (LPCs) of the ERP such as the P300. For instance, studies employing a Sternberg memory paradigm have revealed a systematic relation between LPC latency and search time through STM (Adam & Collins, 1978; Ford, Roth, Mohs, Hopkins, & Kopell, 1979; Gomer, Spicuzza, & O'Donnell, 1976). Various recognition memory paradigms, on the other hand, have demonstrated variations in LPC amplitude. For example, Sanquist, Rohrbaugh, Syndulko, and Lindsley (1980) found that LPCs following semantic judgments were significantly enhanced relative to those following phonemic or orthographic judgments. In addition, they observed that the LPC was larger to words that were recognized than to those that were not. Accordingly, Sanquist et al. suggested that LPC amplitude indexed the amount of "associative activity" evoked during learning of words and their subsequent accessibility in memory. In an investigation of "incidental" recognition, Neville, Snyder, Woods, and Galambos (1982c) recorded ERPs while subjects viewed photographs of familiar and unfamiliar persons, paintings, and places and sorted ERP averages according to responses given on a subsequent recognition test. The amplitude of a positive component (P400) was significantly enhanced in ERPs to photographs that had been recognized relative to those that had not been recognized. Thus, Neville et al. proposed that some aspect of the process of recognition is a major determinant of P400 (i.e., LPC) amplitude.

Donchin and his co-workers (1981) have hypothesized that the P300 manifests the process whereby working memory is modified in response to environmental events; P300 amplitude is assumed to be proportional to the amount of change (e.g., context updating) required. In support of this view, Karis, Fabiani, and Donchin (1984) reported that individual differences in the recall of "isolated" words (the von Restorff effect) were related to individual differences in the relationship between P300 amplitude and subsequent recall. The three subjects who reported using "rote" mnemonic strategies displayed a strong von Restorff effect as well as P300s whose amplitudes upon initial presentation were predictive of later recall. On the other hand, the three subjects who had a very small von Restorff effect showed no relationship between P300 amplitude and recall; rather it was the amplitude of a frontal "slow wave" component which was predictive of recall. Thus many studies have converged on the hypothesis that LPCs including the P300 index the activity of systems associated with mnemonic functioning, its determinants and/or its consequences.

While not specifically designed to assess memory, several recent studies have noted a strong relationship between encoding of semantic information and a negative ERP component (e.g., N400). When subjects read words that are unexpected or incongruous with respect to a preceding context, a large N400 component is elicited (Kutas & Hillyard, 1980a, 1980b, 1984). Several lines of evidence suggest that the N400 is sensitive to the nature of the semantic relationship between a word and its context (Bentin, McCarthy, & Wood, 1985; Fischler, Bloom, Childers, Roucos, & Perry, 1983; Kutas & Hillyard, 1983, 1984; Kutas, Lindamood, & Hillyard, 1984). Consideration of this literature together with behavioral studies showing better memory for words that are congruous with the preceding context (Craik & Tulving, 1975; Eysenck & Eysenck, 1979; Schulman, 1974) leads to the prediction that words which elicit large N400 responses will be less well recognized than words that do not. To our knowledge there are no data that bear directly on this hypothesis. It may be that both N400 and LPC index the degree to which events are encoded in a memorable way or, on the other hand, these two components may bear different relations to mnemonic processes.

The present experiment was designed to examine these issues further in a paradigm known to yield differential yes/no recognition memory behavior and to elicit both N400 and late positive components to words that would and would not be recognized in a subsequent test. Since our aim was to study these processes in a sentence context rather than in response to isolated words, encoding was varied by requiring subjects to decide whether a word did or did not fit with the sense of a preceding phrase (Craik & Tulving, 1975; Schulman, 1974).

A second purpose of this experiment was to assess the inter- and intrahemisphere distributions of the different ERP components associated with the diverse language processes called into play by this task. Several investigators have described asymmetries in ERP components that may reflect the differential specializations of the cerebral hemisphere (reviewed by Rugg, 1983; Molfese, 1983). Such investigations have employed a wide variety of tasks and have revealed asymmetries in different ERP components over different brain regions. Those ERP asymmetries of particular interest to the present experiment are introduced below. For example, Neville (1980) reported that the N150 component to visually presented words was larger over posterior regions of the left than right hemisphere. Kutas and Hillyard (1980a, 1980c, 1983) observed that a slow positive shift recorded over parietal sites to visual words presented in sentences was larger from the left than the right hemisphere and that the N400 to semantically incongruous words was larger over posterior regions of the *right* hemisphere. Neville, Kutas, and Schmidt (1982a) found that a negative component (N410) was more pronounced over anterior regions of the left than right hemisphere during a task in which words were presented in the lateral visual fields for written identification.

To the extent that certain ERP components reflect distinct aspects of language processing, and if different regions *within* the two hemispheres are specialized for these subprocesses, then each of these different findings may be observed in a paradigm which brings into play several language functions. With these considerations in mind we recorded ERPs from several sites over the hemispheres as subjects read phrases, made semantic judgments about words, and performed a subsequent word recognition task.

METHODS EXPERIMENT 1

Subjects

Ten right-handed subjects (six male, mean age 23 years) were paid to participate in the experiment.

Stimuli

The stimuli were words presented on a monitor under the control of a microcomputer. Each word (220-ms duration) consisted of white letters (range 1–9) against a dark background. Words appeared in the center of a 8.5 × 4.5-cm rectangle. The presence of the rectangle indicated that subjects were not to blink or move their eyes. The monitor was 100 cm from the subject, so words subtended a 0.3 degree visual angle vertically and 0.3–2.9 degree visual angle horizontally.

Procedure

Subjects were comfortably seated in a copper-shielded, sound-attenuating room. The experiment was divided into three blocks, each consisting of judgment task followed by a recognition test. In the judgment task, subjects were presented with 40, four word phrases, one word at a time. A trial began with the onset of the rectangle in the center of the screen and was followed 1400–2000 ms later (a random interval in order to attenuate the Contingent Negative Variation (CNV)) by the first word of a four word phrase. The remaining words appeared at intervals ranging between 850 and 1300 ms. Each phrase was followed 1700–2000 ms later by a fifth word which either fit ("fit" words) or did not fit ("no-fit" words) with the sense of the phrase. Most of the phrases and exemplars were chosen from the list employed by Craik and Tulving (1975). Following the fifth word by 1900–2400 ms, the rectangle was turned off and the subject was prompted to press one of two buttons to indicate whether the fifth word did or did not fit. Half of the words fit with the preceding phrase and half did not. Four seconds after the response, the next trial began. Typical phrases are presented in Table 1.

One minute after the end of the 40th phrase, the recognition test began. While the recognition test was unexpected following block 1, it was expected following blocks 2 and 3. Subjects were presented with 80 words, half of which were the fifth words previously presented ("old" words) randomly intermixed with 40 new words. A trial began with the rectangle followed 1950–2050 ms later by a word. The rectangle disappeared 2400–2700 ms after word offset, and subjects were prompted to press a button indicating whether the word was old or new. The next trial began 4 s after

TABLE 1

FIT
A type of bird. Robin
A type of insect. Ant
A type of vehicle. Car
Part of the body. Leg
A type of animal. Dog
Part of a car. Brake
NO-FIT
A type of weapon. Sheep
A type of insect. Sun
A type of sport. Cat
A type of bird. Nail
Grown in the garden. Shirt
Place where people live. Sword

the response. A brief break was given between each of the three blocks. Hand usage was counterbalanced across subjects.

ERP Recording

Scalp electrical activity was recorded with Beckman Biopotential Ag/AgCl electrodes placed, according to the International 10–20 System (Jasper, 1958), over homologous positions of the left and right occipital (01, 02), Wernicke's areas (WL, WR: 30% of the interaural distance lateral to a point 13% of the nasion-inion distance posterior to Cz), temporal (L41, R41: 33% of the interaural distance lateral to Cz), anterior temporal (L22, R22: one-half of the distance between F7(8) and T3(4)), and frontal (F7, F8) regions, and from the vertex (Cz). Recordings from these electrodes and the electro-oculogram from beneath the left eye were referred to the linked mastoids. Electrical activity was amplified with a bandpass of 0.01–100 Hz and was analyzed on a PDP-11/34 computer.

Data Analysis

ERPs were digitized for 100 ms prior to and 1436 ms after word presentation at a sampling rate of 167 Hz. Trials characterized by excessive eye movement or muscle artifact were rejected (approximately 10%).

ERP components were quantified by computer as either peak amplitudes within a latency range or as area measures (the mean voltage within the same latency range), relative to 100-ms prestimulus baseline voltage. The windows employed were 100–205 ms (N100), 160–300 ms (P200), 250–580 ms (N400), 400–950 ms (P300), and 1000–1430 ms (SW).

Results Experiment 1

Behavioral Data

Subjects were very accurate in judging whether the fifth word did (97%) or did not fit (98.5%) the sense of the preceding phrase. During the recognition phase subjects correctly recognized 89% of the 120 old words and correctly identified 87% of the 120 new words. Of the old words, subjects recognized significantly more of the words that fit (93%) than of those that did not (85%) ($F(1,9) = 6.58, p < .04$).

Event-Related Potentials

Judgment Task

First four words in phrase. ERP measures were subjected to a three-way analysis of variance (ANOVA) with repeated measures on two levels of hemisphere (left/right), four levels of experimental condition (words 1–4), and five levels of electrode (occipital, Wernicke's, temporal, anterior temporal, frontal).[1]

As shown in Figure 1, ERPs elicited by the first four words were characterized by posteriorly distributed N150 (154 ± 3 ms) and anteriorly distributed P220 (±5 ms) components. In all but one subject, the occipital N150 was of larger amplitude over the left (mean 3.5 μV) than the right (1.9 μV) hemisphere (sign test for matched pairs, $z = 2.23, p < .02$).

Following the P220, the ERPs displayed a negative shift which was larger over the left than the right frontal and anterior tem-

[1] We also performed a Principle Components Analysis of the ERP data. As the results agree in every respect with those from the traditional analyses, we have not included them here, but they are available from H. J. Neville on request.

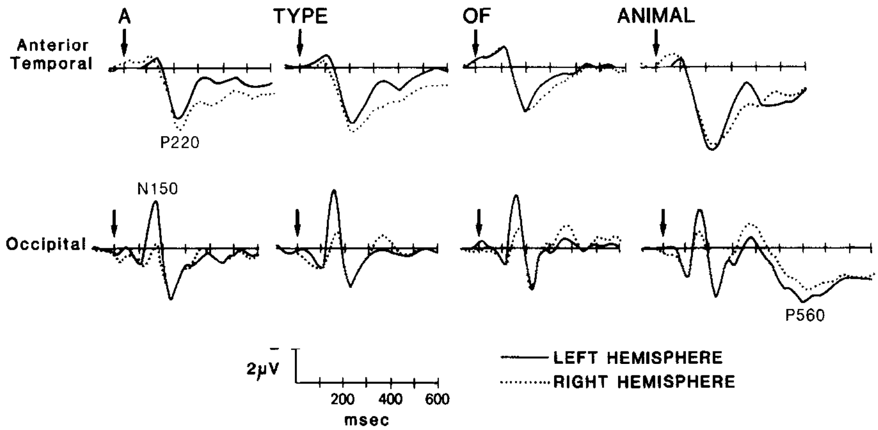

FIG. 1. Grand average ERPs (across all subjects (Ss)) to each of the words in the four word phrase in the judgment task. Note that the N150 component is larger from the left than the right occipital region, while the area from 300–500 ms is more negative from the left than the right anterior temporal region.

poral sites (measured as the area from 300 to 580 ms, main effect of Hemisphere, $F(1,9) = 20.65$, $p < .002$). In view of the similarity of the distribution of this effect to that reported in Neville et al. (1982a) we will refer to it as the N410.

For the fourth word, in addition to these components there was a positive component (mean latency 564 ± 16 ms) with a posterior maximum (see Figure 1; Word × Electrode interaction, $F(12,108) = 3.27$, $p < .0006$); this component was larger over the left than the right hemisphere (Location × Hemisphere $F(4,36) = 3.4$; $p < .02$).

Fit/no-fit: Fifth word which either did or did not fit the sense of the preceding phrase. The ERPs to words which *fit* the sense of the preceding phrase were similar to those elicited by fourth words. ERPs to words which did *not fit* the sense of the phrase likewise had a similar morphology; however, the negative component around 400 ms (391 ± 7 ms) was larger in amplitude and differed in lateral distribution. This difference in negativity began around 250 ms, peaked around 400 ms, and in the right hemisphere, lasted the duration of the epoch. The most negative peak measured between 300 and 580 ms was significantly larger for no-fit than fit words (main effect of Condition, $F(1,9) = 15.54$, $p < .001$). Moreover, this effect was larger over the right hemisphere (Condition × Hemisphere $F(1,9) = 6.1$, $p < .04$). Thus, this effect is similar to that reported by Kutas and Hillyard (1980b, 1982, 1983) and will be referred to as the N400 component. As seen in Figure 2, whereas the N410 was larger from anterior temporal regions of the left hemisphere for words that fit, by contrast the N400 was larger over the right than the left hemisphere at *all* electrodes sites for words that did not fit (Word × Location × Hemisphere interaction $F(4,36) = 3.05$, $p < .03$). No other components systematically varied as a function of the fifth word's relation to the sense of the preceding phrase.

Recognition Test

ERPs elicited by words in the recognition phase of the experiment were also characterized by N150, P220, N410, and P650 (650 ± 15 ms) components. These components were superimposed on a slow positive shift that extended throughout the ERP epoch. As is evident in Figure 3, correctly recognized old words elicited a significantly larger late positivity than did correctly rejected new words (area 400–950 ms; ($F(1,9) = 36.8$, $p < .0001$). This effect was observed in every subject. Moreover, the

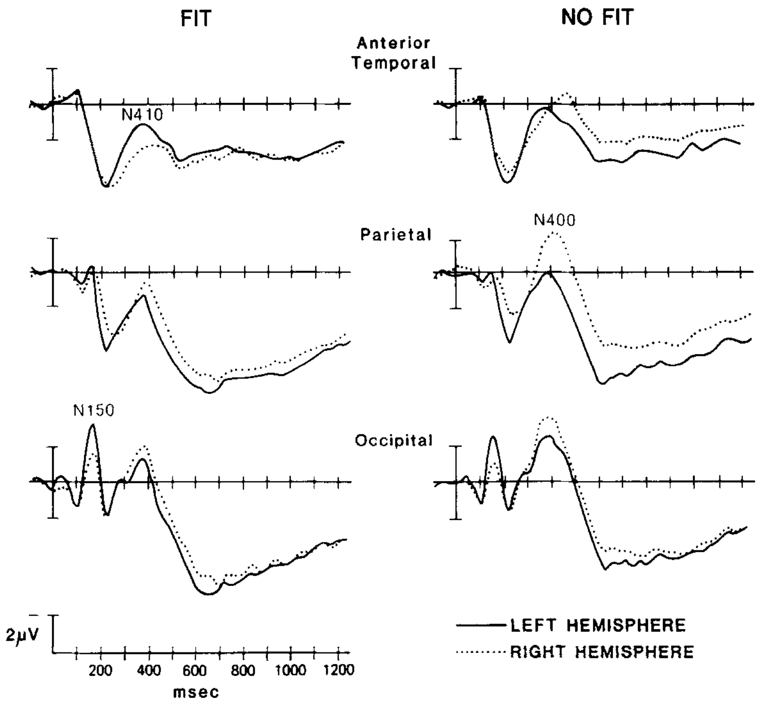

FIG. 2. ERPs from left and right anterior temporal, parietal, and occipital regions to words that did and did not fit with the phrase. Note that for both fit and no-fit words the N150 was larger from the left than the right occipital region. For fit words, the area from 300–500 ms (N410) was more negative from the left than the right anterior temporal region; however, for no-fit words the N400 was larger from over the right than the left parietal and temporal regions.

P650 component tended to be larger over the left than the right parietal regions for recognized words (Electrode × Hemisphere interaction, $F(4,36) = 3.32, p < .03$) but was symmetrical for new words (Word × Hemisphere interaction ($F(2,18) = 4.25$, $p < .04$). When the ERPs to correctly recognized words were segregated according to whether the word had or had not fit the sense of the phrase, paired comparisons showed the P650 was larger to fit than to no-fit words ($F(1,9) = 6.50$, $p < .04$). In either case, "old" words correctly recognized elicited larger P650 amplitudes than did new words (fit: $F(1,9) = 46.42$, $p < .0002$; no-fit: $F(1,9) = 24.35, p < .0009$).

As seen in Figure 3, for all words in the recognition test the N150 again tended to be larger from the left than the right occipital region (sign test for matched pairs, $z = 2.23$, $p < .02$). Additionally, over anterior regions the N410 component was more negative over the left than the right hemisphere (Location × Hemisphere interaction $F(4,36) = 3.6, p < .01$).[1]

DISCUSSION EXPERIMENT 1

To a large extent, both the behavioral and ERP results were as expected on the basis of previous reports. Namely, (1) words associated with yes decisions were better recognized than those associated with no decisions (Craik & Tulving, 1975; Eysenck & Eysenck, 1979; Schulman, 1974), (2) incongruous words elicited larger N400 components than did congruous words (Kutas & Hillyard, 1980b), (3) and a late positive component was larger for correctly recognized old than for correctly identified new words (Karis et al., 1984; Sanquist et al., 1980).

While our results implicated both the N400 and the LPC in the recognition memory process, a clear demonstration of

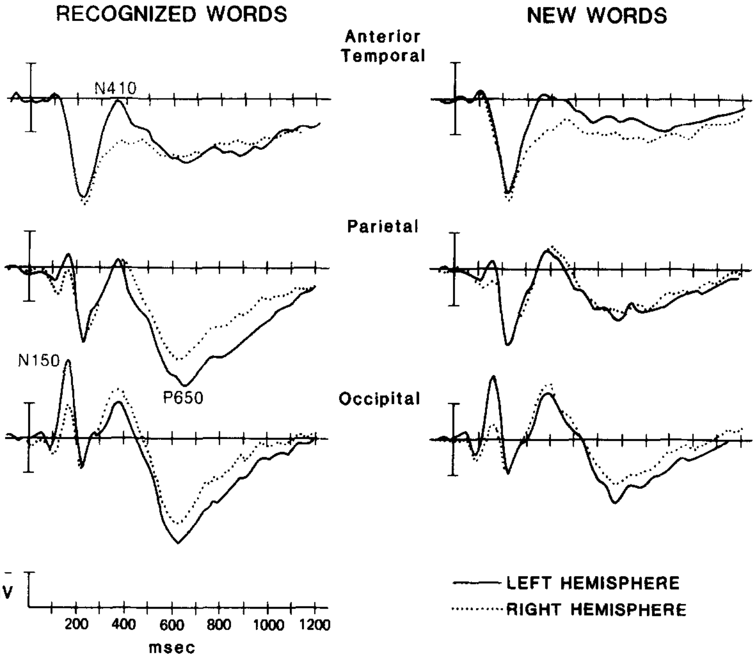

FIG. 3. ERPs to correctly recognized words and correctly identified new words from left and right anterior temporal, parietal, and occipital regions. Both types of words display larger N150 responses from the left than the right occipital regions, and larger N410 from left anterior-temporal regions. Recognized words display larger and more asymmetrical (left parietal larger than right) P650 than new words.

a specific relationship between either component and subsequent memory would require a word-by-word analysis of the ERPs recorded during initial presentation as a function of subsequent performance. Indeed, it was on the basis of such an analysis that Karis et al. (1984) demonstrated that the P300 elicited by the initial presentation of a word was correlated with memory strength defined in terms of free recall. The interpretation of their results, however, was somewhat complicated by their finding of group differences both in mnemonic strategies and the ERP components affected. Since most of our subjects did not commit enough errors to allow an adequate statistical analysis of the ERPs as a function of subsequent performance, we could not evaluate whether the N400 or the LPC on initial exposure might have been predictive of subsequent recognition. However, an examination of the data from two of our subjects who committed between 20 to 30 errors revealed that the late positive component was 30% larger to words that were subsequently recognized than to those that were not.

A similar finding (based on three subjects) was reported by Sanquist et al. (1980) who presented two words to subjects and asked for a same–different judgment based on orthography, phonology, or semantics. However, as in the present case, Sanquist et al. could not contrast the ERPs elicited by words which would and would not be subsequently recognized independent of the nature of the initial decisions. Since words followed by "similar" judgments were not only more likely to be recognized but also to display larger LPCs than words eliciting "different" judgments, the ERP averaged according to subsequent performance may have reflected this unequal composition of words rather than differential mnemonic processing.

In order to address this issue we revised the methods of experiment 1 so as to increase the number of subsequently unrecognized words.

METHODS EXPERIMENT 2

Subjects

Eight right-handed subjects (three females, mean age 23.5, none of whom had served in Experiment 1) were paid to participate in the experiment.

Stimuli and Procedures

Unlike in experiment 1, all 120 phrases and fifth words were presented in a single judgment task, immediately followed by an unexpected recognition test, including 120 old and 120 new words, randomly intermixed. In addition to these modifications, word exposure duration was decreased to 17 ms and all interstimulus intervals were shortened by 200 ms. Finally, in an attempt to "load" subjects' memory prior to the experiment, they were given a list of 40 words to memorize in 5 min. Following the recognition test, these subjects were asked to recall as many of the 40 words as possible.

Aside from these changes, the stimulus and task parameters and data analyses were identical to those for experiment 1. ERPs were recorded from the same sites, with the same system bandpass as in experiment 1; however, in place of silver–silver chloride electrodes, tin electrodes attached to an elastic cap were employed ("Electro-Cap").

RESULTS EXPERIMENT 2

Behavioral Data

Subjects' recognition performance was worse in this revised paradigm than in the first experiment. Subjects correctly recognized 70% of the 120 old words and correctly identified 83% of the new words. Of the old words, words that fit with the sense of the phrase were recognized significantly more often than those that did not (85% vs 62%, $F(1,7) = 34.5$; $p < .0006$). On average subjects recalled 18 (range 17–23) of the 40 words presented prior to the sentences.

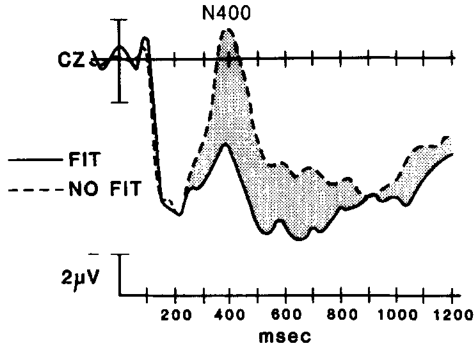

FIG. 4. Grand mean ERPs from Experiment 2 for fit and no-fit words in the judgment task.

Event-Related Potentials

In general, the effects obtained in Experiment 1 were also observed in this experiment. Thus, as seen in Figure 4, words that did not fit with the preceding phrase had substantially larger N400s than words that fit (main effect of Condition, $F(1,7) = 33.8$, $p < .0007$). As in the first experiment the N400 displayed a slight right posterior predominance (Condition $\times$ Electrode $\times$ Hemisphere interaction $F(4,28) = 2.24$, $p = .09$).

In addition, as in Experiment 1 the N150 response was larger from the left than the right occipital region (hemisphere $F(1,7) = 8.5$, $p = .02$) and the anterior N410 was larger over the left than the right temporal and frontal sites (Electrode $\times$ Hemisphere $F(4,28) = 3.7$, $p < .01$).

During the recognition test correctly recognized old words elicited larger P650s than did new words (main effect of Condition $F(2,14) = 4.65$, $p < .02$; see Figure 5). Moreover, ERPs to correctly recognized old words displayed significantly larger P650 components than did old words which were not recognized ("misses") ($F(1,7) = 8.4$, $p < .02$). The P650s to misses were not significantly different from those elicited by correctly identified new words. Additionally, new words, incorrectly "recognized"—that is, identified as old words—

were not significantly different from new words correctly rejected in terms of the P650 ($F(1,7) = 0.7$, $p = .42$).

ERPs to the Initial Presentation of the Final Words Averaged According to Subsequent Recognition

On average subjects failed to recognize 36 of the 120 fifth words (range 11–55). The ERPs to the initial presentation of these words were compared with the ERPs comprised of an equal number of randomly selected words that were subsequently recognized. As seen in Figure 6a, ERPs to words that were subsequently correctly recognized displayed more positivity than did ERPs to words that were not subsequently recognized (main effect of Condition, peak 400–950: $F(1,7) = 9.8$, $p < .01$; area 400–950: $F(1,7) = 7.3$, $p < .03$). This difference onset at 250 ms and was more pronounced over the left than the right hemisphere (Condition × Hemisphere, area $F(1,7) = 7.2$, $p < .03$; peak $F(1,7) = 5.8$, $p < .04$).

Measures of N400 amplitude also differentiated between subsequently recognized and unrecognized words, the latter displaying larger amplitudes over temporal and parietal regions (Condition × Electrode, peak: $F(4,28) = 2.8$, $p < .04$). However, since more incongruous than congruous words were subsequently unrecognized, this effect could well have been due to the larger N400 response to no-fit than fit words.

To investigate this hypothesis ERPs were further segregated according to whether they had been elicited by fit or no-fit words. As three subjects made fewer than six recognition errors on words that fit, this comparison includes data from only five subjects. All the subjects are included in the no-fit comparisons. As seen in Figures 6b and c, both fit and no-fit words that were subsequently recognized displayed greater positivity relative to words from the same category when they were not subsequently recognized (fit words, 400–950 ms peak: Condition × Electrode $F(4,28) = 4.2$, $p < .01$; area: Condition × Electrode $F(4,28) = 3.4$, $p < .03$; no fit words, peak: Condition

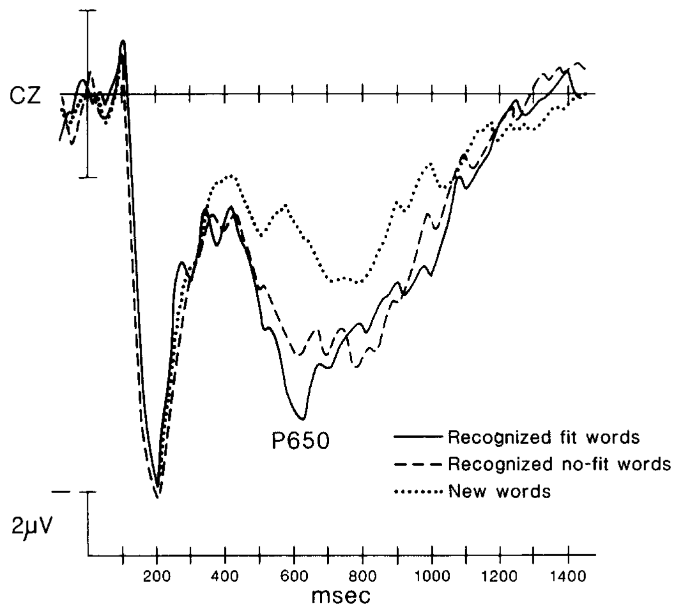

FIG. 5. Grand mean ERPs from Experiment 2 for correctly recognized old fit and no-fit words and new words.

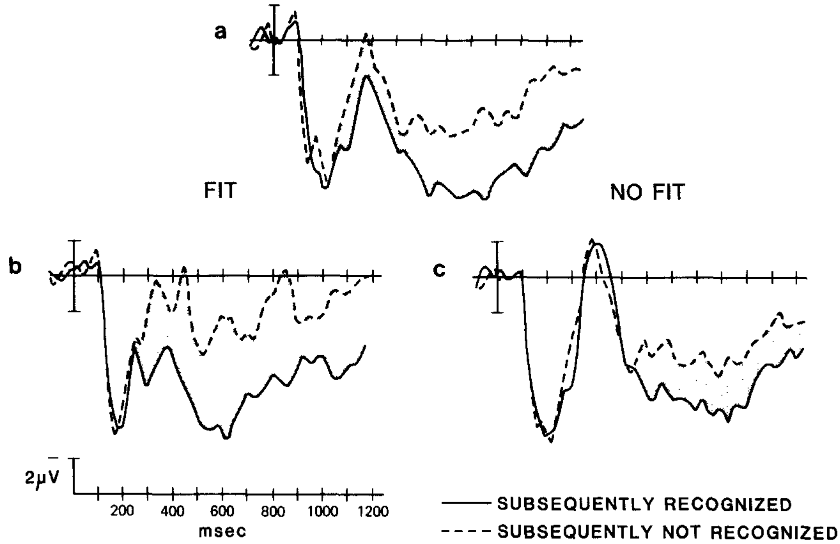

FIG. 6. ERPs recorded from CZ in the judgment task of Experiment 2 averaged according to subsequent recognition in the recognition test. (a) ERPs averaged across fit and no-fit words. (b) ERPs averaged for fit words and (c) no-fit words.

$F(1,7) = 15.4, p < .005$; area: $F(1.7) = 4.0$, $p < .08$.) However, as seen in Figures 6b and c, and in Table 2, the ERP difference between subsequently recognized and unrecognized words was evident earlier for fit than for no-fit words. Additionally, the effect of subsequent recognition was most prominent over temporal and parietal regions of the left hemisphere (see Figure 7 and Table 2).

DISCUSSION

General ERP Findings

These experiments demonstrate that during the encoding and recognition of visual language material several ERP components display considerable specificity in their timings, scalp distributions, and sensitivity to experimental variables. Accordingly these ERP components seem to reflect the activity of different functional processes engaged in this task.

N150 component. For example, all words under the present conditions elicited an N150 component. This N150 to words was localized to the posterior regions of the scalp and was consistently larger over the left than the right hemisphere. In a host of other nonlanguage visual tasks the N150 has been found to be bilaterally symmetrical or larger from the right than the left visual areas or larger over the hemisphere contralateral to the attended visual field (Harter, Aine, & Schroeder, 1982; Hillyard & Munte, 1984; Neville, 1980; Neville et al., 1982a; Van Voorhis & Hillyard, 1977). Thus, the timing and distribution of the N150, together with other reports demonstrating its sensitivity to attention (Eason, Harter, & White, 1969; Hillyard, Munte, & Neville, in press; Hillyard & Munte, 1984; Neville, 1982; Van Voorhis & Hillyard, 1977), are consistent with the view that it reflects asymmetric early attentional priming like that proposed to underlie behavioral asymmetries in the processing of language and nonlanguage material (Kinsbourne, 1975).

Two varieties of N400. Also evident from our data was the existence of two distinct types of late negativities within 300 to 500 ms following word onset. In the present studies, two negative components were elicited around 400 ms. With the exception of incongruent (no-fit) words, all words elic-

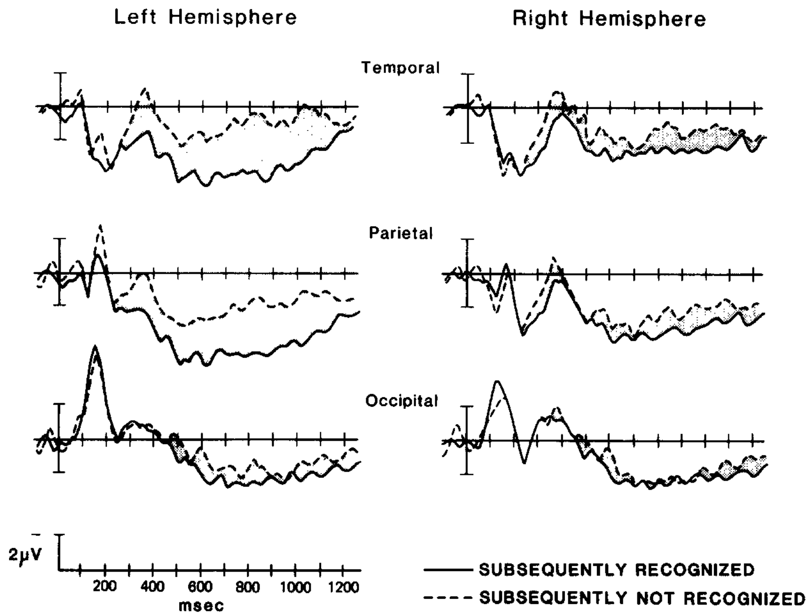

FIG. 7. ERPs recorded in the judgment task of Experiment 2 (averaged across fit and no-fit words) averaged according to performance in the recognition test. The effect showing a larger positivity to words subsequently recognized is largest in ERPs recorded from the parietal and temporal regions of the left hemisphere.

ited an N410 with an anterior distribution that was more prominent over the left than right hemisphere. The timing and distribution of this component are very similar to those of the N410 elicited by isolated words presented to the left and right visual fields for written identification (Neville et al. 1982a, 1982b). Since the N410 to isolated words was not evident in the ERPs of congenitally deaf individuals, we have hypothesized that it might reflect the activation of processes concerned with phonological decoding or grammatical recoding of written language material (Neville et al., 1982b). The observation of a similar response to foveally presented words in the present experiments supports the generality of the earlier findings.

A second negative component within the 300- to 500-ms poststimulus was observed in the ERPs to the fifth and final words. This N400 was most marked over the posterior regions of the right scalp in response to no-fit words. The enhancement of this N400 to incongruous words, its posterior distribution, and its right hemisphere predominance clearly distinguish it from the anterior N410. Rather, our posterior N400 is very similar in latency and distribution to the N400 wave originally observed in response to semantic anomalies (Kutas & Hillyard, 1980a).

TABLE 2
SUBSEQUENTLY RECOGNIZED (SR) AND SUBSEQUENTLY UNRECOGNIZED (SU) YES AND NO-FIT WORDS

	Left parietal	Right parietal	CZ
	Area 250–500 ms (μV ± SE)		
Yes fit words			
SU	1.11 ± 0.62	1.01 ± 0.37	1.89 ± 1.90
SR	2.94 ± 1.15	1.46 ± 1.09	5.38 ± 1.60
No-fit words			
SU	1.14 ± 0.76	0.59 ± 0.96	1.90 ± 1.45
SR	1.43 ± 1.24	0.56 ± 0.92	2.48 ± 1.22
	Area 500–900 ms (μV ± SE)		
Yes fit words			
SU	2.27 ± 1.01	1.88 ± 0.64	2.42 ± 0.89
SR	4.35 ± 0.97	2.52 ± 1.03	6.84 ± 1.47
No-fit words			
SU	2.36 ± 0.85	2.75 ± 0.73	4.86 ± 1.45
SR	3.82 ± 1.35	2.84 ± 0.87	6.52 ± 1.74

The results from several studies have implicated the posterior N400 in cognitive brain systems engaged during word processing (Bentin et al., 1985; Harbin, Marsh, & Harvey, 1984; Holcomb, in press; Kutas & Hillyard, 1984; McCallum, Farmer & Pocock, 1984; Rugg, 1984). While Kutas and her colleagues have focused on developing the posterior N400 as a measure of semantic expectancy or priming, others have argued for its relation to a search process (Bentin et al., in press), other mismatch negativities (Naatanen, in press; Polich, Vanasse, & Donchin, 1980) or a general priming process (Rugg, 1984). However, it is not clear that each of these different studies has been referring to the same electrophysiological event—that is, the posterior N400. Indeed, the results of the present investigations underscore the need for accurate component identification utilizing multiple recording sites including lateral locations.

ERPs and Recognition Memory

The behavioral results from both of the present studies confirm and extend the findings of several investigations which have shown that when subjects are asked to make cognitive judgments about a briefly exposed word, subsequent memory performance is strongly influenced by the nature of the decision. We found that questions concerning whether or not a word fit into a given category or sentence frame led to high levels of performance on a subsequent recognition memory test whether the test was expected (e.g., Experiment 1) or unexpected (e.g., Experiment 2). Furthermore, under both intentional and incidental learning conditions, positive decisions at initial presentation were associated with significantly higher recognition performance than were negative decisions.

ERPs during recognition test phase. This differential recognizability of new and old words following yes and no decisions was reflected in the brain wave patterns recorded from the scalp during the recognition test. The amplitude of a late positivity peaking around 650 ms but lasting the duration of the recording epoch was a reliable index of recognition performance. The P650 was largest for correctly recognized fit words, smallest for correctly identified new words, and intermediate for correctly recognized no-fit words. These results are in many respects similar to several reports of an enhancement in a late posteriorly distributed positivity for correct items during recognition and recall performance (Karis et al., 1982, 1984; Sanquist et al., 1980).

While it may be that the marked enhancement of the P650 component to correctly recognized words is specific to the recognition process, there are alternative explanations for these data.[2] In fact, Karis et al. (1984) have suggested that the larger P3 to recognized words is a function of a combination of factors including a "target effect" and the confidence of the associated decision. For instance, if recognition is considered the outcome of a series of comparisons between the test item and correct and incorrect episodic traces, with only the correct trace yielding a sufficient number of matching features so that a recognition hit occurs, then the amplitude of the P3 may reflect the occurrence of a match in general rather than recognition per se. Same or matching judgments have been found to be associated with larger LPCs than different or mismatching items in a number of different paradigms. Although P3 amplitude has been found to increase with the confidence with which a decision is made (Pritchard, 1981), the relevance of those observations to the relation between P3 amplitude and recognition memory is debatable. There are no empirical data indicating that the yes and no recognition decisions in the Karis et al. or the present studies were arrived at with more or less confidence. However, it is conceivable that low confidence levels associated with false alarms may

[2] The scalp distribution and conditions of elicitation of P650 make it likely that it reflects the process often referred to as the P3. However, we have chosen to label this component according to its mean latency.

have played a role in producing equivalent ERPs for false alarms and correct rejections. Further studies along these lines would benefit from employing measures of confidence and signal detectability.

In the present data, except for the small quantitative difference in the amplitude of the P650 component, the ERPs to correctly recognized fit and no-fit words were morphologically indistinguishable. That is, there was no signature in the ERP elicited by a word during the memory test which revealed the nature of the relationship (i.e., congruity) between that word and its preceding context at the time of initial presentation. Since several ERP investigations have demonstrated that words which are semantically incongruous with a sentence context are associated with an enhanced N400 component under both reading and sense/nonsense decision task situations, the absence of the N400 to correctly recognized no-fit words in the present experiments is provocative. It suggests that under these test conditions, subjects do not recognize the no-fit words by active reconstruction of the initial context and evaluation of the relationship between it and the test word. If all aspects of the original context and encoding and elaborative operations were repeated or encoding dimension reinstated (e.g., as Kolers, 1973, 1979, suggested) at the time of recognition testing, then correctly recognized incongruous words might have displayed a sizable N400 component. Thus these results are more in line with Humphreys' (1976, 1978; also reviewed in Mandler, 1980) view that information about a study item is encoded and retrieved independently of its verbal context and that under certain circumstances accurate recognition can proceed without retrieval of the relational information.

This interpretation is not intended to diminish the role of encoding context or redintegration in memory performance (Rabinowitz, Mandler, & Patterson, 1977; Tulving, 1976), but rather to indicate that the process of recognition may be carried out without invoking the same mental operations engaged during the original study presentation. For example, the results might well have been different if recognition had been queried within the context of the original sentences or if the task had been recall rather than recognition of the test words. Several researchers have indeed proposed that the mental reinstatement of the physical environment is more crucial for recall than recognition performance.

ERPs during initial presentation—Fit vs no-fit responses. Whatever the mechanism of the recognition process per se and the extent to which it differs from those engaged during recall, there seems to be little argument that many of the factors that determine whether an item will or will not be subsequently recognized are brought to bear during the formation of the memory trace (that is, during or shortly after initial presentation) rather than sometime later or during the test phase. Indeed most contemporary theories of recognition memory focus on the qualitative or quantitative differences in the encoding and elaborating operations at input (Anderson & Reder, 1979), the nature of the information stored within or along with the memory trace (e.g., tags, bundles of features, encodable elements) (Anderson & Bower, 1972), the relationship between the studied items and the test environment (Morris, Bransford, & Franks, 1977; Tulving, 1979), or the similarities between encoding and retrieval processes (Fisher, 1981; Morris et al., 1977; Moscovitch & Craik, 1976). Despite this emphasis on encoding/elaborative operations, evidence for their existence and timing is largely inferential.

Several investigators have argued that words associated with yes responses were better remembered than those associated with no responses because they were accorded more elaborate encodings and formed a more integrated unit with the sentence in which they were presented (Craik & Tulving, 1975; Schulman, 1974). However, these researchers have provided neither any operationally defined measure of elaboration or degree of integration nor any direct indication of how the congruity principle acts to differentially affect positive and negative judgments. Generally, the reaction times following yes and no decisions during the study phase have not been found to be significantly different; nor have any other measurable indices. Other investigators have suggested operational definitions of elaboration based on the number of decisions made about congruent encodings; however, it is not apparent how these could be utilized in the present experiment (Johnson-Laird et al., 1978; Mathews, 1977).

In contrast, the brain response (i.e., ERPs) elicited by fit and no-fit words following the sentence fragments were easily distinguishable. In both of our experiments as in previous data, significantly larger N400 waves were elicited by incongruous than congruous words. Thus, according to this electrophysiological index, fit and no-fit words could be distinguished by about 250 ms after their presentation. We take this as evidence for the differential encoding afforded congruous and incongruous words. Insofar as the words which generated large N400s were more poorly remembered than those with smaller N400s, this processing difference is related to the memory process. However, incongruous words had equally large N400 peak amplitudes whether or not they were subsequently recognized. Hence, the nature of the encoding manifested in the N400 amplitude does not completely or specifically determine whether a word will or will not be subsequently recognized. Rather, it is the amplitude of a late positive component which manifests the differential encoding/elaboration predictive of subsequent recognition.

The LPC and subsequent recognition. Similar to the enhancement of a positivity seen during the recognition test phase, words which would be subsequently recognized had more late posterior positivity over the left hemisphere than did words which would not be later recognized. This positive harbinger of recognition was present in ERPs to both congruous and incongruous words, albeit with a different latency of onset. For fit words, the ERP effect of subsequent recognition was evident by 250-ms poststimulus onset and was maintained throughout the recording epoch. On the other hand, for no-fit words, the onset of the enhancement in the late positivity was not evident until around 500–550 ms. That is, the decision required by an incongruous word seems to have resulted in a delay of almost 300 ms in the process manifested by the enhanced LPC. Whereas both fit and no-fit words were associated with qualitatively similar processes, incongruous events displayed the enhanced positivity for a shorter duration.

This delay in the encoding/elaborative process for incongruous words has generally not been evident in reaction times, but it is clear in the delayed LPC onset and may well account for the finding that incongruous words were less well recognized than congruous words. In any case, within 250 ms for congruous words and 500 ms for incongruous words, the brain's response to words which it will subsequently recognize is clearly distinguishable from those which it will not recognize. Whether this process (reflected in the LPC) is one of encoding or elaboration is at present unknown. No theories have specified the time scale along which these processes act and where one stops and the other begins. However, our working hypothesis for further studies is that the LPC enhancement reflects processing beyond the initial encoding (which is reflected in the N100–N400 components), namely, the elaborative/consolidative procedures engaged for the laying down of distinctive memory traces.

As we noted earlier, the nature of the ERP difference predictive of future recognition is similar to the ERP difference subsequently obtained between recognized old and new items. In both cases, the ERP effect was evident in a late, broad positivity that was large over temporo-parietal regions of the scalp and was slightly more pronounced over the left than the right hemisphere. This distribution is consistent with the large clinical literature showing deficits in mnemonic functioning for verbal material after left hemisphere lesions and for nonverbal material after lesions to the right hemisphere (Heilman & Valenstein, 1979). One of us has previously observed that a similar process with a right hemisphere predominance was engaged by the recognition of photographic material (Neville et al., 1982c). These results not only argue for the proposed relationship between recognition memory and LPC enhancement but also suggests that there may be some overlap in the neural systems whose activity renders events more recognizable and systems that are active during recognition itself.

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