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Contextual Effects in Language Comprehension: Studies Using Event-Related Brain Potentials

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In natural spoken or written language, the individual words of a message are understood in relation to the context built up by previous words. A coherent interpretation is achieved by integrating the meanings of successive words within the evolving context. One aspect of this interpretive system is the formation of expectancies for words that are about to occur in the message. In many cases, the subsequent words in a sentence can be predicted accurately after hearing the first few words. These word expectancy effects are readily observable in everyday life when our friends helpfully finish our sentences with an annoying degree of precision. In the more dispassionate setting of the laboratory, it has been shown that word expectancies play an important role in language comprehension (e.g., 6,17,28,33,35–37).

Most studies of context and word expectancy effects have measured verbal or manual reaction times to the stimuli of interest. An alternative approach that we have taken is to record the electrical responses of the brain (event-related potentials or ERPs) that are associated with the processing of individual words in sentences. The ERPs triggered by sensory stimuli represent summated field potentials arising from the neuronal circuits engaged in processing of stimulus information (14). ERPs can be recorded noninvasively from the scalp in the form of voltage-time waveforms that include a number of peaks or "components" at specific latencies.

There are two principal advantages of the ERP technique in studies of language processing. First, the method is nonintrusive, in that the subjects need not perform a secondary behavioral task (such as making a speeded motor response) that might interfere with the reading or listening process under investigation. Second, the ERP latencies give a measure of processing differences that are more closely coupled in time with the relevant cerebral events rather than being delayed by several hundred msec, as are reaction time (RT) measures. In general, ERP recordings and behavioral measures provide converging and mutually complementary data for isolating and defining the processes underlying language comprehension.

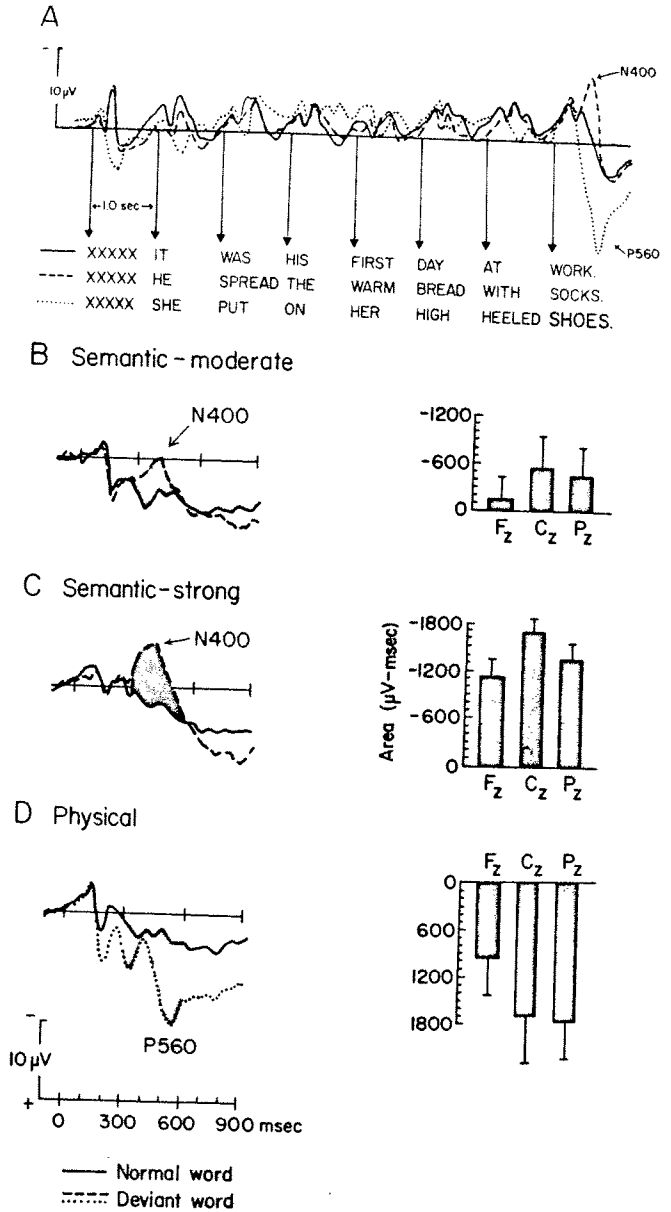

FIG. 1. Event-related potentials elicited by semantically and physically incongruous words occurring unpredictably at the ends of visually presented sentences. **A:** timing of word presentations for three sample sentences and typical ERP waveforms elicited by each sentence type. Note the N400 wave following semantically anomalous ending "socks." **B–D:** In each comparison, grand average ERPs for congruous (*solid line*) and deviant (semantic, *dashed line*; physical, *dotted line*) terminal words are superimposed. The 300-msec area that was quantified is indicated by shading. The means and S.E. of these difference areas (for deviant minus normal endings) are shown in bar graphs at right. From Kutas and Hillyard (19).

The experimental design that we have used in a number of ERP studies of contextual effects is illustrated at the top of Fig. 1 (20). A series of sentences (160 or more) was presented to the subjects, one word at a time, on a video monitor. The only instruction was to read the sentences, with the understanding that questions may be asked about their contents at the end of the experiment. The sentences differed in the degree to which the terminal words fit the context established by the initial words. Some of the sentences were terminated by expected, congruous words, and others ended with semantically anomalous words and still others with physically incongruous words in bold-face type. Sentences having these various types of endings were presented in unpredictable order.

The ERP averaged over the semantically incongruous endings was characterized by a broad negative deflection that had its onset at about 200 msec and peaked at 400 msec; this negative peak was not evident in the ERPs to semantically acceptable endings. The amplitude of this "N400" was larger for those terminal words that were the most highly discrepant from the sentence context. In contrast, the unpredictable occurrence of physically deviant words in bold-face type elicited a late positive complex of waves rather than a negativity.

Subsequent experiments demonstrated that other types of nonsemantic deviations in sentence contexts similarly failed to elicit an N400 wave. Grammatical errors of various types appearing unpredictably in a text elicited only small and inconsistent late waves (Fig. 2) that did not have the posterior, right-sided scalp distribution

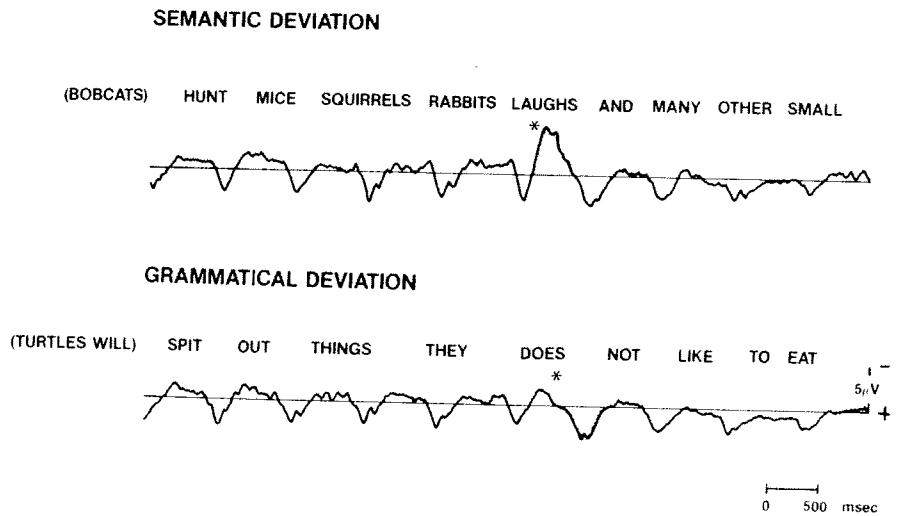

FIG. 2. Comparison of ERPs to semantically and grammatically deviant words presented unpredictably in prose passages. ERPs shown are averaged over several dozen different deviant words of each class for each subject. Note that semantic anomalies elicit an N400 wave, whereas grammatical deviations (incorrect noun number, verb tense, or verb number) do not. Based on data from Kutas and Hillyard (20).

characteristic of the N400 elicited by semantic anomalies (Fig. 3), nor did the occasional appearance of exotic, colored ("modern art") slides in place of words in a text elicit an N400 wave, but rather a late ERP complex consisting of a frontal N300 and a parietal P450 wave (21). Deviant events within a patterned physical sequence or deviant notes within a musical passage also appear to trigger a late parietal positivity that resembles the well-known P300 wave rather than a late negativity (2).

On the other hand, semantic anomalies in linguistic communications were found to elicit N400 waves whether the modality of presentation was auditory, visual, or

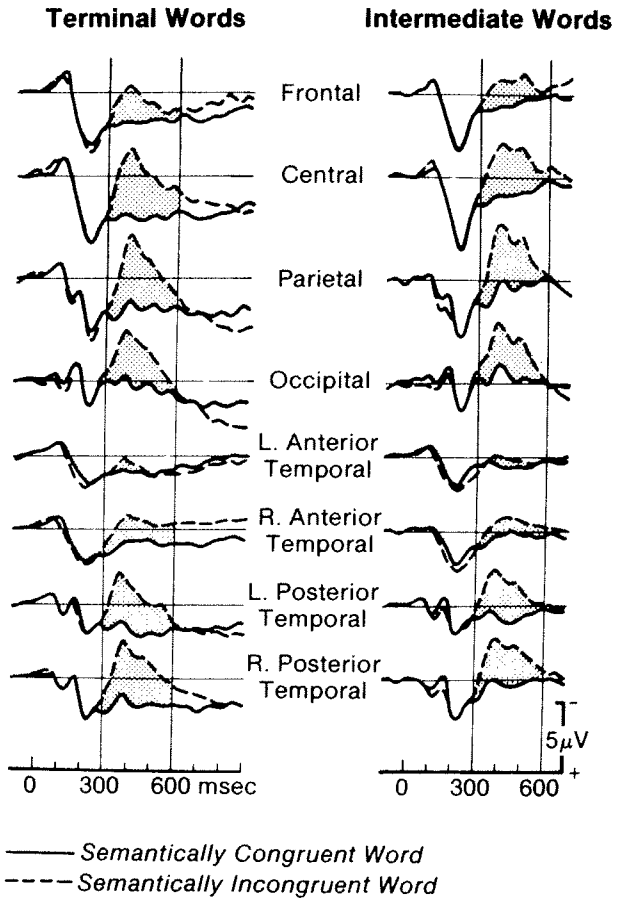

FIG. 3. Grand average ERPs from eight scalp sites elicited by semantically anomalous (*dashed lines*) and semantically congruous (*solid lines*) words in a prose passage. Note N400 component to anomalous words is largest over parietal and posterior temporal areas, with a slight right hemispheric preponderance. N400 waves are elicited equally well by anomalous words at the ends of sentences (left column) and at intermediate positions in the sentences (right column). From Kutas and Hillyard (20).

American Sign Language (15,24,27,29). In each modality the anomalous word or sign triggered an N400 having the typical, posterior scalp distribution, suggesting that a common mode of processing was activated by the semantic discrepancies. These observations narrow the possible interpretations that may be given to the processes underlying the N400. The elicitation of N400 waves by anomalies in spoken language indicates that this ERP does not depend on the transformation of orthographic into phonological representations (i.e., phonemic recoding), since this step is not required when listening to speech, nor does the N400 reflect the accessing of a word's meaning through phonology (i.e., its sound), since this process is obviously absent in congenitally deaf users of sign language. Evidently, the N400 wave is independent of the surface structure and modality of the language in which the anomalies are presented.

A number of studies have demonstrated that semantic anomaly is not a prerequisite for eliciting the N400 wave (7,8,22,23). Instead, the N400 amplitude appears to grow systematically as a function of how unexpected a word is in a given context, with anomalies representing one end of the continuum of expectedness. In one experiment (22), for example, subjects were presented with 320 sentences that all had semantically acceptable endings but varied in the degree to which the terminal word was predictable (expected), as established by the Cloze procedure (3). Sentences varied from those with highly constrained and predictable endings ("He mailed the letter without a *stamp.*") to more open-ended sentences with less predictable endings ("He was soothed by the gentle *wind.*"). Recordings of ERPs to the terminal words showed that N400 amplitude was an inverse function of word expectancy (Fig. 4). The correlation between N400 amplitude and Cloze probability was above 0.9 at posterior electrode sites.

The finding that N400 amplitudes were systematically reduced for more expected words suggested that this ERP might be a manifestation of a semantic priming process (22). Semantic priming is generally conceived as a process whereby specific representations in semantic memory are partially activated by the presentation of a prior stimulus or context. Memory representations of words and their associated meanings are activated according to their semantic or associative relationship to the priming stimulus. Words that have had their representations primed by a prior context can be accessed and recognized faster and more reliably than can unprimed words [for a review see (9)]. Since N400 amplitude varied in a manner similar to behavioral measures of priming, we suggested that the N400 elicited by a word was a graded, inverse measure of the extent to which that word had been primed by the prior context (22).

A number of experimental observations have lent support to the hypothesis linking semantic priming and N400. Fischler and colleagues (8) found that the N400 to terminal words in sentences of the form "A robin is a *bird*" and "A sparrow is not a *vehicle*" did not depend on the truth or falsity of the proposition but rather on the degree of semantic association between the principal noun arguments in the sentence. Thus the word "vehicle" would elicit a large N400 by virtue of not having been primed by "sparrow," even though the sentence is perfectly acceptable

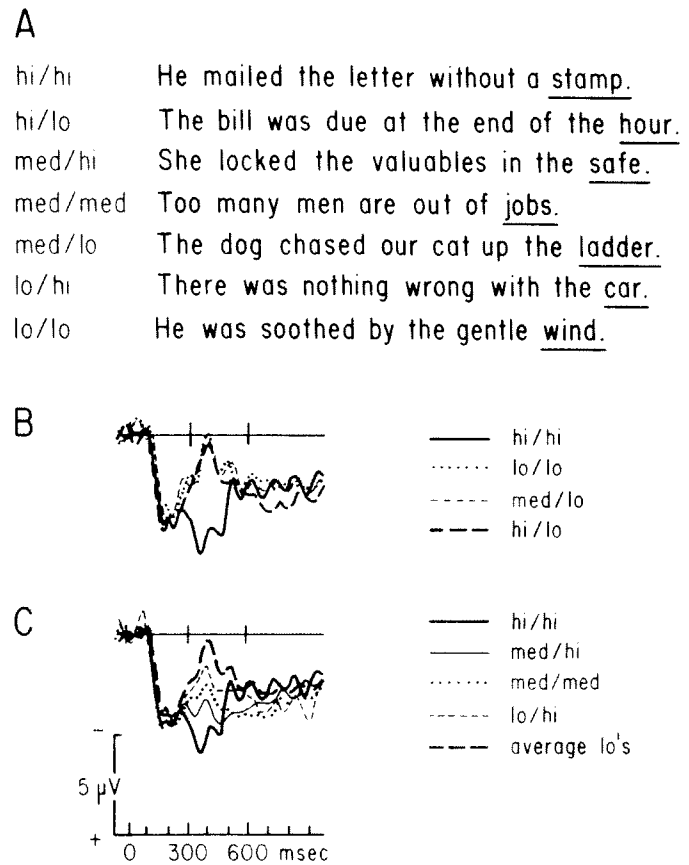

FIG. 4. **A:** Examples of seven sentences that varied both in degree of contextual constraint and in Cloze probability of the terminal word. On the left are shown the degree of contextual constraint/cloze probability for each sentence class. **B:** Comparison of grand average ERP to words having a high Cloze probability (*solid line*) with ERPs to words of low Cloze probability (*dotted* and *dashed lines*). All low Cloze probability words elicited on N400, regardless of the degree of contextual constraint. **C:** Grand average ERPs to low, medium, and high Cloze probability words terminating sentences of medium contextual constraint. From Kutas and Hillyard (22).

grammatically and semantically. A similar effect of semantic association was found when anomalous or low probability sentence endings were segregated according to whether they were semantically related to the most expected endings (22,23). Terminal words that were related to the most expected and, hence, the most primed endings elicited a smaller N400 than did unrelated endings, even though both types of endings were nonsensical. In the sample sentences shown in Fig. 5, for example, the terminal word "drink," which is a semantic associate of the most expected ending "eat," elicited a smaller N400 than did the completely unrelated ending

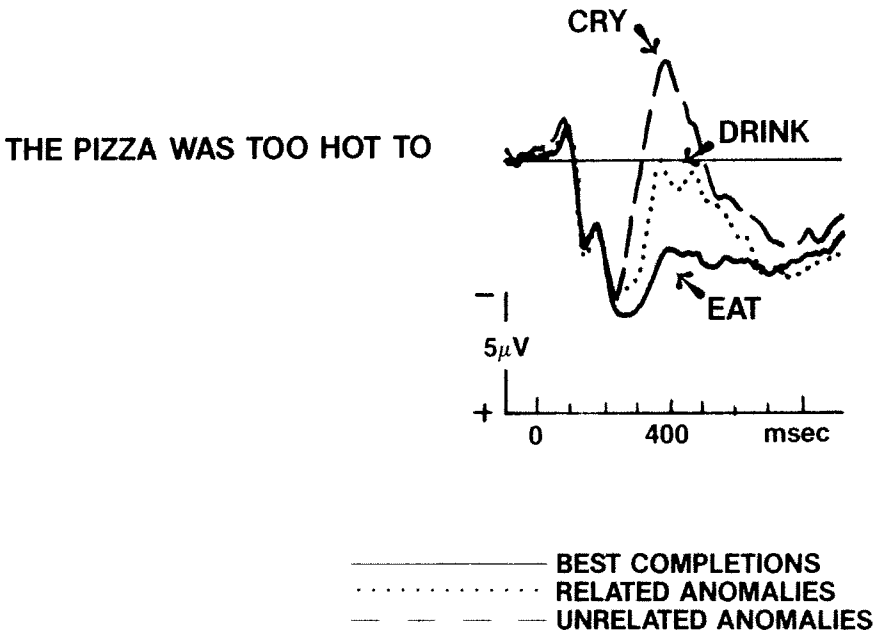

FIG. 5. Grand average ERPs to the most expected terminal words (best completions) and to semantically anomalous words that were either related or unrelated to the best completion. Note that N400 is reduced when anomalous endings are related to the most expected ending. Sample endings are for illustrative purposes only, since the same sentence frames were never repeated in this experiment. Data from Kutas et al. (23).

"cry." Such results were interpreted in terms of a partial priming of the related but incongruous ending.

If the N400 amplitude indeed reflects the amount of semantic priming a word has received from prior context, one would also expect to find N400 waves elicited by all the words in a sentence, varying in amplitude to the extent that each had been semantically primed by prior words. Such N400s can be observed by making across-sentence averages on a longer time base (Fig. 6) (26). These averages highlighted the lateral asymmetry of the N400 component (right hemisphere more negative than left), an asymmetry that was reduced in subjects having a family history of left-handedness. The N400 was found to be larger to the open class (i.e., content) words in the sentences than to the closed class (i.e., function) words; this may reflect a difference in memory organization for these two types of words although other factors such as frequency of usage, concreteness, and word length could not be ruled out in this experiment. In accordance with the priming hypothesis, N400 amplitudes were reduced for the last few content words in a sentence, presumably because they had received more extensive priming from the earlier words.

ERPs that appear equivalent to the N400 have also been observed in studies in which sequences of content words rather than sentences were presented. When the

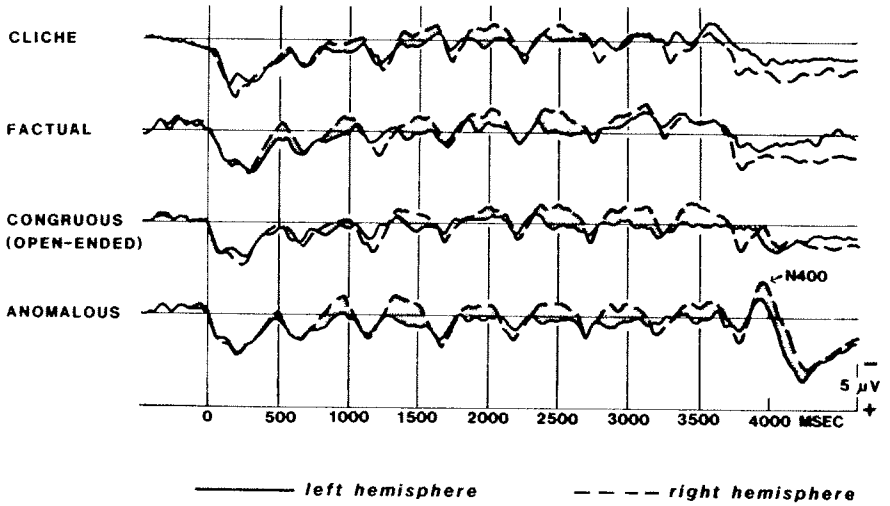

FIG. 6. Grand average ERPs to warning stimuli at time zero (xxxxx) and subsequent seven word sentences, recorded from left and right posterior temporal sites. ERPs to three different types of congruous sentences and to semantically anomalous sentences are shown. Note N400 to terminal word in latter case. From Kutas et al. (26).

first few words of a sequence belonged to one semantic class (e.g., names of cities, birds, and the like), the final word elicited a smaller late negativity at 300 to 400 msec when it was from the same semantic class than when it belonged to a different class (5,13,30). Bentin et al. (1) presented subjects with sequences of words and pseudowords and asked them to make a lexical decision on each item. Again, it was found that words preceded by semantically related words elicited a smaller late negativity than words preceded by unrelated words. The authors related this reduction of N400 to a facilitation of RT for the lexical decision when a word was preceded by semantic associates. Such facilitation is frequently interpreted as an index of semantic priming.

The N400 also behaves as an index of semantic priming in studies in which ERPs were recorded to pairs of words that varied in their degree of semantic association (4,16,18,32). In the study of Kutas (18), for example, each trial consisted of two words separated by a stimulus onset asynchrony (SOA) of 700 msec, followed by a single letter probe. The subject's task was to indicate whether the probe letter was contained in either of the two prior words. Even though this task was designed not to draw the subject's attention to the semantic relationship between the two words it was clear that related word pairs had smaller N400 amplitudes than did unrelated pairs (Fig. 7, left). This suggests that the N400 differences in this task may have reflected an automatic component of semantic priming. In another condition (Fig. 7, right), the subject's attention was actively directed to the semantic relationship between the two words by requiring them to rate the strength of the semantic association between them. This manipulation did not appear to alter the

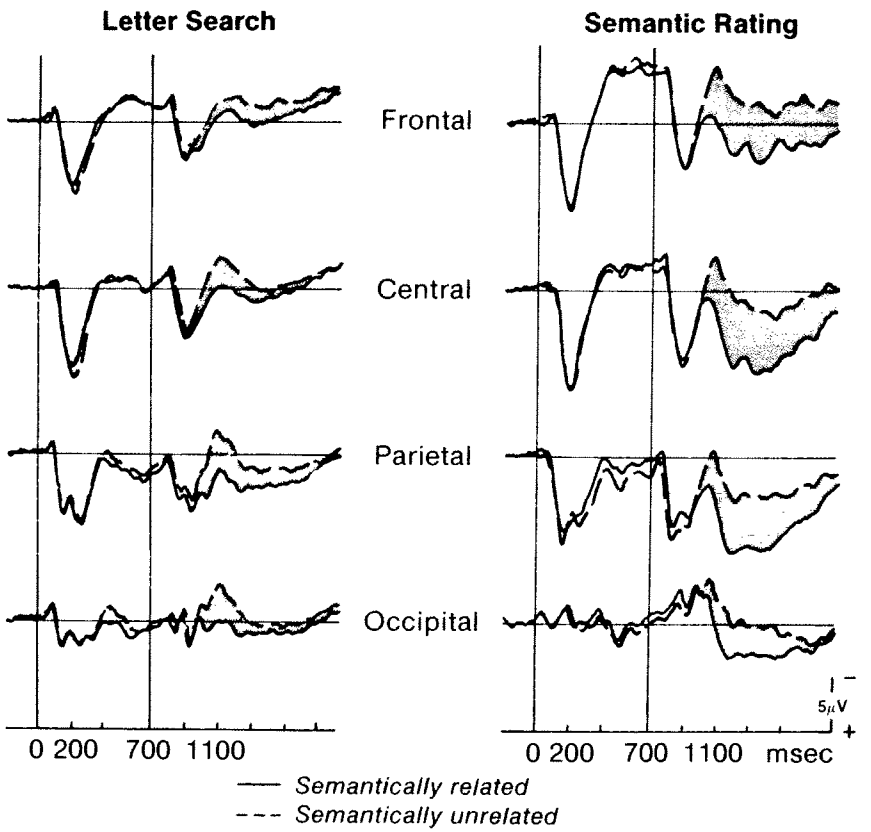

FIG. 7. Grand average ERPs to pairs of words in the letter search task (left column) and semantic rating task (right column). Note larger N400 when second member of word pair is semantically unrelated to the first word. From Kutas and Van Petten (25).

N400 difference between related and unrelated word pairs prior to about 400 msec; after 400 msec the related words elicited an enhanced late positivity. These results suggest that both automatic and attentional components of priming may be reflected in the ERP.

All the evidence reviewed above appears consistent with the view that the N400 wave is closely related to semantic priming processes. Although there are indications that N400 amplitudes may be sensitive to other forms of priming based on phonology and orthography (25,31), it is clear that semantic associations and context exert the strongest influence over this ERP. This finding suggests that the N400 should be useful in the diagnosis and clinical evaluation both of psychopathological conditions in which word associations are made abnormally and of language disorders in which word meanings are not accesssed and related to contexts in the normal manner. Although we are not aware of any studies that employed the N400 measure to

evaluate such clinical conditions, we have used this approach to study a cerebral system that reportedly has its own peculiar language organization— the right cerebral hemisphere of split-brain (cerebral commissurotomy) patients.

The interest in studying commissurotomy patients with ERPs stems from a controversy that has emerged from behavioral studies of right hemisphere language in these patients. On the one hand, Zaidel (38–40) has reported that the surgically separated right hemispheres of two West Coast patients (L.B. and N.G.) possess lexical semantics together with a rudimentary syntactic capability and an impoverished phonological system; this pattern suggested that right hemisphere language has different operating principles from those of left hemisphere language. On the other hand, Gazzaniga and associates (11,12,34) described a marked individual variation in right hemisphere language in a separate group of split-brain patients. This variability was taken as evidence against there being general qualitative differences between the language systems of the left and right hemispheres that would be applicable to all cases (10).

We (M. Kutas, S.A. Hillyard, and M.S. Gazzaniga, *in preparation*) compared the properties of left and right hemisphere language in five commissurotomy patients using a combination of behavioral and ERP methods. The main focus of interest was to determine whether the separated hemispheres were each capable of producing an N400 wave to semantic anomalies presented in a lateralized manner to one hemisphere at a time. Using this ERP index of semantic processing, we addressed the question of whether qualitatively similar neural systems are engaged when the right and left hemispheres are confronted with semantic anomalies.

Subjects were presented with 200 to 300 seven-word sentences in blocks of 20 each. The first six words were presented auditorily, at intervals of about 600 msec, and each sentence was completed by a 180-msec exposure of two words on a video terminal screen, one in the left visual field (LVF) and one in the right visual field (RVF). For 60% of the sentences, the words in the two visual fields were identical and semantically appropriate for the preceding context. The remaining 40% of the terminal word pairs contained anomalies: some had an anomalous word in one visual field (RVF or LVF, on a random basis) and a congruous word in the opposite field, and other sentences had inappropriate endings in both fields. On occasion, the subject was asked to name or write the terminal words that they had recently been shown. The order of normal and anomalous endings was randomized.

The ERPs were averaged separately according to whether semantically anomalous terminal words occurred in the RVF, LVF, both fields simultaneously, or neither field. "Difference waves" were then formed to reveal the N400 component by subtracting the ERP to the bilateral congruous word pairs from each of the ERPs to the word pairs containing unilateral or bilateral anomalies. The shaded areas in the difference waves in Fig. 8 represent the N400 effect associated with the differential processing of the anomaly.

Normal control subjects showed large N400 waves to either LVF or RVF anomalies (Fig. 8, left column). However, the split-brain subjects differed markedly in the amplitude of the N400 to LVF anomalies. Two of the patients (P.S. and

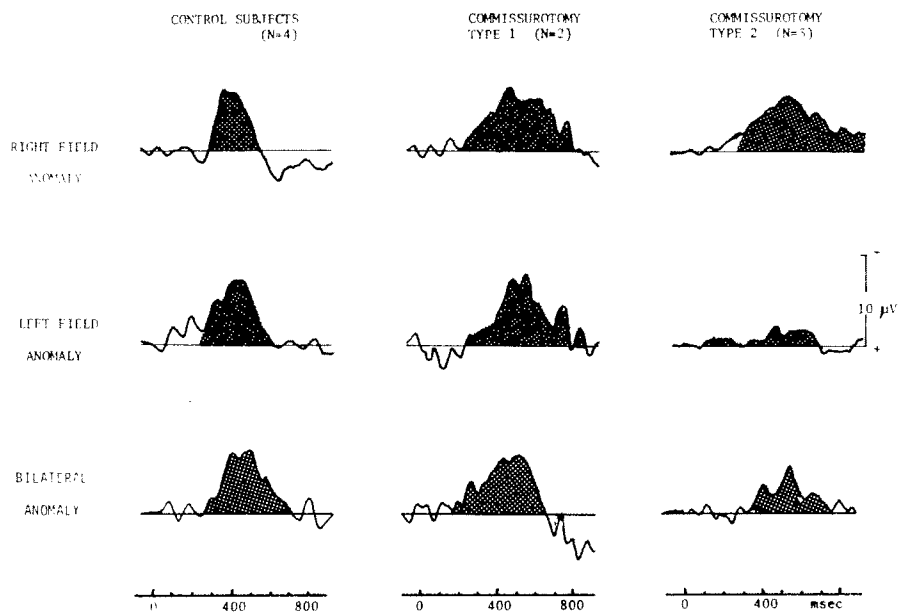

FIG. 8. Difference waves showing the N400 effect (*shaded area*) as a function of whether the anomalous word was presented to the RVF, LVF, or to both fields at once. Each difference wave was formed by subtracting the ERP to bilateral congruous endings from the ERP to the indicated type of anomaly. ERPs are shown averaged over normal control subjects (left), split-brain subjects who showed N400 waves to RVF anomalies (center), and split-brain subjects who did not (right). ERPs were recorded from a midline parietal electrode. Preliminary data from Kutas, Hillyard, and Gazzaniga, *in preparation*.

V.P.—whose data are averaged in the middle column) displayed large N400 waves to LVF anomalies, whereas three others (J.W., N.G., and L.B., right column) showed little or no N400 activity to LVF anomalies.

Although there was considerable intersubject variability in the amplitude of the N400 to bilateral anomalies, for no patient was the bilateral N400 appreciably larger than those elicited by either unilateral anomaly. This finding that the amplitude of the N400 elicited by bilateral anomalies does not approximate the linear sum of the amplitudes engendered by the unilateral LVF and RVF anomalies is inconsistent with the hypothesis that each hemisphere generates its own N400 wave independently of the other.

The large N400 amplitudes elicited by anomalous LVF words in patients P.S. and V.P. correspond with behavioral evidence that these two patients possess more highly developed right hemispheric language systems than do the other three patients. From the time of their surgery P.S. and V.P. were more advanced in syntactic competence, response to commands, and word rhyming judgments than the other patients; most significantly, both P.S. and V.P. have shown evidence for expressive language (overt speech) under the control of the right hemisphere (11,12,34). Thus,

there seems to be a general association between the "generative capacity" of the right hemisphere in these patients and the production of an N400 to semantic anomaly. The ERP evidence is thus consistent with findings of considerable variability in the organization of language in the right hemisphere.

The interpretation of these N400 differences among the patients is aided by behavioral tests that were made in conjunction with the ERP studies. In separate sessions, subjects were shown congruous and incongruous sentence endings lateralized to the LVF and were asked to judge them as "sense" or "nonsense" by pointing to written response choices with the left hand. It was found that all patients, even those who did not produce an N400 to LVF semantic anomalies, could nonetheless make the semantic judgment of sense versus nonsense at an above-chance level. In particular, the right hemispheres of patients J.W., N.G., and L.B. were able to judge whether a word fit a semantic context, but they apparently did so by a mechanism that did not engender the N400 that characterizes the left hemisphere's response to semantic anomaly.

In light of the hypothesis that N400 is a sign of a semantic priming process, it might be expected that the right hemispheres of patients J.W., N.G., and L.B. would show less behavioral evidence of priming than would those of patients P.S. and V.P. Insofar as data are available, this appears to be the case (K.M. Baynes and M.S. Gazzaniga, this volume; 41). Thus, the right hemispheric language systems of the split-brain patients show marked interindividual variability along a number of dimensions that appear to include qualitative differences in the mechanisms by which semantic memory is organized, primed, and accessed.

ACKNOWLEDGMENTS

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