*The London Symposia (EEG Suppl. 39)*
Editors: R.J. Ellingson, N.M.F. Murray and A.M. Halliday



# A Preliminary Comparison of the N400 Response to Semantic Anomalies during Reading, Listening and Signing*,**

MARTA KUTAS[1], HELEN J. NEVILLE[2] and PHILLIP J. HOLCOMB[2]

[1]*Department of Neurosciences, M-008, University of California, San Diego, La Jolla, CA 92093, and*
[2]*Neuropsychology Laboratory, The Salk Institute, P.O. Box 85800, San Diego, CA 92138 (U.S.A.)*

Investigations of language using event-related brain potential (ERP) measures have revealed a remarkably robust difference between the brain waves associated with the reading of semantically congruent and incongruent sentences (Kutas and Hillyard 1980a, 1982, 1983, 1984a; Neville et al. 1986). Numerous experiments with college undergraduates silently reading sentences, presented one word at a time, have demonstrated that unlike most congruent endings of meaningful sentences, semantic anomalies elicit an ERP with a negative peak around 400 msec (N400). Although broadly distributed, this N400 to semantic anomalies appears to be larger over posterior than anterior regions of the scalp and to be slightly larger and more prolonged over the right than the left cerebral hemisphere.

Over the past 7 years, much effort has been directed at determining what it is about the processing of a semantically anomalous sentence that elicits an N400. Such investigations have revealed that while semantic anomalies produce the largest N400 waves, they are not a necessary condition for its elicitation (Fischler et al. 1983, 1984). For instance, meaningful sentences also elicit N400s to the extent that they are terminated somewhat unexpectedly. Sentences may terminate unexpectedly because the experimenter has replaced the expected final word with another (e.g., 'The bill was due at the end of the *session*,' instead of *'month'* or because a sentence context was too weak to constrain its final word (e.g., 'He was soothed by the gentle *wind*'). In either case, less probable completions elicit an N400 wave. The amplitude of this N400 grows largely, although not wholly, as an inverse function of a word's expectancy within its surrounding context (Kutas and Hillyard 1984a).

* M. Kutas is supported by National Science Foundation Grant BNS 83-05525, by Grant NS177778 from the National Institutes of Health and by RSDA 1K02MH0022. H. Neville and P. Holcomb are supported by Grant NS14365 from the National Institutes of Health.

** This is a preliminary report of data from several experiments by Neville and Holcomb, for which more detailed manuscripts are in preparation.

Systematic manipulations of terminal word expectancies have shown that the size of the N400 is also partially determined by the nature of the semantic relationship between the expected word and the word actually presented. A strong semantic association between expected and actual sentence completions produces a smaller N400 than does either a weak association or no association at all. This effect of semantic association is obtained whether the N400 is elicited within the context of meaningful or anomalous sentences (Kutas and Hillyard 1984a; Kutas et al. 1984). Nonetheless, N400s do not seem to be specific to unexpected or anomalous sentence terminations. For example, the ERPs to the so-called content words (e.g., nouns, verbs, adjectives, adverbs) in a sentence also appear to include a small N400 component.

N400s are not unique to words in sentential contexts. Several investigators have recorded N400-like waves to relatively isolated words (e.g., Harbin et al. 1984). For example, N400s have been observed in several variants of a lexical decision task, wherein subjects decide whether a string of letters formed a word or not (Bentin et al. 1985; Holcomb 1986). In experiments of this type, the ERPs to words preceded by a semantically related word (e.g., cat – dog) contained smaller N400s than did the ERPs to words preceded either by nothing (a so-called neutral stimulus) or a semantically unrelated word (e.g., table – dog). Such findings, together with the results demonstrating that neither physical (Kutas and Hillyard 1980b, c, 1984b) nor grammatical deviations (Kutas and Hillyard 1983) within language, nor deviations within well-known melodies (Besson et al. 1984) elicit N400s, have led to our working hypothesis that the N400 reflects some aspect of semantic processes in action.

While most available data are in accord with this view of the N400, the results of a couple of studies seem to be inconsistent with this position (Stuss et al. 1983; Rugg 1984a, b, 1985). In particular, Rugg has reported that rhyming and non-rhyming words are differentiated by a late negative component (N450) following the non-rhyming words in the same way that related and unrelated word pairs are differentiated by the N400 following unrelated words. Accordingly, he has argued that the rhyme/non-rhyme effect on the N400 is not due to word processing at the semantic level, but instead reflects processes occurring at the phonological level.

We attempted to examine this hypothesis further by comparing the ERPs to the processing of semantic anomalies within written English, spoken English, and American sign language (ASL). The ERPs to English were recorded from two groups of normally hearing people who first acquired the vocabulary and grammar of English through the auditory modality while those elicited by ASL were collected from a group of congenitally deaf persons who learned to read English through picture-grapheme association in the visual modality (Holcomb 1985; Neville 1985).

To the extent that the N400 represents phonological processes, it should not be elicited by anomalous signs in the deaf for whom all language is visual or manual rather than auditory.

## METHODS

Three groups of subjects were presented with 100 – 135 sentences of high contextual constraint. In each case, half the sentences ended congruously with the most expected ('best') completion while the other half ended anomalously. At the end of each sentence, subjects indicated whether they thought that the sentence had made sense or not by means of a delayed button press.

In the written English task, 12 subjects read the sentences presented 1 word (200 msec exposure duration) at a time every 700 msec. In the analogous auditory task, 12 different subjects listened via headphones to a female experimenter (whose voice had been sampled at 12 kHz) saying each sentence at a normal speaking rate. ERP averages were synchronized to the onset of each spoken word. In the ASL task, the sentences were presented 1 sign/sec (each sign consisted of 8 digitized frames for a total duration of 240 msec) to 10 congenitally and profoundly deaf adults who were born to deaf parents and whose first language was ASL.

Artifact-free ERPs were averaged from 16 electrodes (Cz, Pz, T5/6, O1/2, F7/8, L/R22 — approximately over Brodmann's area 22, L/R41 — approximately over Brodmann's area 41, and lateral parietal sites over Wernicke's area and its right hemisphere homolog) including vertical and horizontal EOG leads, for sentences that had been responded to correctly. Scalp recordings were referred to the linked mastoids and were amplified with a bandpass of 0.01 – 100 Hz (time constant = 8 sec). The EEG and EOG were digitized at a rate of 1 point/6 msec.

## RESULTS AND DISCUSSION

Representative grand average ERPs elicited by sentence terminal words in the 3 experimental groups are shown in Fig. 1. In each case, the brain's responses to congruent 'best' completions and semantic anomalies are superimposed. Clearly, there are some differences in the ERPs elicited by both sensible and nonsensical sentences in the different modalities. Further research will help determine whether such differences are contingent upon the differences in the physical characteristics of the input or upon differences in processing strategies invoked by the nature of the input. More importantly for our present concerns are the remarkable similarities of the 'N400 region' in the responses to semantic anomalies. The relative differences between the ERPs following congruent and anomalous endings in the 3 groups are best seen in a comparison of the ERP difference waves (see Fig. 2).

For normally hearing adults during reading and listening as well as for congenitally deaf adults viewing signed sentences, semantically anomalous completions are characterized by a large centro-parietal negativity peaking between 350 and 500 msec (N400). The apparently earlier onset of the N400 in the auditory modality may to some extent reflect co-articulatory effects in the penultimate word of the sentence (that is, subjects were often able to determine that the final word would not be appropriate by how the second to last word was pronounced). This line of argument is supported by

the onset latencies of the auditory N400s reported by McCallum et al. (1984), whose stimuli were controlled for co-articulation; their N400s began approximately 100 msec later than those reported here. Likewise, the apparently longer duration of the average N400 in the auditory modality was probably due to the jitter introduced by the variation in final word durations and recognition times.

The late positivity following the N400 to semantic anomalies is most likely a member of the P300 family, elicited by the subjects' mental decision as to whether the sentence in which it occurred was sensible or nonsensical. Such a late positivity is generally not as evident in the ERPs to semantic anomalies recorded during semi-natural reading conditions in which subjects are not required to make any overt decisions (Kutas and Hillyard 1980a; Kutas et al. 1984; Fischler et al. 1985).

These ERP data indicate that the brain processes associated with the analysis of semantic anomalies are essentially equivalent during reading, listening and the perception of ASL signs. By inference, these ERPs also suggest that the 'cognitive' process reflected by the N400 wave is independent of the surface structure and modality of the

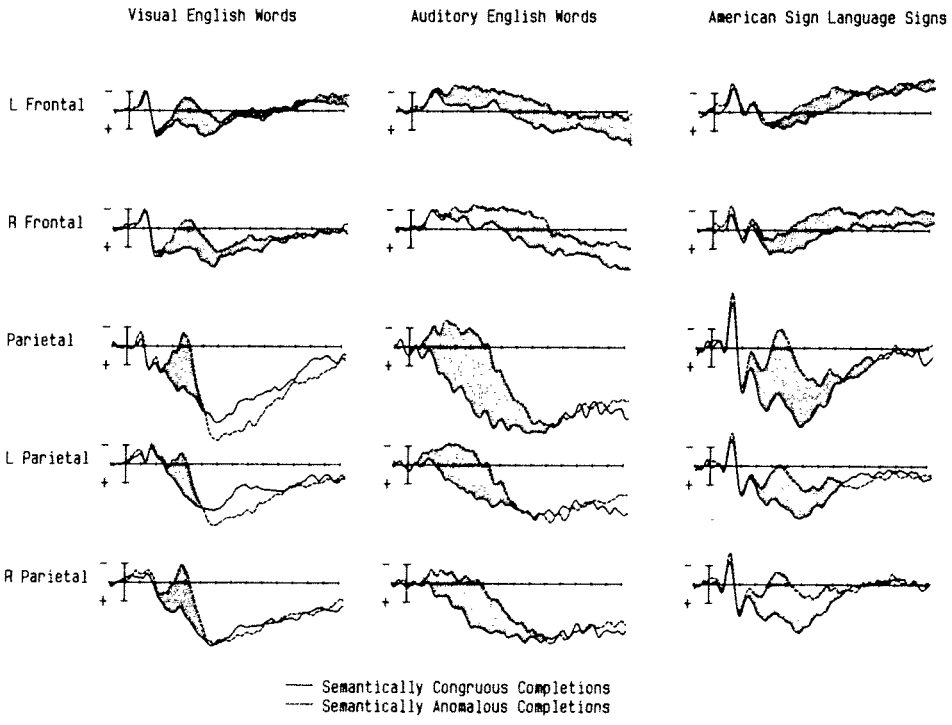


Fig. 1. Grand average ERPs for sentence terminal words in 3 different groups of subjects during reading (N = 12), listening (N = 12), and perception of signs in American sign language (N = 10). In each column, the ERPs to congruous (solid line) and anomalous (dashed line) sentence terminal words are superimposed. The representative electrode locations chosen from the total set record include left and right frontal (F7/8), midline parietal (Pz), and left and right parietal (Wernicke's area and its right hemisphere homolog; 30% lateral and 12.5% back from the interaural line). Calibration = 4 $\mu$V; 1 tick mark = 100 msec.

language in which the eliciting anomalies occur. The modality non-specificity of this effect argues against any view of the N400 which ties it to the orthography or phonology of a written word.

The N400 cannot be specific to the process whereby a written word is transformed into its phonological representation (i.e., phonemic recoding), because while this step is bypassed during listening, the N400 is not. Semantic anomalies within the auditory modality yielded substantial N400-like potentials (see McCallum et al. 1984 for similar results). Similarly, the N400 cannot be specific to the process whereby a word's sound (i.e., phonological representation) is used to access the word's meaning because it is elicited during the apprehension of anomalies within American sign language. Remember that the ERPs to anomalies in ASL were recorded from a group of congenitally deaf adults for whom English was neither a first nor a phonetically based language. Clearly such logic does not argue against the possibility that orthographic and phonological manipulations within an experimental setting might influence N400s in some way. Rather the claim is that the present data are inconsistent with any theory which posits a critical role for either orthography or phonology in the elicitation of the N400 component.

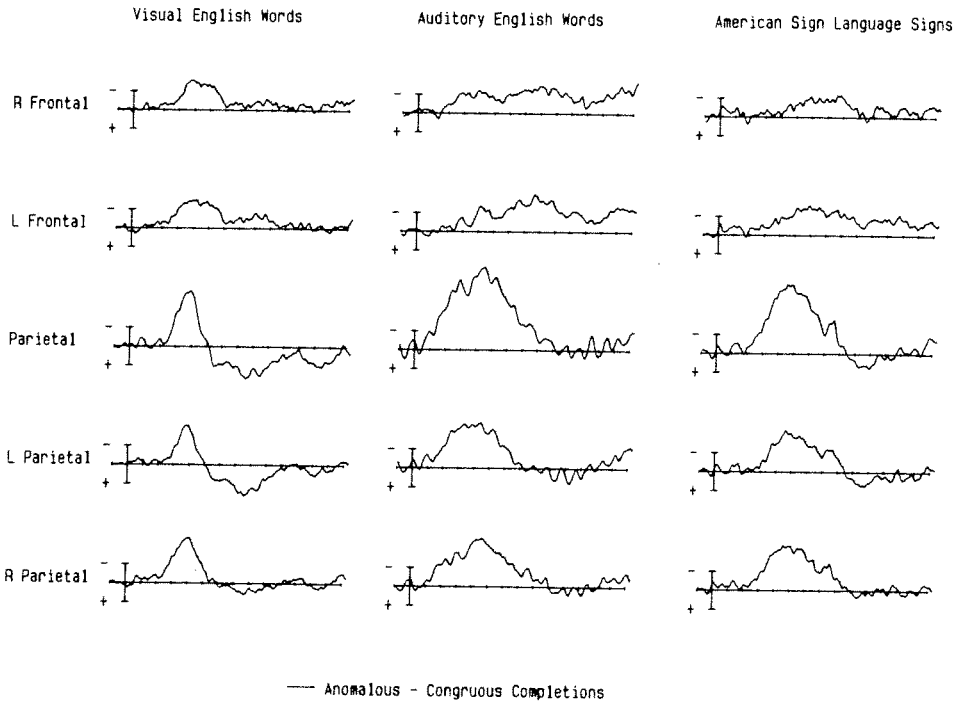


Fig. 2. Grand average ERP difference waveforms (incongruous-congruous) for the normally hearing groups in written and auditory English and for congenitally deaf adults in ASL. The difference waves are formed via a point-by-point subtraction of the ERP waveforms elicited by congruous completions from those elicited by anomalous completions. Calibration = 4 $\mu$V; 1 tick mark = 100 msec.

## REFERENCES


Bentin, S., McCarthy, G. and Wood, C.C. Event-related potentials associated with semantic priming. *Electroenceph. clin. Neurophysiol.*, 1985, 60: 343 – 355.

Besson, M., Macar, F. and Pynte, J. Is N400 specifically related to the processing of semantic mismatch?. *Soc. Neurosci. Abstr.*, 1984, 10: 841.

Fischler, I., Bloom, P.A., Childers, D.G., Roucos, S.E. and Perry, Jr., N.W. Brain potentials related to stages of sentence verification. *Psychophysiology*, 1983, 20: 400 – 409.

Fischler, I., Bloom, P.A., Childers, D.G., Arroyo, A.A. and Perry, N.W. Brain potentials during sentence verification: late negativity long-term memory strength. *Neuropsychologia*, 1984, 22: 559 – 568.

Fischler, I., Childers, D.G., Achariyapaopan, T. and Perry, Jr., N.W. Brain potentials during sentence verification: automatic aspects of comprehension. *Biol. Psychol.*, 1985, 21: 83 – 105.

Harbin, T.J., Marsh, G.R. and Harvey, M.T. Differences in the late components of the event-related potential due to age and to semantic and non-semantic tasks. *Electroenceph. clin Neurophysiol.*, 1984, 59: 489 – 496.

Holcomb, P.J. Unimodal and multimodal models of lexical memory: an ERP analysis. *Psychophysiology*, 1985, 22: 576 (abstr.).

Holcomb, P.J. ERP correlates of semantic facilitation. In: W.C. McCallum, R. Zappoli and F. Denoth (Eds.), *Cerebral Psychophysiology: Studies in Event-Related Potentials. Electroenceph. clin. Neurophysiol., Suppl. 38.* Elsevier, Amsterdam, 1986: 320 – 322.

Kutas, M. and Hillyard, S.A. Reading senseless sentences: brain potentials reflect semantic incongruity. *Science*, 1980a, 207: 203 – 205.

Kutas, M. and Hillyard, S.A. Reading between the lines: event-related brain potentials during natural sentence processing. *Brain Lang.*, 1980b, 11: 354 – 373.

Kutas, M. and Hillyard, S.A. Event-related brain potentials to semantically inappropriate and surprisingly large words. *Biol. Psychol.*, 1980c, 11: 99 – 116.

Kutas, M. and Hillyard, S.A. The lateral distribution of event-related potentials during sentence processing. *Neuropsychologia*, 1982, 20: 579 – 590.

Kutas, M. and Hillyard, S.A. Event-related brain potentials to grammatical errors and semantic anomalies. *Mem. Cogn.*, 1983, 11: 539 – 550.

Kutas, M. and Hillyard, S.A. Brain potentials during reading reflect word expectancy and semantic association. *Nature (Lond.)*, 1984a, 307: 161 – 163.

Kutas, M. and Hillyard, S.A. Event-related brain potentials (ERPs) elicited by novel stimuli during sentence processing. In: R. Karrer, J. Cohen and P. Tueting (Eds.), *Brain and Information: Event-Related Potentials. Ann. NY Acad. Sci.*, 1984b, 425: 236 – 241.

Kutas, M., Lindamood, T. and Hillyard, S.A. Word expectancy and event-related brain potentials during sentence processing. In: S. Kornblum and J. Requin (Eds.), *Preparatory States and Processes.* Erlbaum, Hillsdale, NJ, 1984.

McCallum, W.C., Farmer, S.F. and Pocock, P.K. The effects of physical and semantic incongruities on auditory event-related potentials. *Electroenceph. clin. Neurophysiol.*, 1984, 59: 477 – 488.

Neville, H.J. Biological constraints on semantic processing: a comparison of spoken and signed languages. *Psychophysiology*, 1985, 22: 576 (abstr.).

Neville, H.J., Kutas, M., Chesney, G. and Schmidt, A. Event-related brain potentials during initial encoding and recognition memory of congruous and incongruous words. *J. Mem. Lang.*, 1986, 25: 75 – 92.

Rugg, M.D. Event-related potentials in phonological matching tasks. *Brain Lang.*, 1984a, 23: 225 – 240.

Rugg, M.D. Event-related potentials and the phonological processing of words and non-words. *Neuropsychologia*, 1984b, 22: 435 – 443.

Rugg, M.D. The effects of handedness on event-related potentials in a rhyme-matching task. *Neuropsychologia*, 1985, 23: 765 – 775.

Stuss, D.T., Sarazin, F.F., Leech, E.E. and Picton, T.W. Event-related potentials during naming and mental rotation. *Electroenceph. clin. Neurophysiol.*, 1983, 56: 133 – 146.