

# Event-Related Brain Potentials (ERPs) Elicited during Rapid Serial Visual Presentation of Congruous and Incongruous Sentences

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It has been well established that semantic anomalies elicit a large negative wave with a peak latency around 400 msec. Because the amplitude of this N400 has been found to be sensitive to semantic expectancies and associations, it has been hypothesized that the N400 may provide a relatively non-invasive, on-line measure of comprehension and semantic priming mechanisms (for review see Kutas and Van Petten 1987). However, the utility of the N400 as a means of investigating language processing might be questioned because ERP studies to date have presented words at a much slower rate than occurs in natural reading situations (Boddy 1986). Thus, the present study was designed to determine whether the ERP congruity effects observed at relatively slow presentation rates (1 word every 500–1000 msec) would still obtain when sentences were presented at a much faster rate (e.g., 10 words/sec). Several investigators have shown that subjects can read and comprehend sentences presented at a rate as high as 12 words/sec via the rapid serial visual presentation (RSVP) technique (Forster 1970; Potter et al. 1980; Masson 1987).

## **METHODS**

Data were collected from 11 young adults (8 male, mean age = 24.4 years, range 20–30); 2 subjects' ERPs were deemed too contaminated to include in the final analysis. Of the remaining 9 subjects, 8 were right-handed according to self-report and the Edinburgh Inventory (Oldfield 1971). Four of the subjects had a left-handed relative in their immediate family. Four of the 9 subjects also read an additional set of sentences presented at a rate of 1 word every 700 msec (see Kutas et al. 1984).

Subjects silently read 160 highly constrained sentences for content. Half of these sentences were terminated by the most probable word as determined in a cloze

procedure\* (i.e., best completion) and half by a semantically anomalous word. Of the semantic anomalies, approximately half were semantically related to the best completions and half were unrelated. These sentences were the same as those employed by Kutas et al. (1984, expt. 2). The sentences were presented 1 word at a time on a CRT. Words were flashed for durations of 50 msec at a rate of 1 every 100 msec. The inter-sentence interval was 3 sec.

EEG activity was recorded from 8 silver-silver chloride scalp electrodes all referred to linked mastoids. Four were placed according to the International 10–20 convention at Fz, Cz, Pz and Oz locations. Symmetrical anterior temporal electrodes were placed halfway between F7 and T3 and F8 and T4 sites, respectively. Symmetrical posterior temporal electrodes were placed lateral (by 30% of the interaural distance) and 12.5% posterior to the vertex. Vertical eye movements were monitored via an electrode placed below the right eye referenced to linked mastoids. Horizontal eye movements were monitored via a right versus left external canthus montage. Trials with excessive EOG artifact (as determined by computer algorithms computing peak-to-peak voltage amplitudes, deviations from baseline, and polarity inversions between the lower eye and Fz recordings) were excluded from the final ERP averages. EEG activity was amplified with long time constant (8 sec) AC amplifiers (upper cutoff = 60 Hz) or DC amplifiers (upper cutoff = 100 Hz). A 1024 msec epoch of EEG data beginning 100 msec before the onset of each stimulus was analyzed at a sampling rate of 250 Hz. ERP measurements were made relative to a 100 msec prestimulus baseline in the averaged waveforms.

## RESULTS

Fig. 1 shows the superimposition of the grand average ERPs ( $N = 9$ ) elicited by the congruous and anomalous words that terminated the sentences presented at 10 words/sec. Visual inspection of these terminal word ERPs reveals a reduction of the early components such as the N1 (relative to those observed at slower rates) without a significant reduction in the amplitude of later positive and negative components. Even at this fast rate of presentation, there was a clear differentiation in the ERPs elicited by congruous and incongruous sentence terminal words. In many respects, the nature of this difference is quite similar to that obtained when these same sentences were presented to a different group of subjects at a slower rate of 1 word every 700 msec (see Kutas et al. 1984). That is, the response to best completions was characterized by a late positivity whereas the response to semantically anomalous endings displays a large negative component within this same time region (mean amplitude 300–600 msec post stimulus, main effect of anomaly type,  $F(2, 16) = 13.73$ ,  $P < 0.001$ ).

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\* In this cloze procedure subjects were given sentences with the final words missing and asked to fill in the blank for each sentence with the word that best completed the sentence. Each word's cloze probability was calculated by dividing the number of subjects who responded with a particular word by the total number of subjects tested.

Moreover, the amplitude of this negative component elicited by semantic anomalies was sensitive to the nature of the semantic relationship between the anomaly and expected completion; at all but the occipital site, the negativity was smaller following anomalies that were related to the best completions than following anomalies that were

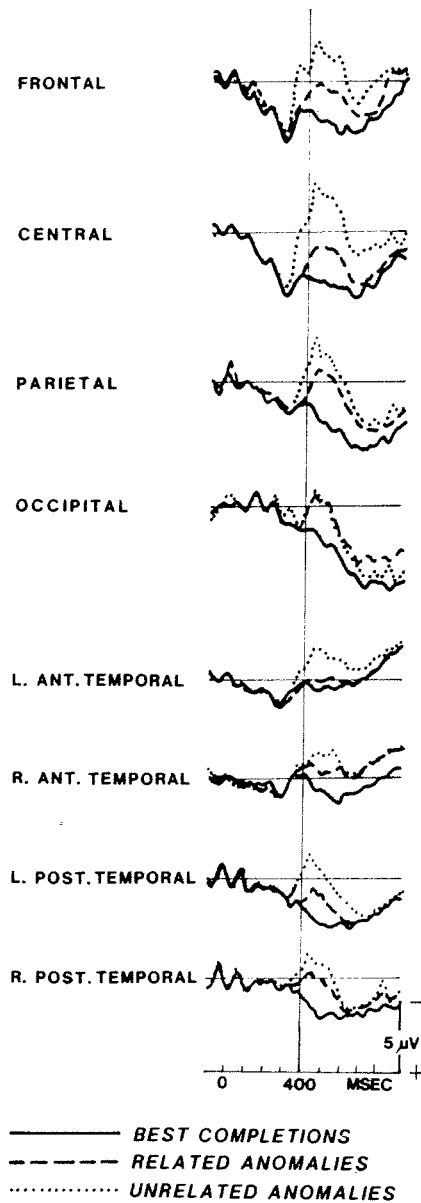


Fig. 1. Grand-average ERPs ( $N = 9$ ) to terminal words of sentences presented at a rate of 10 words/sec. Superimposed are the ERPs to highly expected, congruous endings (best completions), anomalous endings semantically related to the best completions and anomalous endings not related to the best completions.

not so related (mean amplitude 300–600 msec, ending by electrode interaction  $F(7, 56) = 3.20, P < 0.006$ ).

Although the ERPs elicited by semantic anomalies presented at 10 words/sec were highly similar to those elicited by incongruous sentences presented at slower rates, there was one striking difference. The negative component elicited by semantic anomalies peaked approximately 80–100 msec later when the sentences were presented at the fast relative to the slow rate. A direct comparison of the N400 ‘incongruity effect’ at the two different rates of sentence presentation can be seen in the left-hand column of Fig. 2, wherein the incongruous minus congruous difference ERPs are shown superimposed. Across all electrode locations, the N400 difference ERP peaks around 420 msec for the slow rate group and around 507 msec for the fast rate group. However, since the data in the left-hand column of Fig. 2 represent primarily between-subject comparisons

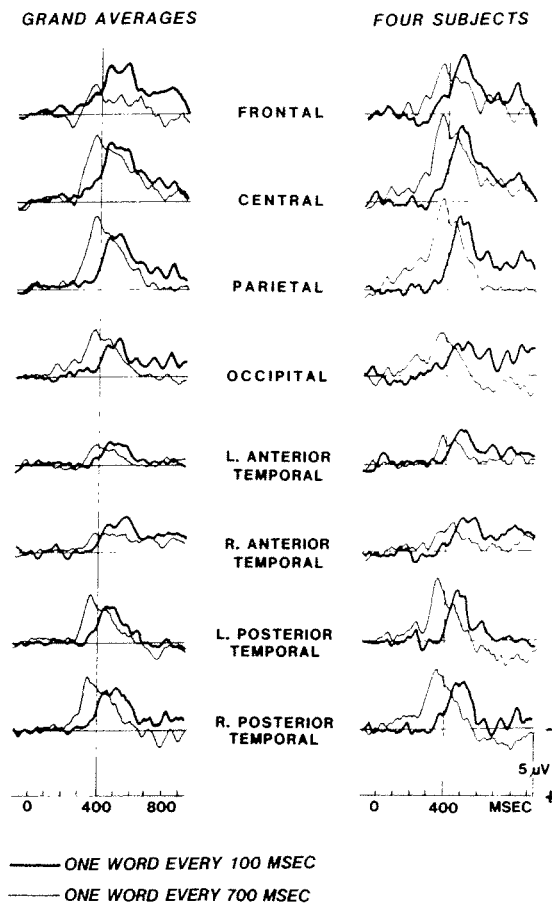


Fig. 2. Left column: between-subject difference waves (anomalous minus congruous endings) for the 2 groups of subjects who read the sentences presented at a rate of either 1 word every 100 msec ( $N = 9$ ) or 1 word every 700 msec ( $N = 10$ ; detailed report of the latter data is available in Kutas et al. 1984, exp. 2). Right column: within-subject comparison of the difference ERPs at both fast and slow rates of presentation.

we cannot argue with complete certainty that the 80 – 100 msec shift in the N400 peak latency at higher rates does not partly reflect individual differences. However, the difference ERPs in the right-hand column of Fig. 2 represent a within-subject comparison for the 4 subjects who experienced sentences at both the fast and slow rates; the delayed N400 for sentences presented at 10 words/sec is still clearly evident (peak latency for difference ERP, slow rate: 379 msec and fast rate: 494 msec, main effect of rate,  $F(1, 3) = 111.3, P < 0.002$ ).

## DISCUSSION

These experiments replicate behavioral studies showing that sentences can be read and understood at rates as high as 10 words a second, almost twice the rate of the average reader. The similarity of these ERP data to those recorded at slower rates can be taken as evidence that subjects comprehend the grammatically simple sentences presented at these different rates via similar mechanisms. The delays in the late positivity to congruous endings and in the late negativity to anomalous endings suggest that the sentence integration processes which are prerequisites for their elicitation are slowed significantly at a rate of 10 words a second. Further experiments are necessary to determine whether the different ERP components and their interaction with the different presentation rates can be related to the facilitatory or inhibitory aspects of the semantic priming mechanisms hypothesized to account for the reaction time patterns observed in such experiments (Fischler and Bloom 1980).

In general, the present findings suggest that it may be possible to generalize from ERP data collected via the RSVP technique at fast and slow rates to normal reading. However, it is important to note that there is evidence showing that readers modulate their reading times on a word by word basis according to the properties of each word and that this mechanism is compromised during RSVP reading (Just et al. 1982). Since the differences between natural reading and the RSVP technique tend to be most pronounced for difficult reading matter, they probably played no role in the reading and comprehension of the grammatically and conceptually simple sentences used in this experiment. Future experiments will determine to what extent the ERP effects are influenced by the uniform exposure duration and spatial location of their eliciting words.

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