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EVENT-RELATED BRAIN POTENTIALS TO SEMANTICALLY INAPPROPRIATE AND SURPRISINGLY LARGE WORDS

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Event-related brain potentials (ERPs) were recorded from young adult subjects as they silently read 160 different seven-word sentences, presented one word at a time. The sentences either ended normally or were completed by unexpected words that were either semantically inappropriate, physically deviant or both. These two types of deviations were associated with distinctly different ERP components – a late negative wave (N400) for semantic deviations and a late positive complex for physical deviations. A deviation along either one or these dimensions (semantic or physical) did not appear to alter the ERP effect of a concurrent deviation along the other. In addition, it was found that the ERPs elicited by the words during the reading condition were characterized by a left-greater-than-right asymmetry in a slow, positive component. This asymmetrical scalp distribution was most pronounced for right-handed subjects having no left-handers in their immediate family.

1. Introduction

Several types of event-related brain potentials (ERPs) are particularly sensitive to the occurrence of unexpected, surprising or discrepant stimuli (for reviews see Donchin, Ritter and McCallum, 1978; Picton, Campbell, Baribeau-Braun and Proulx, 1978; Sutton, 1979). These ERP components are primarily endogenous and include a negative wave around 200–250 msec (the N2 or N200), a later positivity which typically peaks at 300–500 msec (the P3 or P300), and a prolonged 'slow wave' lasting several hundred msec (Squires, Squires and Hillyard, 1975). In the vast majority of experiments, the most prominent component of the ERP following unexpected stimuli has been a P300 wave having a parieto-central scalp distribution; accordingly, it has been proposed that the P300 may reflect the resolution of prior uncertainty (Sutton, Braren and Zubin, 1965; Ruchkin and Sutton, 1978) and the task-relevant surprise value of the stimulus (Donchin et al., 1978; Donchin, 1979).

We have recently investigated ERPs to surprising events in a language context – the occurrence of absurd, semantically inappropriate words in otherwise meaningful sentences (Kutas and Hillyard, 1980b). It turned out that incongruous words (such as 'dog' at the end of the sentence 'I take coffee with cream and') elicited a large negative wave (N400) which was not accompanied by any late positivity over and above that elicited by congruous words. In contrast, when an appropriate word was unexpectedly presented in oversize, bold-faced print during this silent reading

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task, a later positive complex of waves was elicited (Kutas and Hillyard, 1980a), which was similar to the ERPs reported to other types of physically deviant visual stimuli (Courchesne, Courchesne and Hillyard, 1978; Friedman, Vaughan and Erlenmeyer-Kimling, 1978).

In these previous studies, the divergent effects of semantic and physical incongruity on the ERP were observed in separate groups of subjects. The present experiment used a within-subjects design to find out whether both types of waveforms could be elicited in the same series of sentences, and, in particular, what would happen when a word was both semantically and physically deviant. Thus, the subjects were shown sentences that either ended normally or were completed by unexpected words that were either semantically inappropriate, physically deviant (too large), or both inappropriate and too large. This design allowed us to explore whether the brain's differential responses to semantic incongruity (the N400) and physical deviation (late positive complex) are mutually exclusive, interactive, or occur in parallel.

Comparisons of recordings over Wernicke's area and its right hemisphere homologue in a previous study (Kutas and Hillyard, 1980a) revealed that the ERPs to the initial words in the sentences were asymmetrically distributed on the scalp, with the left hemisphere showing significantly more positivity in a very slow, late component. Furthermore, this lateral difference was not as prominent for the ERPs to either the warning stimuli or to isolated words. The present study allowed an evaluation of the reliability of these findings.

2. Methods

2.1. Subjects

Fourteen young adults, eight male and six female, (age range 19–35, mean = 23.6) were paid for participating in the experiment. Twelve of the subjects were right-handed according to self-report and as tested by the Edinburgh Inventory (Oldfield, 1971) and six of these had left-handers in their immediate family. The remaining two subjects were left-handed. None of the subjects had participated in prior ERP experiments. Although the general nature of the experiment was explained to them, subjects were unaware of the specific hypotheses under investigation.

2.2. Stimuli

Slides containing single words were back-projected onto a translucent screen. Each word was flashed for 100 msec under the control of an electronic shutter. The subjects sat 2.06 m from the screen, and the words subtended a vertical angle of either 0.89 or 2.64 deg for the standard (typewritten) and bold-faced (Instantype No. L-1026) stimuli, respectively. The terminal words contained between three and nine letters and did not differ in length between congruous (5.15 letters) and incongruous (5.25 letters) words. The luminance of the background of these black-on-white slides ranged from 6.0 to 6.5 mL. Environmental sounds and clicks from the shutter were masked by white noise presented through headphones.

2.3. Recording system

The electroencephalogram (EEG) was recorded from five scalp sites, each referred to linked mastoids. Non-polarizable Beckman Ag–AgCl electrodes were placed at frontal (Fz), central (Cz), and parietal (Pz) midline locations and at two temporo-parietal sites (W1 and W2) situated laterally (by 30% of the interaural distance) and posteriorly (by 12.5%) to the vertex. These latter placements were situated approximately over Wernicke's area and its right hemisphere homologue. Eye movements and blinks were monitored via an electrode placed on the lower orbital ridge, referred to linked mastoids. In addition, a bipolar, right supraorbital to external canthal montage was used to record lateral eye movements (L-EOG).

The three midline and the lower eye derivations were amplified with Grass 7P1 preamplifiers. The system bandpass was d.c. to 40 Hz (half-amplitude cutoff). The bipolar L-EOG and the lateral scalp electrodes were amplified with Grass 7P5 preamplifiers (system bandpass down 3 dB at 0.15 and 150 Hz).

The EEG, EOG, and stimulus trigger codes were recorded on an FM tape recorder. Analog to digital conversion and ERP averaging was performed by a PDP 11/45 computer. A 1024 msec epoch of EEG data beginning 100 msec before the onset of each stimulus was analyzed at a sampling rate of 4 msec per point.

2.4. Procedure

Subjects were tested in one session that lasted $2\frac{1}{2}$ to 3 h while seated in a comfortable reclining chair. They were informed that they would be presented with a series of simple, English sentences, one word at a time. Each sentence would be a grammatically correct, meaningful unit in itself and would not bear any relation to preceding or following sentences. Subjects were told that the sentences were similar to one another in grammatical structure and that some might be very familiar. Their instructions were to read each of the sentences silently 'in order to answer some questions about their contents at the end of the experiment'.

The general timing sequence as well as a sample sentence of each type are presented in fig. 1. The start of each sentence was signalled by a warning slide containing XXXXX. This was followed 1 sec later by the sequential presentation of the seven words at intervals of 1 sec, the last of which was followed by a period to indicate sentence completion. After a 2 sec delay the next sentence was presented, and so on.

At the beginning of the session, subjects were exposed to 10 practice sentences

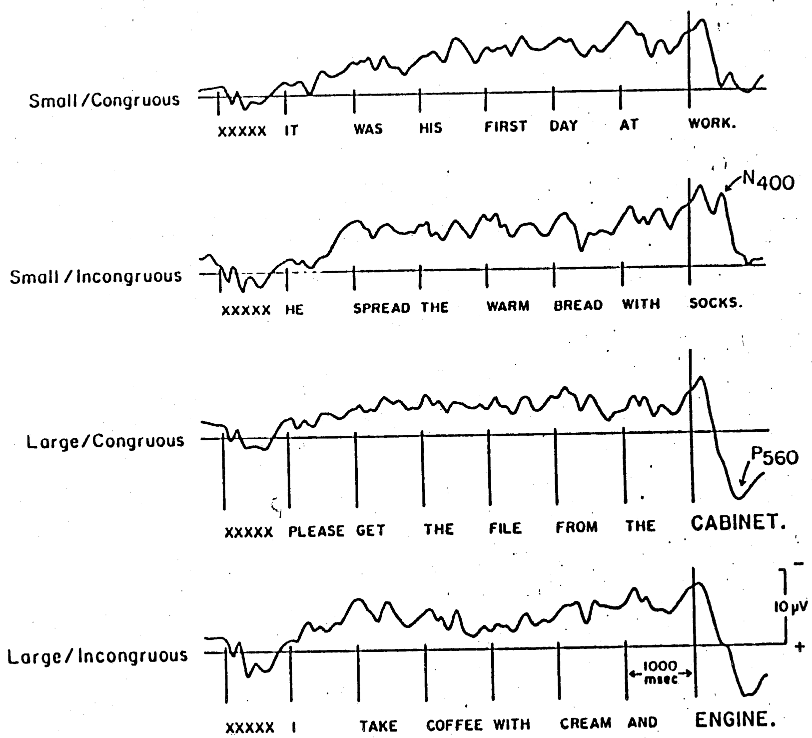

Fig. 1. Grand average ERP waveforms (across all subjects) recorded over each of the four types of seven-word sentences. An example of each type of sentence is shown below, with vertical lines marking the word presentations. Recordings are from Pz.

with no ERPs being recorded. The practice trials were followed by 16 experimental series of 10 sentences each. Each sentence was completely different from and independent of the others. Of these 160 sentences, 100 were completed by a semantically appropriate word in the same standard-sized type as the previous six words in the sentence ('small/congruous'), 20 were completed by a semantically inappropriate word printed in this standard type ('small/incongruous'), 20 were completed by a semantically appropriate word printed in the large, bold-faced type ('large/congruous') and 20 were completed by a semantically inappropriate word written in the large type ('large/incongruous'). These four types of sentences were presented in random order, so that the subject could not anticipate the type of ending. Each series of 10 sentences was followed by a 2–3 min break, with an 8–10 min rest given midway through the experiment.

Following the completion of all the sentences, the subject was asked to look at the screen where the word 'station' was flashed repeatedly for two runs of 80 presentations each. For half of the subjects, the word was shown in standard-size type for the first run and in bold-face type for the second run. For the remaining subjects the order of these conditions was reversed. These repetitive control stimuli were given in order to elicit the ERP components specific to the physical characteristics of the word stimuli. The same word was repeated in order to minimize endogenous components associated with word meaning and semantic context.

Following the ERP recordings, subjects were given a memory/recognition questionnaire on the sentences. The test listed the first six words of 42 different sentences, 32 of which were selected from the sentences just seen and 10 of which were 'new' and not shown before. The subject's task was to check whether each sentence was 'old' or 'new' and to fill in the word they remembered as ending each of the 'old' sentences. Of the 32 sentences seen before, 22 had ended with appropriate words and 10 with semantically incongruous words.

Then, for each of the 160 sentences, the subjects were asked to write the word which best completed the sentence. Finally, the subjects were shown a list of all 160 of the complete sentences and were asked to rate each of the last words as to their unexpectedness on a seven-point scale.

3. Results

The waveforms in fig. 1 show the ERPs elicited during this silent reading task on a 8.4 sec time base. A slow negative shift (the Contingent Negative Variation or CNV) is sustained throughout the sentence, upon which are superimposed the ERPs elicited by the individual words. Thus, the ERP to the final word in each sentence overlaps with the resolution of the CNV.

Visual inspection of these waveforms indicated that the CNVs associated with each type of sentence were quite similar, but the ERPs to the final words were not. As reported previously, the semantically deviant seventh words were followed by a late negative component (N400), while the physically deviant, 'large' seventh words elicited a late positive complex of waves (P560), both of which were absent following the small, congruous seventh words.

In these and the following comparisons among the ERPs to the four types of sentences, the averaged ERPs are based on 16–20 trials/subject.

3.1. Effect of semantic incongruity

The effects of semantic and physical deviations are shown at higher resolution in the grand average waveforms in fig. 2. Here, the individual effects of semantic and physical incongruity are illustrated by overlapping different pairs of the ERPs to the four types of endings. The top half of the figure shows the effect of semantic

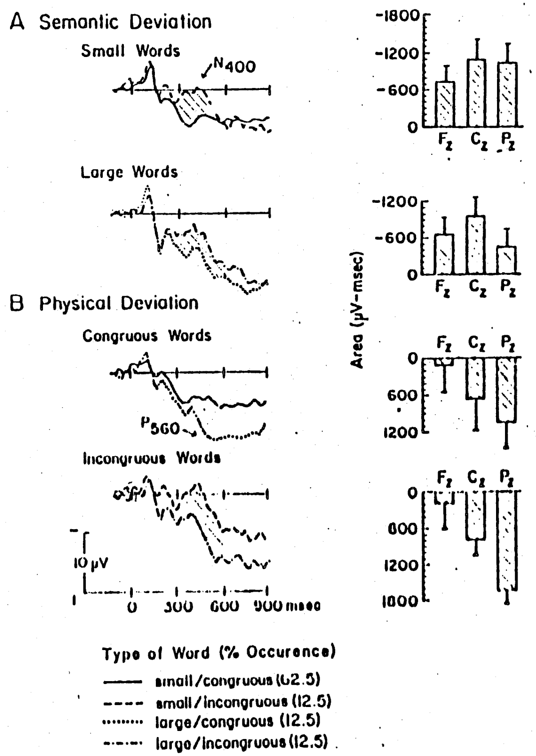

Fig. 2. Paired comparisons of the grand average ERPs (averaged across all subjects) elicited by the four types of seventh words and associated area measures of the differences. (a) In the top comparison, the ERPs elicited by the small congruent and incongruent seventh words are overlapped. Similarly, in the lower comparison, the ERPs elicited by the large-sized congruent and incongruent words are superimposed. Recordings are from the vertex. (b) In the top comparison, the ERPs elicited by the semantically appropriate small and large-sized words are overlapped. In the lower comparison, the ERPs elicited by the small and large-sized words when both were semantically incongruous are superimposed. Recordings are from Pz. The area of the difference between the two ERPs in each of these comparisons is shaded between 300–600 msec; the means and standard deviations for each of these values electrodes site are plotted in the bar graphs to the right of the ERPs.

deviation for words presented in standard-sized (small) type as well as for the words presented in large type. Despite the obvious differences in the ERPs evoked by small and large words, the effects of semantic deviancy, as manifested in the difference between the congruent and incongruent ERPs (shaded areas), appear quite

similar. In each case, the semantic anomaly is associated with a broad, monophasic negative wave, peaking between 400 to 500 msec (N400).

The N400 was quantified as the average amplitude difference between the congruent and incongruent ERPs in the region 300–600 msec post-stimulus (shaded areas). The mean area of this 'difference N400' at each of the midline electrode locations is plotted to the right of the corresponding ERP comparisons; averaged across midline sites this area was significantly different from zero in the ERPs to both the small ($t = 3.81$, df = 13, $p < 0.01$) and the large words ($t = 2.52$, df = 13, $p < 0.02$).

A two-way repeated measures analysis of variance (ANOVA) of these areas corroborated the observation that the difference – N400 did not differ significantly in amplitude or scalp distribution as a function of the type style in which the incongruous word appeared. Further, this component was similar in amplitude across the three midline sites [$F(2, 26) = 2.58$, for main effect of electrode site].

The unimportance of type size in the subject's evaluations of the semantically anomalous words was also evident in their behavioral ratings of semantic incongruity made at the end of the experiment. Each of the last words was rated on a seven-point scale, where 1 was 'expected' and 7 was 'totally unexpected'. The mean ratings of the congruous words were 1.40 ± 0.06 and 1.84 ± 0.12 for the standard and large-sized type, respectively. Each of these was significantly different (Mann–Whitney U, $p < 0.001$) from the mean ratings for the semantically incongruous words in standard sized (6.58 ± 0.33) and large-sized type (6.78 ± 0.07), but these latter ratings were not different from each other.

Detailed waveform analysis

The 300–600 msec area measure was chosen to be consistent with our previous report (Kutas and Hillyard, 1980b). However, careful inspection of the waveforms indicated that the effect of semantic deviation was evident as early as 200 msec post-stimulus, and that the anterior–posterior distribution of this effect was not constant throughout its duration. A two-way repeated measures ANOVA (scalp site X interval) of the area under successive 100 msec intervals of the difference N400 shown in fig. 3 established that there were significant changes in its amplitude and midline distribution between 200 and 600 msec post-stimulus. Whereas the negativity was fairly evenly distributed across midline sites in its initial (200–300 msec) and terminal (500–600 msec) phases, it was significantly larger over centro-parietal regions during its middle range near the peak (400–500 msec) [$F(6, 78) = 4.37, p < 0.001$].

An ANOVA of the area of the difference wave between (600–900 msec post-stimulus) demonstrated that there was no significant difference in the amount of later positivity between the semantically congruous and incongruous ERPs at any of the electrode locations (see fig. 2a and fig. 3). This result corroborated our previous observation (Kutas and Hillyard, 1980b) that the N400 was not merely a precursor to a centro-parietal positivity such as the P300.

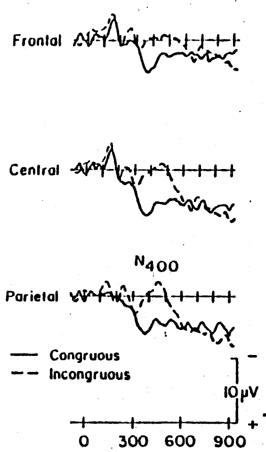

Fig. 3. Comparison of the grand average ERPs (across all subjects) to the small, semantically congruent and incongruent seventh words at frontal, central and parietal sites.

3.2. *Effect of physical deviation*

The lower pairs of tracings in fig. 2 show the effect of physical deviation separately for the semantically congruous and incongruous last words. In each case, an enhanced late positivity starting around 200 msec and lasting throughout the recording epoch was evident in the ERPs elicited by the large words relative to those elicited by standard-sized final words. The effect of physical deviation was also quantified as the area of the difference wave formed by subtracting the ERP to standard-sized words from the ERP to large-sized words in the region 300–600 msec post-stimulus. The means of these areas are depicted in the bar graphs to the right of the corresponding ERPs in fig. 2b. This area measure was significantly greater than zero at the central and parietal sites for both the congruous (parietal, $t = 2.22$, df = 13, $p < 0.05$) and incongruous (parietal, $t = 6.84$, df = 13, $p < 0.01$) seventh words, but not at the frontal site.

A two-way ANOVA of this measure revealed that the effect of physical deviation on the ERP in this region was essentially the same whether the eliciting word was semantically appropriate or inappropriate. In addition, there was a significant main effect of electrode site [$F(2, 26) = 7.14$, $p < 0.003$], with greater positivity over parietal than frontal sites. The enhanced positivity to the physically deviant last words was also present in the 600–900 msec post-stimulus region (at all electrode sites $p < 0.05$).

3.3. *Control stimuli*

The ERPs elicited by control presentations of a word in small-sized type (SC) and the same word in large type (LC) are compared at the each of the midline locations in fig. 4. The change in word size primarily affected the amplitude of the P2 component (latency 200 msec). The P2 was larger over fronto-central areas and about twice as large for the LC than the SC words [$F(1, 13) = 14.11$, $p < 0.002$].

The enhanced late positivity associated with the large words when they occurred as deviations in the reading condition was not evident in the ERPs to the LC words. In fact, the ERP to the LC words showed a greater *negativity* than the ERP to the SC words in the latency range 300–600 msec, although this was not significant at any electrode location. Thus, the late positivity associated with the infrequent physical deviations could not be attributed solely to the change in the physical characteristics of the eliciting word.

3.4. *Comparison of ERPs over left and right hemispheres*

The 'grand mean' ERPs from the lateral electrode sites averaged across the 12 right-handed subjects are depicted in fig. 5 (left). Left-handed subjects were excluded from this analysis. Left-right hemispheric comparisons are presented for the ERPs to the control words, the warning stimuli (WS), and to the first six words

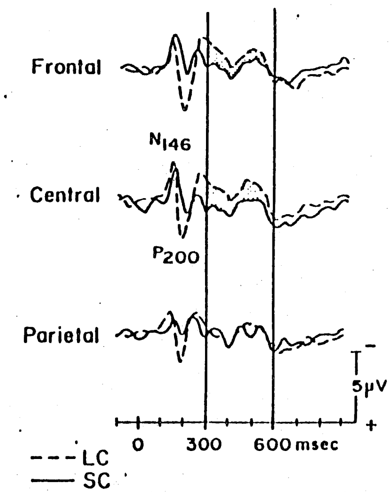

Fig. 4. Comparison of the grand average ERPs (across all subjects) elicited by the repeated presentations of the word 'station' in small, standard-sized (SC) and large-sized type. ERPs are averaged over 50–80 stimuli/subject.

in the sentences (averaged together) during the reading task. Visual inspection of these waveforms indicated that the left hemisphere was more positive than the right in the region 300–900 msec post-stimulus for the average of words 1–6. Similar trends were also evident in the ERPs to the control stimuli, although none of these reached significance.

The left–right hemispheric difference averaged across words 1–6 was quantified as the area of the region 400–700 post-stimulus, relative to a 90 msec pre-stimulus baseline. While the two hemispheres were significantly different when all the right-handers were included in this analysis (Wilcoxon matched pairs signed rank test $N = 12$, $T = 13$, $p < 0.025$; matched pair t-test $t = 2.58$, $df = 11$, $p < 0.05$) inspection of the individual subjects' waveforms revealed that the degree of left–right asymmetry was bimodally distributed in this group according to the subject's

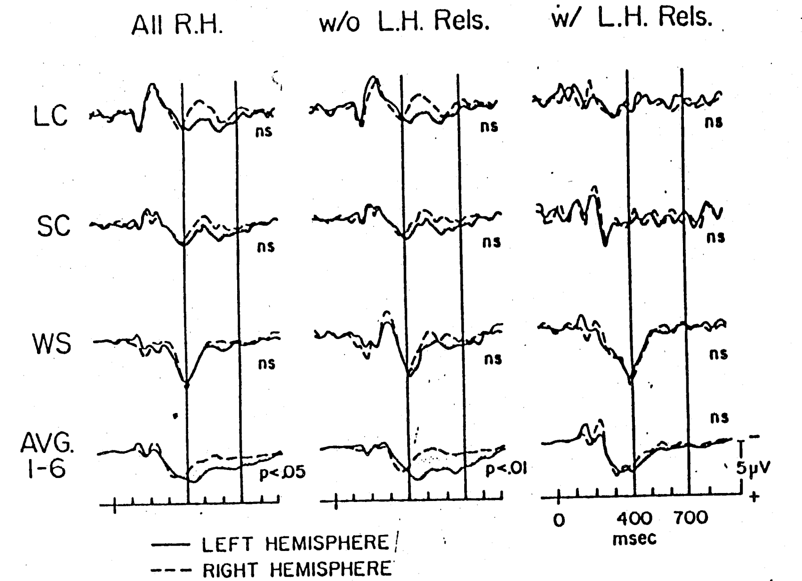

Fig. 5. Comparisons of the grand average ERPs recorded over Wernicke's area (solid line) and its right hemisphere homologue (dashed line) during the reading and control conditions for the 12 right-handed subjects. The middle and right-hand columns represent the same data averaged according to whether the subjects did ($N = 6$) or did not ($N = 6$) have any left-handed relatives in their immediate family. Right–left comparisons are presented for the ERPs elicited by control stimuli in large type (LC) and in standard-size type (SC), as well as by the warning stimulus (WS) and by words 1–6 (averaged together) during sentence reading. Next to each pair of waveforms is the resultant p-value for the matched pair t-test comparing the left–right areas in the 400–700 msec region.

familial history of left-handedness. As shown in fig. 5, the right-handers with left-handed relatives showed greatly reduced ERP asymmetries for all stimuli.

The extent to which the 400–700 msec area measure differed between the hemispheres was evaluated using matched pair t-tests. The left-greater-than-right positivity to words 1–6 was significant only for the right-handers without left-handers in their family ($t = 5.03$, $df = 5$, $p < 0.01$). Further, when the degree of hemispheric asymmetry of the average of words 1–6 was compared with that for the warning stimuli (which were not words), significant differences were obtained only for the right-handers without left-handers in their family ($t = 3.10$, $df = 5$, $p < 0.05$).

The consistency of these lateral asymmetries during reading is seen in the ERPs elicited by each of the words in the sentence (fig. 6). The p-values next to the waveforms are again based on matched pair t-tests comparing the right and left hemisphere areas. An ANOVA of these data with position in the sentence (1–6) and

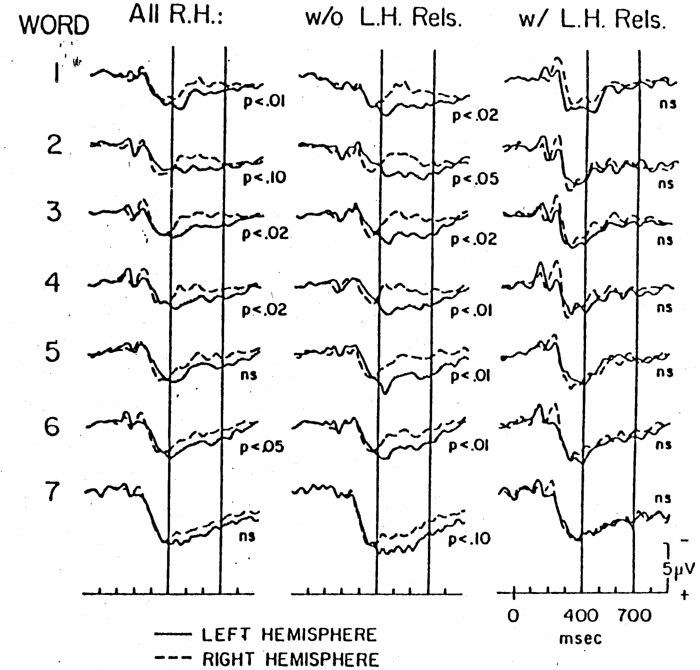

Fig. 6. Grand average ERPs from the left (Wernicke's) and right temporo-parietal areas to each of the seven words in the sentences for all right-handers, and for those with and without sinistrals in their immediate family. Next to each ERP comparison is the resultant p-value for matched pair t-test comparing the areas between 400 and 700 msec post-stimulus.

laterality of electrode as factors also revealed significant asymmetries when all 12 right-handers [$F(1, 11) = 6.70, p < 0.025$] or when only the right-handers without left-handed relatives [$F(1, 5) = 25.37, p < 0.004$] were included in the analyses.

Although the ERPs of the right-handers with and without left-handed relatives appeared to be characterized by different degrees of left–right asymmetry, an ANOVA comparing the two groups did not yield a significant group by electrode interaction [$F(1, 10) = 3.58$]. This failure to reach significance might well be a function of the small size of the two samples ($n = 6$) and the greater variability of the hemispheric asymmetry for the right-handers with left-handed relatives (s.d. = ±498) as compared to that for the right-handers without left-handed relatives (s.d. = ±267).

Additional analyses of these data, however, tended to corroborate that the degree of ERP asymmetry was different in the two groups. All of the subjects without left-handed relatives had a significant left more positive than right asymmetry in the region 400–700 for each of the first six words in the sentence (that is, 36/36 comparisons), whereas for the right-handed subjects with left-handed relatives only 19 out of these 36 comparisons showed such an asymmetry. Further, a non-parametric analysis of the area of the left minus right ERPs, averaged over words 1–6, revealed the two right-handed groups to differ marginally (Mann–Whitney U, $p < 0.06$).

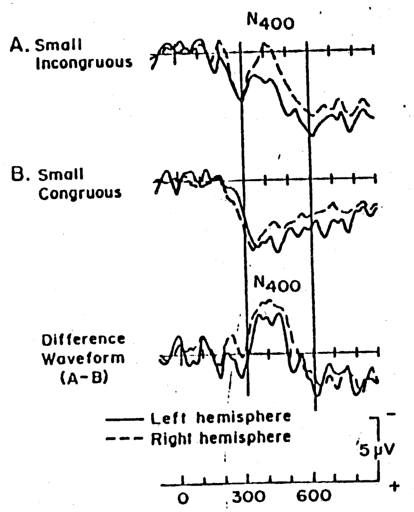

Fig. 7. The grand average ERPs (across 12 right-handed subjects) elicited by (a) semantically congruent and (b) incongruent seventh words in standard-size type, and the difference waveform obtained by subtracting them. In each case, the ERPs recorded from homologous sites over the two hemispheres are superimposed.

3.5. N400 asymmetry

We also examined the hemispheric asymmetry of the N400 component elicited by the standard-sized congruous and incongruous seventh words in the 12 right-handed subjects (fig. 7). An ANOVA of the area of the 300–600 msec region for the incongruous seventh words yielded a significant difference between the hemispheres [electrode main effect, $F(1, 11) = 8.40, p < 0.014$]. However, this asymmetry may simply represent the same left-greater-than-right positivity seen for words 1–6. Indeed, a similar analysis for the difference waveform (incongruous minus congruous) showed no significant difference between the hemispheres in the 300–600 (N400) region, although the trend was again for the N400 to be larger over the right hemisphere (fig. 7).

3.6. Memory/recognition questionnaire

The subjects correctly identified an average of 80% of the 32 'old' six-word sentences on the list as belonging to the set they had seen before. They correctly filled in the seventh word that was actually shown for 60% of the sentences that had ended appropriately and for 2% of those that had ended incongruously.

4. Discussion

The present results confirm our previous report (Kutas and Hillyard, 1980b) that semantically and physically deviant words in a silent reading task are associated with distinctly different ERP components. On the one hand, a semantically inappropriate word at the end of a sentence elicits a large, negative component peaking between 400 and 500 msec (N400) with no subsequent positivity. On the other hand, a physical deviation in the letter size and font is associated with a predominantly positive complex over the centro-parietal regions. The present results show further that these two distinct ERP effects may be elicited concurrently by the same word when it exhibits both types of deviations.

The amplitude of the N400 wave to semantic incongruity was essentially the same whether or not the word was physically deviant. Likewise, the late positive ERP to the oversize words was similar whether or not they were semantically anomalous. Thus, a deviation along one of these two dimensions did not appear to alter the ERP effect of a deviation along the other. Such results suggest that the two types of deviancy are registered in parallel and do not interact substantially, at least in their physiological manifestations.

To further examine the additivity of the processing of semantic and physical incongruity, the ERP waveforms were recombined algebraically. Under the assumption of simple additivity of these effects, the ERP to the dual-deviation stimulus (the large incongruous or l_i waveform) should be equivalent to the small congruous

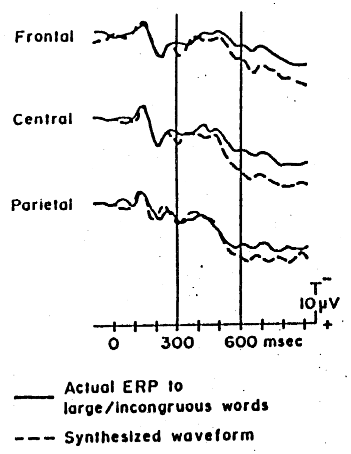

Fig. 8. Comparison of the grand average ERP elicited by the large, uncongruous words (l_i) and the synthesized waveform: $s_c + (l_c - s_c) + (s_i - s_c)$.

(s_c) waveform plus the effects of the size deviation alone (l_c minus s_c) and the semantic deviation alone (s_i minus s_c). That is:

$$l_i = s_c + (l_c - s_c) + (s_i - s_c)$$

Figure 8 illustrates this comparison, with the solid line being the actual ERP to the large, incongruous words and the dotted line being the algebraic combination of ERPs defined by the right side of the equation. The close correspondence between the two waveforms over the latency range 300–600 msec (they did not differ significantly) is consistent with an independent additivity of the size and semantic deviation effects and suggests that the two dimensions may be processed in parallel.

It should be noted that the above equation may be manipulated to form the following relationships:

$$l_i - l_c = s_i - s_c, \tag{a}$$

and

$$l_c - s_c = l_i - s_i \tag{b}$$

These equations reiterate the independence of the semantic incongruity effect from the stimulus size effect, and vice versa, illustrated in fig. 2a and b, respectively.

4.1. Relation of N400 to other ERPs

The relationship of the N400 to other late negative waves that have been reported is unclear. Among the many ERPs that bear more or less resemblance to the N400 are the CNV, (Walter, Cooper, Aldridge, McCallum and Winter, 1964), post-imperative negative variation (Timsit-Berthier, Delaunoy, Koninckx and Rousseau, 1973), N2 or N200 (Squires et al., 1975; Simson, Vaughan and Ritter, 1977), 'mismatch negativity' (Näätänen and Michie, 1979), 'processing negativity' (Näätänen, Gaillard and Mantysalo, 1978), 'slow wave' (Rohrbaugh, Syndulko and Lindsley, 1979), and other late negativities reported by Symmes and Eisengart (1971), and Neville (1977). It is difficult to decide which of these negativities are equivalent to one another, because the possible criteria for equivalency are numerous and not generally agreed upon.

We have noted (Kutas and Hillyard, 1980b) that the monophasically negative N400 has certain similarities with the CNV, which is certainly present in this sentence reading experiment (fig. 1). However, it is unlikely that N400 represents a simple prolongation of the CNV beyond the seventh word, because in some conditions the N400 represents a substantial increase in negativity over the CNV baseline (Kutas and Hillyard, 1980b, fig. 1). It is possible, however, that the N400 is a phasic modulation of the more sustained CNV. If this were so, our current conceptions of the psychological correlates of the CNV, usually expressed in terms of expectancy and preparation, would have to be expanded.

We also noted previously that the timing, distribution, and monophasic nature of the N400 were unlike those reported for the N2 or N200 wave. While the longer latency of N400 is not a critical consideration here (N2 latency may increase considerably as a function of the subject's decision time; Ritter, Vaughan and Friedman, 1979), it is noteworthy that the N400 was not followed by a positive ERP of the P300 variety. In all the experiments where an N200 has been recorded to an attended, relevant stimulus, it was followed by a (usually larger) P300 centered over the parietal and central scalp. Thus, the absence of a subsequent parieto-central positivity sets the N400 effect apart from most reports on the N200.

What makes comparisons among these components even more difficult is the indication that the N400 described here may be composed of a number of subcomponents. Thus, it is possible that the earlier aspects of the N400 might be related to the previously described N200 or mismatch negativity components, while the later phase may be specific to the reading/semantic anomaly situation. In any case it remains to be seem how many distinct types of late 'mismatch negativities' there are, the extent to which they can be independently elicited, and the nature of psychological processes each is associated with.

A posteriorly distributed P300 wave has been reported by others to follow physically deviant events in an attended sequence, even when those events were not expressly task-relevant (Squires, Donchin, Squires and Grossberg, 1977; Courchesne et al., 1978; Roth, Ford, Lewis and Kopell, 1976). Their results and ours indicate that a stimulus does not have to belong to a preassigned task-relevant category or call forth a specific response in order to elicit a late positivity of the P300 variety. In addition, the ERP to the bold-faced letters was polyphasic, having positive peaks at around 220, 360, and 560 msec superimposed upon a longer-lasting baseline shift

(Kutas and Hillyard, 1980a). If there were an N200 wave present within this late positive complex to physically deviant words, it was not large enough to rise above the baseline.

4.2. Hemispheric asymmetries

Numerous studies have looked for ERPs which are asymmetrically distributed over the two hemispheres as correlates of linguistic or semantic processes. Such results have remained fairly elusive (reviewed by Desmedt, 1977b; Donchin, Kutas and McCarthy, 1977; Hillyard and Woods, 1979). In the present as well as in a previous study (Kutas and Hillyard, 1980a) we found that the ERPs elicited by the words in this silent reading task were characterized by a left-greater-than-right asymmetry in a slow, positive component. While it is not clear which specific aspect of the reading task is important for producing this lateral asymmetry, it is similar to the asymmetries reported in slow potentials by others during hemispherically specialized tasks (Desmedt, 1977a; Butler and Glass, 1976). Perhaps these very slow waves may be more revelatory of hemispheric specialization in man than the phasic ERPs.

The different degree of ERP asymmetry that was observed between right-handers with and without left-handed relatives suggests that this variable may have import for electrophysiological studies of hemisphere specialization. Although the effects of familial sinistrality on various behavioral measures of hemispheric specialization are poorly understood, numerous studies have demonstrated a profound influence of the presence of left-handers in one's immediate family upon dichotic listening and lateralized visual performance scores (Zurif and Bryden, 1969; Hines and Satz, 1971; McKeever, Van Deventer and Suberi, 1973; Hannay and Malone, 1976). With only a few exceptions (Higgenbottam, 1973; Briggs and Nebes, 1976), a family history of left-handedness has been associated with less lateralized performance on tests of auditory and visual perception. Moreover, some studies have shown that a person's familial history of left-handedness may have a more potent influence upon his/her behavioral lateralization scores than does his/her own handedness (Andrews, 1977; Varney and Benton, 1975). It has also been reported that familial sinistrality can influence the amount of task-dependent EEG asymmetry a person can generate (Davidson, Schwartz, Pugash and Bromfield, 1976). Likewise, our data suggest that this variable ought to receive due consideration in ERP studies of hemispheric specialization.

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COMPONENTS OF THE EVENT-RELATED POTENTIAL FOLLOWING DEGRADED AND UNDEGRADED VISUAL STIMULI *

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Event-related potentials were recorded in response to visual stimuli in two different reaction tasks in which subjects were instructed to react immediately to the stimuli, or to delay their response for a 2 sec period, respectively. There were four types of stimuli: frequent-degraded, frequent-undegraded, infrequent-degraded and infrequent-undegraded letters. In all conditions the stimuli evoked complex waveforms which comprised a frontal-negative wave (N400) and a late positive wave that reached a maximum amplitude on the parietal scalp site (P500). In addition, a slow positive wave with a central-parietal scalp distribution was found in the waveforms that were associated with the delayed reaction task. A principal components analysis of the waveforms yielded two major components: an early composite component that peaked around 400 msec, and a late component that became maximally active towards the end of the recording epoch. The scores of the earlier component were more negative (or less positive) and the scores of the late component were more positive when infrequent or degraded stimuli were presented, in comparison with frequent or undegraded stimuli.

1. Introduction

There is an impressive amount of evidence showing that the event-related potential (ERP) to task relevant stimuli consists of several late components that differ in latency and scalp-topography (Squires, Squires and Hillyard, 1975; Squires, Donchin, Herning and McCarthy, 1977; Duncan-Johnson and Donchin, 1977; Roth, Ford and Kopell, 1978; Friedman, Vaughan and Erlenmeyer-Kimling, 1978). Two components that have attracted much attention are a parietal maximum component at about 250–500 msec in latency (P300) and a late 'slow wave' that is positive at posterior scalp sites and negative at frontal scalp sites (Squires et al., 1975, 1977; Duncan-Johnson and Donchin, 1977). Since both components are elicited by low-probability and task relevant stimuli it has been suggested that they are closely related. However, some evidence has been presented that P300 and the slow wave

* A preliminary report of this experiment was presented at the Fifth International Symposium on Electrical Potentials Related to Motivation, Motor and Sensory Processes of the Brain (MOSS V), Ulm, West Germany.