EVENT-RELATED POTENTIALS, LEXICAL DECISION AND SEMANTIC PRIMING [1]

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This paper is concerned with the electrophysiological concomitants of semantic priming in a lexical decision task. Such a task requires subjects to indicate as rapidly as possible whether a letter string stimulus presented on each trial is or is not a word; that is, whether it is present in their lexicon. Reaction time (RT) data in such experiments have repeatedly demonstrated that words preceded by semantically related words are more quickly recognized as words than if they are preceded by unrelated words or by nonwords (e.g., Meyer and Schvaneveldt 1971; Becker 1979, 1980; Foss 1982). This 'semantic priming' effect has been interpreted in a variety of ways. Some theorists have suggested that the semantic features of each stimulus word remain activated to some extent on subsequent trials, thereby reducing the thresholds of hypothetical word recognition units (e.g., Morton's 'logogens') for words sharing those features (Meyer and Schvaneveldt 1976). Others have suggested that semantic context allows subjects to generate an expected set of words which is scanned first during the lexical decision process (Becker 1976). Whatever the specific mechanism proposed, most theorists agree that the occurrence of a given word stimulus in some way alters the state in memory of semantically related words. As a result, less processing (and hence less time) is required to make a lexical decision for semantic associates than for unrelated words or nonwords on the subsequent trial.

In this experiment we sought to determine whether any indication of the differential processing of primed and unprimed words in a lexical decision task is evident in scalp ERPs and, if so, to document its temporal and spatial characteristics. Obtaining such information is an essential first step in using ERPs to investigate the neural substrates of semantic processes. We therefore recorded RT, accuracy, and ERP data to word and nonword stimuli in a lexical decision task of a type commonly used to investigate semantic priming.

Methods

Subjects

Sixteeen undergraduates, 18–21 years old (6 males) were paid for participating in a single 2 h session. All subjects except 2 males were right-handed (LQ > +50) according to the Edinburgh Handedness Inventory (Oldfield 1971).

Stimuli

The stimuli were 240 words and 240 nonwords presented one word per trial at a fixed inter-trial interval of 2500 msec. On each trial a word or nonword was presented and subjects were required to press as rapidly as possible a 'Yes' button for words and a 'No' button for nonwords. 'Yes' responses were always made with the dominant hand.

Although subjects were instructed only about

the word-nonword discrimination, stimuli were generated and data were analyzed according to 4 stimulus types: Targets (N = 80), Primes (N = 80), Fillers (N = 80) and Nonwords (N = 240). Primes and Targets were words from the same semantic category (e.g., rain–snow, tulip–lilac) presented on consecutive trials, with the Prime preceding the Target. The order of the specific words within the Prime/Target pairs was reversed for half of the subjects so that each member of a pair served as both Prime and Target across subjects. Fillers were words unrelated to either Primes or Targets. The average word frequency across all words was 51.07 (Kucera and Francis 1967) and did not differ significantly between word types (57.34, 51.22 and 44.64 for the Prime-Target lists and for the Fillers, respectively). Word length ranged from 3 to 6 letters with an average of 4.7 letters per word and did not differ significantly between word types. The 240 Nonwords were pronounceable permutations of the words used in the other lists.

The 480 stimuli were presented in pseudo-random order, with the constraint that the Primes and Targets were presented consecutively and that no more than 3 words or 2 nonwords occurred in sequence. Four different randomizations were used with 4 subjects assigned to each. The stimuli were 4 mm × 6 mm characters (0.4° visual angle) presented foveally on a dark CRT and were exposed for 1000 msec.

Procedure

Subjects were tested individually in a semi-darkened sound-attenuating chamber. They first received 15 words and 15 nonwords in random sequence as practice, followed by the 480 test trials in 6 blocks of 80 trials each. Two minutes of rest separated the blocks. Single trial EEG and behavioral data were stored on magnetic tape for offline analysis. The maximum allowable RT was 1500 msec; longer responses as well as errors were excluded from the ERP analyses presented below.

ERP recordings

Sixteen channels of EEG were recorded from silver disk electrodes (impedance less than 5 kΩ), amplified (gain = 20,000) with a bandpass of 0.1–100 Hz (-3 dB), and sampled at 250 Hz beginning 100 msec before stimulus onset and continuing for 1024 msec. The montage included 10-20 electrode sites Fpz, F3, Fz, F4, T3, T4, C3, Cz, C4, P3, Pz, P4, O1, O2, A1, and the right suborbital ridge. A non-cephalic reference was used, consisting of two electrodes (one over the C7 spine and one over the sternum) joined by a variable resistor to balance ECG (Stephenson and Gibbs 1951). The A1 electrode was included for possible use as reference in cases of excessive residual ECG artifact.

Data analysis

Semantic priming effects on performance were assessed by comparing RTs for correct responses and error rates for each of the 4 stimulus types (Targets, Primes, Fillers, and Nonwords). Additional analyses were conducted to assess the relationship between semantic priming and other possible sequence effects.

Initial examination of the ERP data indicated that the A1 reference was necessary in 4 subjects, two because of residual ECG artifact and two because of low frequency activity throughout the sampling epoch that was equipotential at all scalp locations. Analysis of left–right ERP differences included only the 12 subjects with the non-cephalic reference.

To avoid prejudging the relationship between possible ERP priming effects and conventionally defined ERP components, we first examined the ERP wave forms for the different word types, identified a latency interval over which differences between conditions were consistently observed, and calculated an area measure for each subject's data over that interval. After demonstrating the statistical reliability of the basic word condition effect in this manner, we conducted a number of additional analyses aimed at determining the relationship between the priming effect, P300, and other ERP components.

The statistical significance of experimental manipulations in both the performance and ERP data was assessed by repeated measures ANOVAs in which within-subject means were the dependent variable. Significant treatment effects in the ANOVAs were analyzed further using the Tukey

A procedure for individual comparisons among cell means (Winer 1962). The significance criterion was $P < 0.05$ for both types of test. Degrees of freedom were adjusted according to the Geisser-Greenhouse procedure to compensate for inhomogeneous variances and covariances across treatment levels which can produce sizable increases in type I error in repeated measures ANOVAs (Greenhouse and Geisser 1959; Kesselman et al. 1980).

Results

Performance

The validity of the priming manipulation was assessed by comparing mean RTs for the 4 stimulus types shown in Table I. RTs for Targets were significantly faster than RTs for Primes and Fillers which did not differ from each other, and all 3 word types were significantly faster than Nonwords (F (2.04, 30.67) = 45.11, $P < 0.0001$; these and subsequent statements regarding the significance of individual comparisons are based on the Tukey A procedure). A similar analysis using within-subject medians instead of means as the dependent variable did not change the pattern of significance. Fewer errors were made for Targets than for Primes, Fillers, and Nonwords (Table I), with no significant difference among the latter (F (2.11, 31.58) = 6.20, $P < 0.005$).

In the comparison of all Targets, Primes, and Fillers just described, stimulus type is partially confounded with whether a word or nonword occurred on the preceding trial. That is, Targets were always preceded by other words (the Primes), whereas Primes and Fillers could be preceded by either words or nonwords. To determine whether the obtained Target-Prime effect was secondary to differential word-nonword sequence effects, RTs for Targets were compared to RTs for the following trial types: (a) Primes and Fillers that followed words (Word-Word trials); (b) Primes and Fillers that followed Nonwords (Nonword-Word trials); (c) Nonwords that followed words (Word-Nonword trials); and (d) Nonwords that followed nonwords (Nonword-Nonword trials). The overall stimulus type effect was significant (F (2.76, 41.38) = 36.05, $P < 0.0001$), and RTs for Targets (600 msec) were significantly faster than both the Word-Word and Nonword-Word sequences, which did not differ from each other (629 and 642 msec, respectively). All 3 word sequences were faster than both of the nonword sequences, which did not differ significantly (Word-Nonword: 690 msec and Nonword-Nonword: 701 msec).

ERPs

Fig. 1 presents ERPs for Targets, Primes, and Fillers at 3 midline scalp sites and the suborbital ridge. The wave forms at a given electrode site are similar in morphology, with the main difference being a divergence between ERPs for Targets and those for Primes and Fillers. The divergence is maximal in the region of a negative-going deflection at about 400 msec, but extends over several peaks and troughs in the wave form including the large posterior positivity. ERPs for Nonwords (not shown in Fig. 1) were similar to those of the Primes and Fillers, but with a slightly later posterior positivity.

To determine whether the ERP differences across stimulus type were statistically reliable, repeated measures ANOVAs were performed on

TABLE I

Performance and ERP measures for the 4 stimulus types.

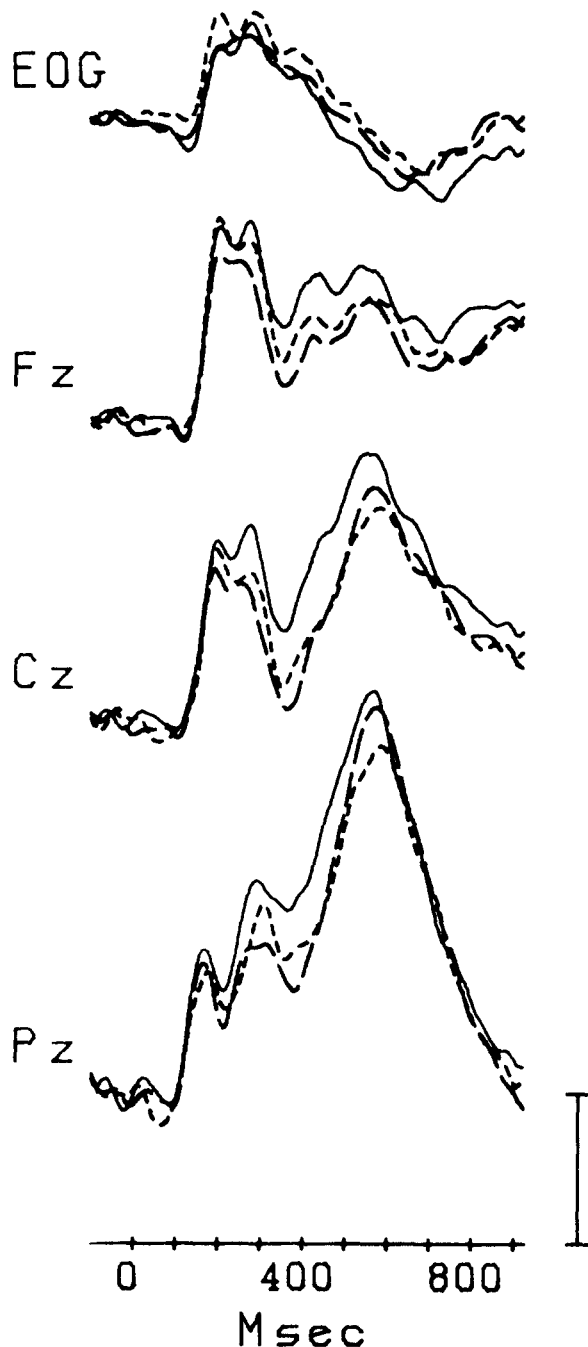| Stimulus type	Reaction time (msec)	Errors (%)	P300 latency at Pz (msec)	P300 amplitude at Pz (μV)	Area 250–600 msec (arbitrary units)
Target	600	4.0	561	17.3	10680
Prime	629	7.5	578	16.6	9317
Filler	648	9.4	584	15.3	9642
Nonword	696	7.9	612	13.7	8791

Fig. 1. ERPs for Targets (solid), Primes (long dash), and Fillers (short dash) at 3 midline locations (Fz, Cz, and Pz) and the right suborbital ridge (EOG). Calibration: 5 μV; positive upward.

the areas under the ERPs between 250 and 600 msec at 13 electrode sites (the suborbital ridge, Fpz, and A1 were excluded). To avoid negative

values in the area calculation, the baseline above which areas were measured was defined as the minimum amplitude value within the 250–600 msec time window. This value was determined separately for each subject across electrode sites and conditions so that differences among conditions and electrodes would be maintained. A two-way ANOVA (stimulus type × anterior-posterior location) was performed on the area measures for ERPs at the 3 midline sites (Fz, Cz, Pz) based on data from all 16 subjects. This analysis was designed to assess the significance of the stimulus type effect across all subjects. A three-way ANOVA (stimulus type × left-right × electrode location) was performed to assess the scalp distribution of ERP effects and the significance of differences between left- and right-hemisphere scalp locations. The three-way analysis excluded the midline sites (since they do not bear on left–right differences) and was based only on the 12 subjects for whom a non-cephalic reference electrode was used.

In the midline analysis, area measures for the 4 stimulus types differed significantly (F (2.18, 32.67) = 12.49, $P < 0.0001$). As shown in Table I, the largest area was obtained for Targets and the smallest area for Nonwords; Targets differed significantly from both Primes and Fillers, which did not differ from each other. The anterior-posterior effect was also significant (F (1.37, 20.58) = 11.10, $P < 0.002$), with larger areas at Pz than at either Cz or Fz, which did not differ significantly. There was no stimulus type × anterior-posterior interaction.

The scalp distribution of the ERP differences between Targets and Primes is shown in Fig. 2. ERPs for Targets, Primes, and their difference (Targets − Primes) are shown for each electrode site. The difference wave forms at all scalp locations diverged from zero between 200 and 250 msec, reached a maximum at approximately 400 msec (vertical lines), and decreased thereafter. At posterior locations the difference wave forms returned to zero by approximately 600 msec, whereas at frontal locations the differences persisted at longer latencies. As in the two-way ANOVA for the midline locations, there was a significant main effect of stimulus type in the 3-way analysis (F (2.13, 23.38) = 8.04, $P < 0.002$), indicating that
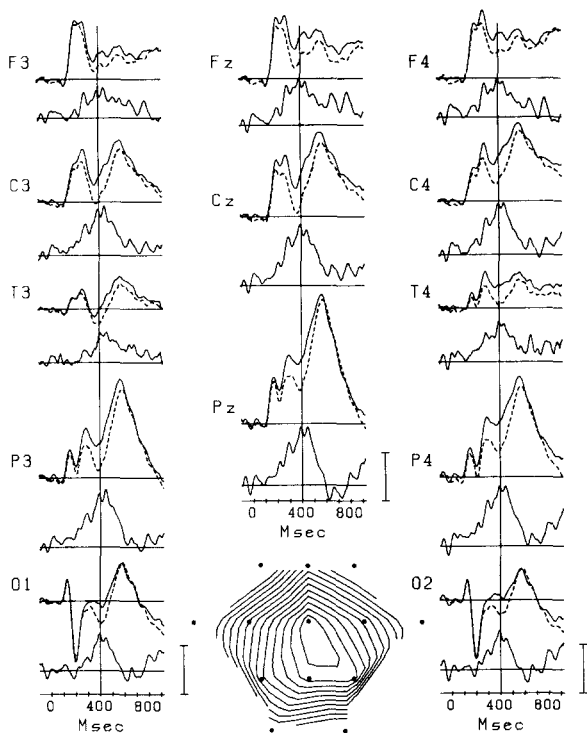
Fig. 2. Scalp distribution of ERPs for Targets (solid), Primes (dash), and their difference (Targets − Primes). Calibration: 5 μV for ERP wave forms, 2.5 μV for difference wave forms; positive upward. The isovoltage topographic map (top view of the head) shows the scalp distribution of the difference wave form at its peak (400 msec, indicated by vertical lines in the wave form plots). Contour lines derived by linear interpolation are plotted at intervals of 0.1 μV. The 13 scalp recording sites are indicated by dots; anterior is upward.

areas for Targets differed significantly from the other stimulus types. The main effects for left-right and electrode location were also significant (F (1, 11) = 6.40, $P < 0.03$; and F (1.48, 16.30) = 4.71, $P < 0.04$, respectively). These effects indicate that areas were significantly larger at locations over the right hemisphere than the left and were significantly larger at parietal and central sites than frontal, temporal, or occipital. These differences are evident for Primes and Targets in Fig. 2, and the left-right asymmetry is shown more directly in Fig. 5A below.

As shown in Fig. 2, the ERP differences between Targets and Primes were evident over both hemispheres and were largest near the midline at

central and parietal locations. A separate ANOVA on areas for Prime and Target ERPs indicated that there was no significant left − right difference in the magnitude of the priming effect. Its scalp distribution is shown most directly in the isovoltage topographic map at the bottom of Fig. 2, which plots the distribution of the difference wave forms at 400 msec, the approximate latency of their peak amplitude.

As noted above for the RT data, it is possible that the ERP differences between Targets and other stimulus types were due to differential word-nonword sequence effects, not to facilitation by a preceding semantically related word. Because ERP areas for Primes and Fillers did not differ significantly as noted above, we pooled them, averaged separately those trials preceded by a word or nonword, and conducted another ANOVA on the ERPs from midline sites. The resulting ERPs are shown in Fig. 3. ERP areas for the Word-Word and Nonword-Word sequences did not differ significantly, whereas both differed significantly from the area for Targets (F (1.97, 29.58) = 4.68, $P < 0.02$).

The preceding analyses establish the statistical reliability of the ERP differences between primed and unprimed words shown in Figs. 1–3 and demonstrate that they cannot be attributed to differential word-nonword sequence effects. Additional analyses were performed to examine the relationship of such differences to the apparent amplitude and latency effects on the late positivity evident in Fig. 1 which we will provisionally refer to as P300 (based on morphology, latency, and scalp distribution). Peak amplitudes and latencies of P300 were determined for each subject by measuring the most positive peak at Pz between 360 and 900 msec; results are shown in Table I.

P300 latencies varied across stimulus type in the same manner as the RTs, with the shortest latencies for Targets and the longest latencies for Nonwords (F (2.30, 34.45) = 9.47, $P < 0.001$). Targets differed significantly in latency from both Primes and Fillers which did not differ significantly from each other, and latencies for Nonwords were significantly longer than for all other stimulus types. P300 amplitudes also differed significantly among conditions, becoming smaller as latency increased
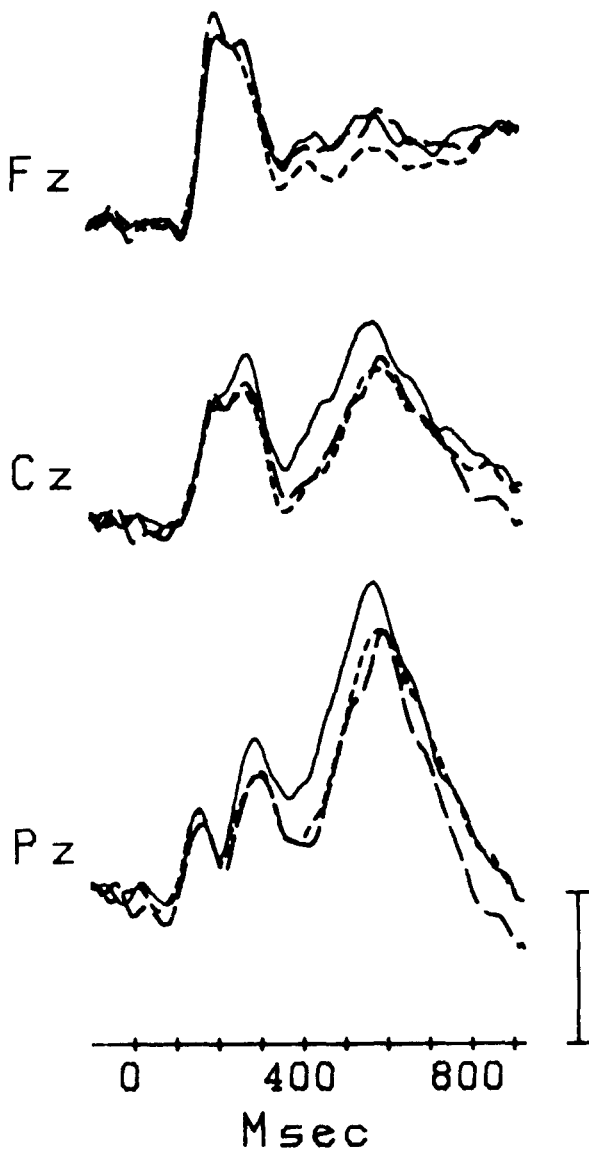
Fig. 3. ERPs for Targets (solid), Nonword-Word sequences (long dash), and Word-Word sequences (short dash) at midline locations. Calibration: 5 μV; positive upward.
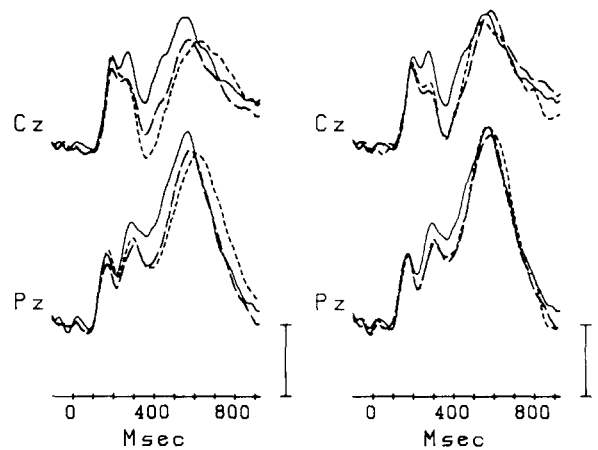

Fig. 4. Left: ERPs for Targets (solid), Words (pooled Primes and Fillers — long dash), and Non-words (short dash). Right: ERPs for the same 3 stimulus types, but with Word and Nonword ERPs including only those trials on which RT was less than the mean RT for Targets + 0.5 S.D. Calibrations: 5 μV; positive upward.

$(F (2.87, 43.01) = 12.06, P < 0.0001)$.

Fig. 4A presents ERPs for Targets and Nonwords overlapped with ERPs representing the average of pooled Prime and Filler trials (hereafter termed Words). (Note that the P300 latency and amplitude differences shown in these grand averages are smaller than those in Table I because the grand average wave forms confound amplitude and latency variability across subjects.) Because P300 latency has previously been demonstrated to covary with RT, it is possible that the ERP differences between Targets and the other stimulus types are secondary to differences in P300 latency. To address this possibility, ERPs for Nonwords and Words (Primes and Fillers) for each subject were reaveraged, including only those trials having RTs less than the mean + 0.5 S.D. of that subject's mean RT to Targets. The ERPs resulting from this analysis are shown in Fig. 4B. Mean RTs, P300 latencies, and P300 amplitudes did not differ significantly between the 3 sets of ERPs, but the same 250–600 msec area measures reported above were again significant (F (1.98, 29.73) = 5.71, $P <$ 0.01). Targets were significantly different from Nonwords and just missed the 0.05 significance criterion when compared to the Words. Because the ERP differences between Targets and the selected Words/Nonwords began and ended earlier than for the unselected ERPs, another area analysis was performed between 200 and 500 msec. Targets differed significantly both from Words and Nonwords, which did not differ from each other (F (1.31, 28.61) = 8.19, $P < 0.002$).

Possible effects of the responding hand on the left-right ERP asymmetries described above were

assessed by comparing the asymmetry for Words (which required 'Yes' responses with the dominant hand), with the asymmetry for Nonwords (which required 'No' responses made with the non-dominant hand). This comparison is shown in Fig. 5, which presents ERPs from homologous locations over the left and right hemispheres for Words and Nonwords (Fig. 5A and B, respectively). The fact that asymmetries in the same direction occurred with responses of either hand indicates that such asymmetries cannot be due entirely to movement-related activity associated with the lateralized response.

Discussion

Since the interpretation of the ERP data depends critically upon the validity of the semantic priming manipulation, we first consider the evidence that semantic priming in fact occurred. Subsequently we consider the relationship of the obtained ERP differences between primed and unprimed words and previously described P300, N200, and N400 potentials, and whether the obtained ERP differences are due to semantic priming per se, to generalized (i.e., not specifically semantic) priming, or to expectancies for specific stimuli or stimulus categories.

Behavioral evidence for semantic priming

The performance data indicated that RTs for Targets (i.e., words that had been primed by semantically related words on the preceding trial) were significantly faster than RTs for either of the other word types (Primes and Fillers) as well as faster than RTs for Nonwords. The performance facilitation for Targets cannot be attributed to differences in specific words, since exactly the same words were used as Primes and Targets in different subjects. Other alternative explanations for the obtained Target facilitation can also be eliminated. First, error rates were lowest for Targets, indicating that the facilitation cannot be attributed to a speed-accuracy tradeoff. Second, comparison of RTs for Targets with RTs for Word-Word and Nonword-Word sequences indicates that the facilitation was not due to differential distributions of Words and Nonwords on the preceding trial. Third, although the RT difference between Primes and Fillers approached statistical significance, a subsequent experiment in which a single set of words was used as Targets, Primes, and Fillers in different subjects showed no such difference, indicating that it was due to some uncontrolled difference between the specific words employed as Primes and Fillers in the present
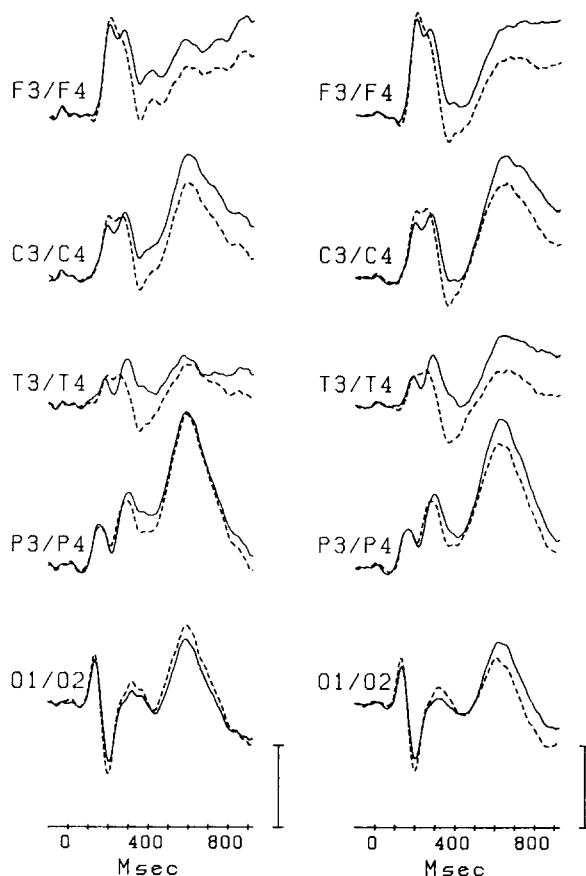

Fig. 5. Left: ERPs for pooled Primes and Fillers (which required a response with the dominant hand) at homologous electrode locations over the left (dash) and right (solid) hemispheres. Right: ERPs for Nonwords (which required a response with the non-dominant hand) at the same homologous electrode locations. Calibrations: 5 μV; positive upward.

experiment [2]. Taken together, these performance data provide strong evidence that semantic priming occurred in the present experiment and that it is valid to compare ERPs for Primes and Targets to assess possible ERP concomitants of semantic priming.

Priming effect on ERPs and its relationship to P300, N200, and N400 components

The ERPs for Targets diverged from those for Primes, Fillers, and Nonwords beginning at approximately 250 msec, and the difference persisted until approximately 600 msec at parietal locations and longer at frontal locations (Figs. 1 and 2). The difference was not evident at the suborbital ridge, which argues against EOG artifact as its source. The scalp distribution of the difference wave forms shown in Fig. 2 indicates that the priming effect occurred at locations over both hemispheres and was largest at the midline in the centroparietal region.

Because the Prime – Target ERP difference lasted over a number of peaks and troughs in the wave forms, we were disinclined to characterize it using procedures such as peak amplitude measurement or principal component analysis (PCA) which explicitly or implicitly associate the ERP difference to specific wave form deflections or sources of variance in the data set [3]. Rather, our strategy was first to use the area analysis to document the statistical significance of the effect without commitment to specific ERP components and second to conduct additional analyses to assess its relationship to such components. The significant area differences between Targets and Primes (Fig. 2), between Targets and Words in semantically unrelated Word-Word sequences (Fig. 3), and between Targets and Words selected for fast RTs (Fig. 4A) provide strong evidence of the statistical reliability of the basic ERP difference between primed and

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[2] Although the RT difference between Primes and Fillers did not reach the 0.05 level, the possibility that it might have reflected a true difference was puzzling: (a) because what distinguished Primes from Fillers (apart from the specific words in each category) was whether the stimulus on the *subsequent* trial was a semantically related word or not; and (b) because they were matched for both word frequency and length. Because a true Prime – Filler RT difference might indicate a flaw in the design which could invalidate the Prime-Target comparison, we conducted additional analyses and replications to be sure that the marginally significant difference obtained did not indicate a true difference. First, RTs for Fillers remained significantly longer than those for Primes: (a) in an analysis of covariance with word frequency and length as covariates; (b) when sequence effects 3 stimuli deep were assessed; and (c) in a new RT experiment in which only Fillers, Primes, and Nonwords were presented (i.e., with no semantically related pairs on successive trials). These results indicate that the Prime – Filler difference was not simply due to sampling variability (i.e., a type I error), but more important they conclusively rule out any unanticipated sequence effects which could invalidate the Prime-Target comparison. Rather, they suggest that some uncontrolled differences in the specific sets of words used as Primes and Fillers were responsible. Strong support for this conclusion derives from a replication of the present experiment (Bentin et al. in preparation) in which a single set of words served as Targets, Primes, and Fillers in different subjects. In that experiment the difference in RTs between Targets and Primes (i.e., the priming effect) was replicated, with a small and clearly non-significant RT difference between Primes and Fillers.

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[3] Although we have a number of reservations about conclusions based on statistical analysis of component scores derived from PCA (e.g., Wood 1980; Wood and McCarthy 1984), we will briefly describe results based on a covariance PCA derived from ERPs for Targets, Primes, and Fillers at 13 electrode sites (excluding EOG, A1, and Fpz). Six components, accounting for 92% of the total variance, were rotated using the Varimax criterion, and univariate repeated measures ANOVAs (stimulus type × electrode location) were computed on the 6 sets of rotated component scores. Of the 6 components, three contributed significantly to the 250–600 msec latency range over which the Target – Prime differences were observed. The earliest of the 3 components had two peaks (268 and 348 msec), the middle component peaked at 492 msec, and the third peaked at 620 msec (after the Target – Prime differences terminated at most locations). Of the 6 components, only the one peaking at 492 msec was significantly affected by stimulus type. Note that its peak latency is later than the peak of the difference wave forms (400 msec) and earlier than the peak latency of P300 (584 msec). Thus, to the extent that one wishes to trust the results of ANOVAs on PC scores, this analysis lends additional support to the area analysis in demonstrating that ERPs for Targets and Primes differed significantly during the time interval preceding P300. However, we do not regard the PCA component peaking at 492 msec as a definitive characterization of the Target – Prime differences for two reasons. First, it is not necessary that the ERP differences between Primes and Targets correspond in a one-to-one manner to a particular component of the total variance across subjects and electrode locations (Wood 1980). Second, there is no guarantee that PCA correctly reconstructs the 'true' component structure of a given set of ERPs or correctly allocates variance across components (Wood and McCarthy 1984).

unprimed words. It is therefore appropriate to attempt to characterize that difference and to consider its relation to ERP components previously identified in similar tasks.

P300. Large positive potentials peaking near 600 msec were obtained for all 4 stimulus types; these we tentatively identified as P300s based on their morphology, latency, and scalp distribution. This interpretation is supported by ERP data obtained from 8 of the 16 subjects in an 'oddball' counting task using visual 'XXXXX' and 'OOOOO' patterns presented at probabilities of 0.8 and 0.2, respectively. The low-probability counted stimuli elicited large P300s with similar morphologies, amplitudes (mean = 15.2 μV), and scalp distributions to the late positivities in the priming task, whereas the high-probability stimulus elicited no detectable P300s. The fact that all stimuli in the priming task elicited large P300s whereas only the low-probability stimulus did so in the oddball task suggests that the absence of P300s for high-probability stimuli in oddball tasks may be a more important phenomenon to explain that their presence for low-probability stimuli.

Positive relationships between P300 latency and RT have been obtained in a number of information processing tasks including lexical decision (Ritter et al. 1972; Kutas et al. 1977; Ford et al. 1981; McCarthy and Donchin 1981, 1983; Rugg 1983). The present data are consistent with the pattern of results thus far reported in the literature: P300 latency covaried with RT but increased more slowly over stimulus type than did RT (Table I). This correlation between RT and P300 latency raises the possibility that the ERP differences between Targets and Primes at shorter latencies were at least in part secondary to the P300 latency effects; that is, that the earlier onset of P300 for the Targets created the divergence noted in the 250–600 msec interval.

Four types of evidence argue against this interpretation. First, as shown in Fig. 1, the differences between Target and Prime ERPs occurred on the upslope and peak of the large late positivity, but its downslope was virtually identical across all stimulus types. If P300 is defined as the entire positive deflection and if the only effect of priming is a P300 latency shift, then the upslope, peak, and

downslope of P300 should have been shifted in latency by a similar amount. Second, the Target − Prime differences were still present between Targets and the selected Word trials having fast RTs (Fig. 4B), in which there were no significant differences in P300 latency or RT. Third, differences between ERPs for homologous left- and right-hemisphere scalp locations (Fig. 5A) were similar in form to the Target − Prime differences, without associated differences in P300 latency. Finally, ERP differences between Targets and Primes have been obtained in a recognition memory experiment without overt responses or concomitant P300s (Bentin et al. in preparation). Thus, although there were significant differences between P300 latency for Targets and Primes, the earlier ERP differences cannot be attributed solely to P300 latency effects. These considerations indicate the need to distinguish apparent experimental effects on P300 latency from effects on earlier, overlapping portions of ERP wave forms.

N200 and N400. The ERP differences between Targets and Primes, as well as the negative-going deflection peaking at 400 msec in the ERPs for all stimulus types, are similar to previously investigated ERP phenomena termed N200 and N400. Kutas and Hillyard (1980, 1983, 1984) have described a negative-going ERP deflection (N400) to words presented in sentences which is sensitive to semantic relationships between the word and its sentence context. In early studies N400 was interpreted as reflecting the 'reprocessing' of semantic anomalies (Kutas and Hillyard 1980), whereas more recent work has suggested that N400 reflects semantic priming or expectancy created by the sentence context (Kutas and Hillyard 1984). Other investigators have described negative or negative-going deflections with latencies of 200–500 msec (N200) in a variety of linguistic and non-linguistic tasks (e.g., Simson et al. 1976, 1977; Polich et al. 1981; Näätänen et al. 1982; Stuss et al. 1983). These potentials have been interpreted in a variety of ways, including mismatch detection (Näätänen et al. 1982), stimulus classification (Ritter et al. 1983), and category expectancy (Polich et al. 1981) among others.

There is considerable disagreement about the relationship between N400 and N200 and about

the empirical and theoretical bases for distinguishing between them, with the key question being whether N400 is 'just another N200' (for discussion, see Kutas and Hillyard 1983; Ritter et al. 1984). In light of this disagreement, it is not profitable in our opinion to attempt to draw definitive conclusions about the relationship between N200-N400 and either the negative deflection peaking at about 400 msec or the Target – Prime differences in the present experiment. Rather, we note two aspects of the present results that must be considered in attempting to draw such relationships. First, the negative-going deflection at 400 msec seen in ERPs for all 4 stimulus types was negative relative to baseline only at far lateral and posterior electrode sites (T3, O1, and O2, see Fig. 2). This distribution is superficially similar to that reported for visual N200 (Simson et al. 1977) but it is not definitive because the negative-going deflections were increasingly more positive toward the midline, implying that they were superimposed upon overlapping positive-going potentials at central locations. The possibility of such overlap complicates the interpretation of the different distributions of the negative-going deflection (most negative at lateral sites) and the Target – Prime differences (largest at the midline). In a semantic priming experiment which attempted to dissociate the negative- and positive-going potentials (Bentin et al. in preparation), a broader distribution of the negative-going deflection was obtained. Second, in comparing the ERP differences between Targets and Primes with N200 and N400, it is important to note that they could be due to differences in the magnitude of a positive potential (larger for Targets than Primes), differences in the magnitude of a negative potential (larger for Primes than Targets), or the net result of combined effects on a number of positive or negative potentials. If the Target – Prime difference is interpreted as resulting from differing amounts of a negative potential, then the latency and morphology of such differences are similar to those of N400 in the Kutas and Hillyard experiments. However, there is nothing in the present data that demands such an interpretation. Similar considerations apply to the interpretation of experimental effects on N200 and N400 in other experiments.

Semantic priming, generalized priming, and expectancy for stimuli or stimulus categories

Although the present results provide strong evidence that ERPs for primed and unprimed words differ significantly, they do not address two important questions about the nature of such differences. The first is whether Target – Prime ERP differences reflect differences in lexical or semantic processes presumed to mediate the facilitation effect on performance, or whether they reflect other processing differences that are not specific to semantic tasks. A similar question has played a central role in the debate about the relationship between N400 and N200 (see Kutas and Hillyard 1983; Stuss et al. 1983; Ritter et al. 1984). On one hand, the negative-going deflection and the Target – Prime ERP differences might reflect some portion of the neural events that mediate the process of accessing a word's representation in lexical memory. This interpretation would account for the ordering of the ERP data across stimulus types by assuming that the magnitude of the hypothesized negative-going deflection is proportional to the amount of lexical search required (largest for Nonwords, smallest for Targets, and intermediate for Primes and Fillers), and is consistent with the recent report of Kutas and Hillyard (1984) that N400 varies inversely with the Cloze probability of sentence-final words. Alternatively, the Target – Prime differences could reflect a sensitivity to relationships between successive stimuli of a more general sort that is not limited to semantic tasks (e.g., Stuss et al. 1983). According to this interpretation, similar performance facilitations and similar ERP findings should be obtained in non-semantic analogs of the present experiment.

A second important question concerning the interpretation of the present results is whether the negative-going deflection and the Target – Prime ERP differences represent *automatic* or *strategic* processes (Posner and Snyder 1975; Neely 1977). Automatic processes (such as spreading activation through semantic memory) are assumed to be fast-acting, not to involve conscious attention or awareness, and not to be influenced by manipulations of subject strategy. Strategic processes (such as the development of explicit, conscious expectancies) are assumed to be relatively slow-act-

ing, to require conscious attention or awareness, and to be influenced by manipulations of subject strategy. Proponents of dual theories of semantic priming have argued that both automatic and strategic processes are required to account for different types of priming effects (Neely 1977), whereas other theorists have attributed the entire semantic priming effect to expectancy or related strategic processes (Becker 1979, 1980). With few exceptions (e.g., Näätänen et al. 1982), the ERP literature has been notably silent on this important distinction. Whether N200, N400, and related potentials reflect automatic processes, strategic processes, or both, is an important empirical question for future research.

In conclusion, the present experiment has demonstrated that at least some portion of the neural activity that differentiates primed and unprimed words in a lexical decision task is evident in scalp ERPs. Such activity cannot be due solely to differences in P300 latency, although P300 latency differences accompanied the RT differences between Targets and Primes. Whether these ERP concomitants of semantic priming reflect semantic priming per se, priming of a more general sort, or the development of expectancies for specific stimuli or stimulus categories remains to be determined.

Summary

ERPs were recorded during a lexical decision task in order to investigate electrophysiological concomitants of semantic priming. The stimuli were 240 words and 240 nonwords presented one per trial at a fixed intertrial interval. Subjects were required to classify each stimulus as a word or nonword by pressing one of two response buttons. ERPs were recorded from 14 scalp locations, the right suborbital ridge, and the left earlobe, all referred to a balanced non-cephalic reference. RT and error data confirmed that semantic priming occurred under the conditions employed: primed words (those preceded by a semantically related word) were identified as words faster and more accurately than were unprimed words (those preceded by semantically unrelated words or nonwords).

ERPs for all stimulus types were characterized by a large positivity peaking between 550 and 650 msec, preceded by a negative-going deflection peaking at approximately 400 msec. ERPs for primed and unprimed words were shown to differ significantly, diverging 200–250 msec following stimulus onset, reaching a maximum near the peak of the negative-going deflection at 400 msec. These differences were observed at locations over both hemispheres and were maximal in the centroparietal region. Although P300 latency differences between primed and unprimed words were also obtained, the priming effect on ERPs at shorter latencies could not be explained solely by P300 latency effects. Possible relationships between these ERP concomitants of semantic priming and P300, N200, and N400 were discussed.

Résumé

Potentiels liés à l'événement, décision lexique et préparation sémantique

Les potentiels liés à l'événement (PLE) ont été enregistrés pendant l'exécution d'un test de décision lexique afin de rechercher les événements électrophysiologiques concomitants de la préparation sémantique. L'ensemble des stimulus comprenait 240 mots et 204 'non mots'; un stimulus était présenté à chaque essai, la durée entre deux essais étant fixe. La tâche des sujets était de classer chaque stimulus en tant que mot ou 'non mot', la réponse était effectuée en appuyant sur un des deux boutons présentés. Les PLE ont été enregistrés à partir de 14 sites différents sur le scalp, du sillon suborbitaire droit et du lobe de l'oreille gauche, tous avec une référence non céphalique bien équilibrée. Les données concernant le temps de réaction et les erreurs ont confirmé l'existence d'une préparation sémantique dans les conditions utilisées: les mots 'préparés' (déjà précédés par un mot lié du point de vue sémantique) ont été identifiés en tant que mot plus vite et avec plus de précision que ne l'ont été les mots non 'préparés' (précédés par un mot non lié sémantiquement ou par un stimulus 'non mot').

Pour tous les types de stimulus, les PLE ont été

caractérisés par un ample pic positif entre 550 et 650 msec, précédé par une déflexion négative à environ 400 msec. Les PLE pour les mots préparés et non préparés ont montré des différences significatives, divergeant de 200, 250 msec après le début du stimulus, atteignant un maximum proche du pic de déflexion négative vers 400 msec. Ces différences observées dans les deux hémisphères étaient maximales dans la région centropariétale. Bien que des différences de latence de l'onde P300 entre mots préparés et mots non préparés aient également été obtenues, les effets de la préparation sur les PLE à courte latence n'ont pas pu être expliqués par les seuls effets sur la latence de l'onde P300. On discute des relations éventuelles entre les événements des PLE concomitants de la préparation sémantique et les ondes P300, N200 et N400.

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