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Research report

Event-related potential indices of semantic priming using masked and unmasked words: evidence that the N400 does not reflect a post-lexical process

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Abstract

Several authors have contended that the N400 is a reflection of a post-lexical event such as that proposed by Neely and Keefe [J.H. Neely, D.E. Keefe, Semantic context effects on visual word processing: a hybrid prospective/retrospective processing theory, in: G.H. Bower (Ed.), The Psychology of Learning and Motivation: Advances in Research and Theory, Vol. 23, Academic Press, New York, 1989, pp. 207–248.], whereby the subject compares the word on the current trial to the ''context'' provided by the word on the preceding trial [M. Besson, M. Kutas, The many facets of repetition: A cued-recall and event-related potential analysis of repeating words in same versus different sentence contexts, Journal of Experimental Psychology: Learning, Memory and Cognition, 19 (5) (1993), 1115-1133; C. Brown, P. Hagoort, The processing nature of the N400: Evidence from masked priming. Journal of Cognitive Neuroscience, 5(1) (1993), 34–44; P.J. Holcomb, Semantic priming and stimulus degradation: Implications for the role of the N400 in language processing, Psychophysiology 30 (1993), 47–61; M.D. Rugg, M.C. Doyle, Event-related potentials and stimulus repetition in indirect and direct tests of memory, in: H. Heinze, T. Munte, G.R. Mangun (Eds), Cognitive Electrophysiology, Birkhauser Boston, Cambridge, MA, 1994]. A study which used masked primes to directly test this possibility has been reported by Brown and Hagoort [C. Brown, P. Hagoort, The processing nature of the N400: evidence from masked priming. Journal of Cognitive Neuroscience, 5(1) (1993), 34–44]. When the primes were masked, no priming effect was observed on the N400. When behavioral data were collected in the same paradigm, from another group of subjects, the usual priming effect on RT was obtained. Considered together, the data from the two groups of subjects indicated that activation of semantic representations had occurred without conscious awareness. As no N400 priming effect was observed, it was suggested that N400 must reflect a post-lexical process. This interpretation, however, is at odds with the findings of other studies which have reported N400 priming effects under conditions where post-lexical processes would not be thought to operate[J. Anderson, P. Holcomb, Auditory and visual semantic priming using different stimulus onset asynchronies: an event-related brain potential study. Psychophysiology 32 (1995), 177–190; J. Boddy, Event-related potentials in chronometric analysis of primed word recognition with different stimulus onset asynchronies, Psychophysiology 23 (1986), 232–245; D. Deacon, T. Uhm, W. Ritter, S. Hewitt, The lifetime of automatic priming effects may exceed two seconds, Cognitive Brain Research 7 (1999), 465–472; P.J. Holcomb, Automatic and attentional process: an event-related brain potential analysis of semantic priming. Brain and Language 35 (1998) 66–85]. The present study replicated Brown and Hagoort using a repeated measures design, a shorter SOA (stimulus onset asynchrony), and a slightly different threshold setting procedure. Significant priming effects were obtained on the mean amplitude of the N400 regardless of whether the words were masked or unmasked. The findings imply that the processing subserving the N400 is not postlexical, since the N400 was manipulated without the subjects being aware of the identity of the words.

Keywords: N400; Masked priming; Semantic priming

1. Introduction

A late negative component of the human event-related potential (ERP), termed the N400, is elicited by linguistic stimuli provided that the subject attempts to process the stimuli for their meanings [3,12,26]. The earliest reports of the N400 manipulated its amplitude by varying the congruity or close probability of the terminal words of sentences [19,20]. On the basis of these early studies, it was concluded that the N400 reflected the process of integrat-

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ing the terminal word into the context of the sentence. The N400 has since been examined in a variety of single word priming paradigms where the only context is the preceding word. In several studies using single words significant priming effects were found on the N400, even though the SOA was too short to allow the operation of post-lexical processes [1,5,13,15]. The notion that N400 primarily reflects post-lexical integration has nevertheless been adopted by some investigators in interpreting their data [4,6,18,27,28].

Holcomb [18] came to this conclusion on the basis of data derived from degraded stimuli. The degraded stimuli elicited N400s which peaked later than for undegraded stimuli but the latency difference was constant, regardless of whether the words were primed or unprimed. Holcomb reasoned that priming should have interacted with degradation if N400 reflected an aspect of lexical/semantic processing. The fact that no interaction was obtained, Holcomb argued, was evidence that N400 reflects a post-lexical process. While these conclusions are logical, the data upon which they were based contained a large late positivity, the P3, overlapping the N400, which was earlier for primed than for unprimed words and was larger and earlier for nondegraded than degraded stimuli. The P3 is known to be post-lexical in that it reflects stimulus classification processes for both linguistic and nonlinguistic stimuli [16,21,22,25]. Since variability in the P3 would have contributed to the difference wave, interpretation of the finding is not straight forward.

In a more recent study, Brown and Hagoort [6] applied a pattern mask to the primes in one condition, rendering them unidentifiable. In another condition the primes were clearly visible. An N400 was obtained in both conditions but its amplitude was modulated by the relatedness of the preceding prime only when the prime was not masked and could be identified. A priming effect was found on reaction time (RT), which was much smaller when the primes were masked but was nevertheless significant. The authors concluded that the N400 does not reflect automatic semantic processing, since it was only modulated by priming when the primes could be consciously recognized. They suggested instead that it must reflect a post-lexical process of the sort discussed by Neely and Keefe [24]. A process which Neely and Keefe term ‘‘semantic matching’’ is purported to occur in lexical decision tasks, where the subject must decide if the probe stimulus is a real word or pseudoword. The subject attempts to fit the probe stimulus into the ‘‘context’’ provided by the prime. If the probe stimulus fits or matches the prime then the subject knows that it is a real word. This hypothesized strategy has been used to account for variability in RT which does not appear to have been related to lexical access time.

The findings of Brown and Hagoort are somewhat at odds with findings from a subsequent study, in which repetition priming effects were apparent on the amplitude of N400 even when the stimuli were masked [30]. The data regarding repetition priming raise the question of whether the absence of an N400 priming effect in the Brown and Hagoort study could be attributed to idiosyncrasies in the methods employed rather than the functional significance of the N400. At the same time it is also possible that masking produces different results when repetition is manipulated as opposed to associative or categorical priming.

Other data germane to this subject have been presented by Condor and Campbell [9]. In a speed–accuracy tradeoff paradigm these authors obtained the usual effect of RT being shorter when subjects were told to stress speed than when they were encouraged to stress accuracy. The latency of N400, however, remained constant under these same manipulations. It is difficult to conceive of a post-lexical process which would not be affected by speed-accuracy tradeoff, particularly those discussed by Brown and Hagoort, which could be expected to be invoked to a greater or lesser extent depending upon the subject’s level of certainty.

The present study was conducted in order to clarify whether the N400 reflects post-lexical processes. If a priming effect were obtained in the present study using masked stimuli this would provide further evidence that the N400 is not a manifestation of decision or response related processes.

2. Methods

2.1. Subjects

Ten City College undergraduate and graduate students (two female, eight male) between the ages of 18 and 35 (mean = 27) participated in the study as paid volunteers. Each of the subjects were right-handed, native English-speaking, had normal or corrected-to normal vision, and no history of neurological or psychiatric impairment. Informed consent was obtained prior to the subjects participating in the study.

2.2. Stimuli

Common English nouns, presented in black on a grey background in the center of a computer monitor, served as stimuli. The length of words ranged from three to nine characters (mean = 5.81), and they were, on average, 1 cm high and 4 cm long. A trial was comprised of three sequentially presented words, within which semantic relatedness was manipulated, followed by a question mark and then a probe word. The critical stimuli on which ERP data were compared were the third words to appear in each trial. The first word of each trial was included for the purpose of a different investigation and is irrelevant to the present experiment. One third of trials contained a triplet of unrelated words (e.g., doctor–truck–dog), hereafter referred to as unprimed trials. One third contained a triplet in which the first word was unrelated to the others, but the second and third words were related to each other (e.g., truck–cat–dog). Thus, on these trials (referred to as primed trials) the third word was primed by an adjacent related item. On the remaining one third of trials, related words appeared in the first and third position within the triplet, but were separated by an unrelated item in the second position (e.g., cat–truck–dog). The data from these trials are not presented here as they will be analyzed as part of a separate study. In one condition the second word of each trial was preceded and followed by masking stimuli, and in the other condition, no mask was used. In each of the two conditions 960 different words were used; 240 for the first word of each trial (which was irrelevant to the present experiment), 240 for the primes (the second words of each trial); 240 for the critical third word of each trial (80 unprimed words, 80 primed words, 80 trials not analyzed in this experiment on which the third words were related to the first word in the trial but not the second); and 240 probe words (124 were repeated and 116 non-repeated items). An additional 48 words were used to construct a practice block. With the exception of probes, none of the words were repeated. The methods of stimulus presentation are illustrated in Fig. 1.

Semantic relatedness of the words was established using the Battig and Montague [2] category norms. The frequencies of the words used in each condition were equated using the norms of Carroll et al. [8]. The Standard Frequency Indices of the words were 42.88 for unmasked unprimed words, 42.67 for unmasked primed words, 43.39 for masked unprimed words and 43.68 for masked primed words.

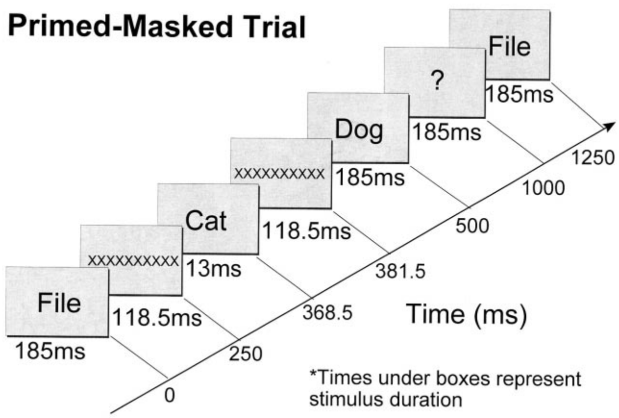

Fig. 1. Method of stimulus presentation on masked trials when the critical stimulus was primed. Stimuli are represented by shaded boxes. The numbers directly under each box indicate stimulus duration. The oblique axis illustrates the temporal sequence of stimuli.

3. Procedure

Prior to recording, the subject's threshold for consciously recognizing the masked words was determined in a separate task using different words, which were half primed and half unprimed. If subjects could recognize more than three out of 10 words presented at the first mask and word durations used, the duration of the prime was shortened and the mask durations lengthened until the criterion of three out of 10 or less was met. This criterion is essentially the same as that used by Brown and Hagoort (11 out of 33). In practice, eight of the subjects were tested using primes which were 13 ms in duration (i.e., the refresh rate of the monitor) and backward and forward masking stimuli which were 118.5 ms in duration. Only two subjects were tested using a prime duration of 27 ms and mask durations of 111.5 ms. At these levels no subject recognized more than three of the 10 words. The average number of words recognized was two. Following the recording session the threshold setting task was repeated to insure that thresholds for identifying the primes had not shifted during testing. The data for an additional five subjects who were tested are not reported here because their ability to identify the masked words exceeded the criterion, even when stimuli were presented at the shortest possible duration. Four other subjects, who met the above criterion, were excluded because their ERPs to unmasked words failed to evidence priming.

In the unmasked condition, three words were presented at stimulus onset asynchronies (SOAs) of 250 ms. Following an SOA of 500 ms, a question mark appeared in the middle of the screen. The purpose of the question mark was to prepare subjects to respond to the subsequent probe word, which followed the question mark at an SOA of 250 ms. The duration of all stimuli was 185 ms.

In the masked condition a word was presented for 185 ms, followed at an SOA of 250 ms by a forward mask consisting of a row of 10 X's which was displayed for either 118.5 or 111.5 ms, as determined by the threshold setting task. The second word appeared as soon as the mask was erased from the screen (an inter-stimulus interval [ISI] of 0) for a duration of either 13 or 27 ms. A backwards mask was then presented (at an ISI of 0) for either 118.5 or 111.5 ms. The inter-trial interval was 2.5 s in both the masked and unmasked conditions.

The subject was asked to indicate if the probe word was one of the words in the triplet just seen. In the masked condition, where subjects were unable to identify the words, they were told to simply do their best and make a guess if necessary. A response pad was provided for this purpose with two buttons labelled ''yes'' and ''no''. Subjects were told that they would find the task easier if they processed the meanings of the words as fully as possible. Even though they could not consciously do this in the masked condition, it was expected that the strategy of semantically processing words would promote priming. In a practice

Table 1
Mean amplitudes (μV) of the N400 when the averaged voltage between −200 and 0 served as the baseline (standard errors are in parentheses)

	Unmasked unprimed	Unmasked primed	Masked unprimed	Masked primed
F3	0.13 (3.11)	4.61 (2.47)	0.13 (2.49)	2.47 (2.63)
Fz	−1.12 (2.63)	3.13 (2.19)	−0.61 (3.04)	1.00 (2.78)
F4	−0.89 (2.21)	3.05 (1.67)	0.07 (3.12)	2.93 (2.94)
C3	−4.02 (3.69)	1.43 (1.56)	−4.93 (3.70)	−1.33 (2.37)
Cz	−2.26 (2.82)	1.80 (2.00)	−4.10 (2.84)	−0.28 (3.20)
C4	−1.40 (2.69)	1.85 (1.49)	−3.89 (2.95)	−0.76 (2.56)
P3	−6.88 (3.28)	−0.10 (1.93)	−5.89 (1.82)	−5.13 (2.65)
Pz	−5.92 (2.31)	−0.69 (1.96)	−7.32 (2.15)	−4.87 (1.89)
P4	−4.85 (2.16)	0.38 (1.32)	−4.07 (1.67)	−2.91 (2.41)
T3	−2.16 (2.05)	2.09 (1.28)	−2.14 (2.33)	0.17 (2.73)
T4	−1.45 (2.57)	1.84 (1.39)	−2.83 (1.69)	0.14 (1.53)
T5	−6.35 (2.37)	−2.89 (2.73)	−8.29 (2.07)	−6.09 (1.86)
T6	−6.14 (2.51)	−2.05 (1.75)	−5.61 (1.58)	−3.82 (1.27)
O1	−11.24 (4.04)	−4.65 (2.46)	−8.73 (2.08)	−6.69 (1.44)
Oz	−9.15 (3.26)	−3.95 (2.50)	−8.20 (2.22)	−5.24 (1.46)
O2	−8.58 (3.21)	−3.73 (2.19)	−7.70 (1.91)	−6.11 (1.65)

session an extra sequence of stimuli, some masked and some unmasked, was presented as many times as were necessary for the subject to feel comfortable with the task. A minimum of three practice trials were given to each subject.

4. EEG recording

The electroencephalograph (EEG) was recorded from 18 standard 10–20 system scalp locations (FP1, FP2, Fz, F3, F4, Cz, C3, C4, Pz, P3, P4, T3, T4, T5, T6, Oz, O1, O2) and referenced to the nose. Vertical eye movements were recorded by electrodes placed on the supra- and infraorbital ridges of the right eye, and horizontal eye movements by electrodes placed lateral to the outer canthi of the right and left eyes. Interelectrode impedances were below 5 kΩ.

The EEG and EOG data were filtered using bandpass of 0.1–35 Hz. Sweeps consisting of 775 data points were sampled from 200 ms preceding the first word in a trial until 1000 ms after the third word (i.e., a total of 1700 ms, which encompassed the first three stimuli of each trial). Baseline correction was performed in relation to the averaged EEG activity from 200 ms prior to the beginning of the sweep to the onset of the first stimulus. Trials on which EEG or eye movements exceeded plus or minus 50 μV were automatically rejected from the averaging process. This criterion resulted in the exclusion of approximately 20% of trials.

5. Data analysis

Response latency and accuracy data were sorted according to condition (masked or unmasked, primed or un-

Table 2
Mean amplitudes (μV) of the N400 when the averaged voltage between −200 and 500 served as the baseline (standard errors are in parentheses)

	Unmasked unprimed	Unmasked primed	Masked unprimed	Masked primed
F3	0.05 (1.32)	1.86 (1.05)	0.05 (1.06)	0.99 (1.11)
Fz	−0.45 (1.12)	1.26 (0.93)	−0.25 (1.29)	0.40 (1.17)
F4	−0.36 (0.94)	1.22 (0.71)	0.03 (1.32)	1.18 (1.25)
C3	−1.62 (1.56)	0.57 (0.66)	−1.98 (1.57)	−0.53 (1.01)
Cz	−0.91 (1.19)	0.72 (0.85)	−1.65 (1.20)	−0.11 (1.35)
C4	−0.56 (1.14)	0.74 (0.63)	−1.57 (1.25)	−0.31 (1.08)
P3	−2.77 (1.39)	−0.04 (0.82)	−2.37 (0.77)	−2.06 (1.12)
Pz	−2.38 (0.98)	−0.28 (0.83)	−2.94 (0.91)	−1.96 (0.80)
P4	−1.95 (0.92)	0.15 (0.56)	−1.64 (0.71)	−1.17 (1.02)
T3	−0.87 (0.87)	0.84 (0.54)	−0.86 (0.99)	0.07 (1.16)
T4	−0.58 (1.09)	0.74 (0.59)	−1.14 (0.72)	0.06 (0.65)
T5	−2.57 (1.16)	−1.16 (1.16)	−3.34 (0.88)	−2.45 (0.79)
T6	−2.47 (1.07)	−0.82 (0.74)	−2.22 (0.67)	−1.54 (0.54)
O1	−4.52 (1.71)	−1.87 (1.04)	−3.51 (0.88)	−2.69 (0.61)
Oz	−3.68 (1.38)	−1.59 (1.06)	−3.30 (0.94)	−2.11 (0.62)
O2	−3.45 (1.36)	−1.50 (0.93)	−3.10 (0.81)	−2.46 (0.70)

Table 3
Percentage of correct responses and reaction times (standard errors are in parentheses)

	Umasked	Masked
Percentage of correct responses		
New words	95 (0.46)	98 (0.38)
Repeated words	86 (0.98)	83 (1.7)
Reaction times in ms		
New words	982 (125)	993 (138)
Repeated words	884 (113)	892 (116)

primed). The mean reaction times and percentage of correct responses to the probe words were calculated for each subject, separately for each condition.

The amplitude of N400s elicited by the critical stimuli were initially measured in relation to a baseline which was calculated on the basis of the averaged EEG activity in the 200 ms epoch preceding the onset of the first stimulus. The critical stimuli were presented 500 ms after the onset of the first stimulus of each trial. At the request of an anonymous reviewer, additional analyses were performed using a baseline which corresponded to the average voltage in the −200 to 500 ms epoch which preceded the critical stimulus (S3). For both sets of analyses, the mean amplitude (area) of N400 was measured in the 200–450 ms epoch following the onset of critical stimuli (at 700–950 ms after the beginning of each trial). Mean amplitudes, measured with respect to each of the two baselines, are presented in Tables 1 and 2.

In order to compare the topography of the priming effects in the masked and unmasked conditions, mean amplitude measures were performed on the N400 subtraction waves (unprimed minus primed) which were then scaled using the same procedure as in Deacon et al. [12] and Deacon et al. [14], i.e., the mean amplitude of N400 at each electrode was converted to a percentage of its amplitude at the electrode where it was largest within particular conditions. The scaled data were submitted to ANOVA on the factors of Condition (masked, unmasked) and Electrode.

Mean amplitude data were submitted to repeated measures ANOVA. Statistical comparisons were performed on the ERPs recorded to the third word on four types of trials (unmasked primed, masked primed, unmasked unprimed, masked unprimed). For the purpose of quantifying priming effects on the N400, an overall ANOVA was first performed using Masking, Priming, and Electrode as factors in order to establish that a main effect was present. This was followed by separate ANOVAs performed on the masked and unmasked data in order to establish that the main effect was not carried by the unmasked data alone.

6. Results

6.1. Behavioral data

The behavioral data are presented in Table 3. Averaging across conditions, performance on the task was 89% accu-

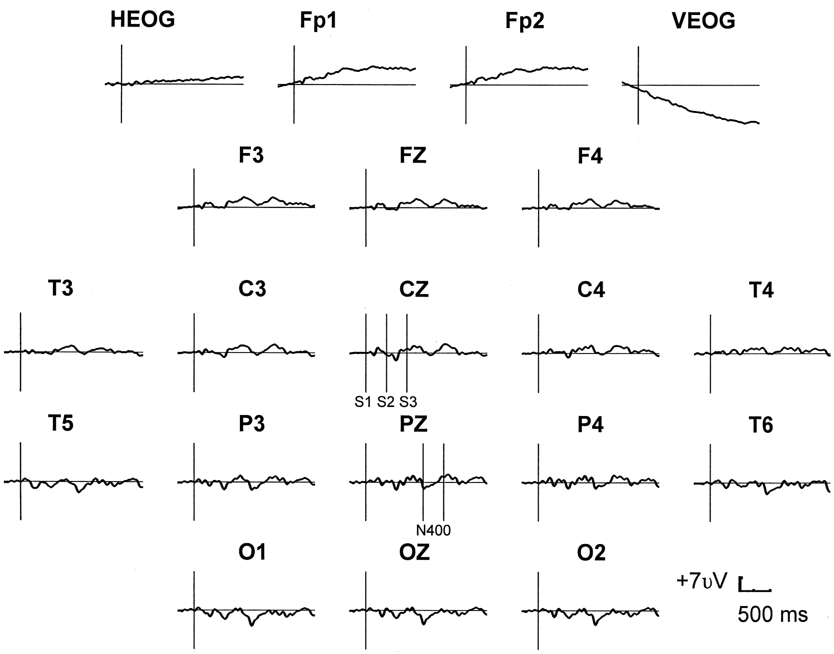

Fig. 2. The N400 at all recording sites, in the unprimed, masked condition. This figure, and subsequent Figs. 3 and 4, display the compound ERP, recorded during the presentation of all of the stimuli in the trial. Baseline correction has been performed in relation to the averaged activity between −200 and the onset of the first stimulus in each trial. Since the sweep is triggered from the onset of the first word in the trial, the N400 peaks at about 880 ms (i.e., 380 ms from the onset of the critical stimulus). The onsets of the first, second, and third stimuli in each trial are labelled at Cz as S1, S2 and S3, respectively. The epoch within which the mean amplitude of N400 was quantified is indicated by two vertical lines (see Pz). Positive is up in all of the figures.

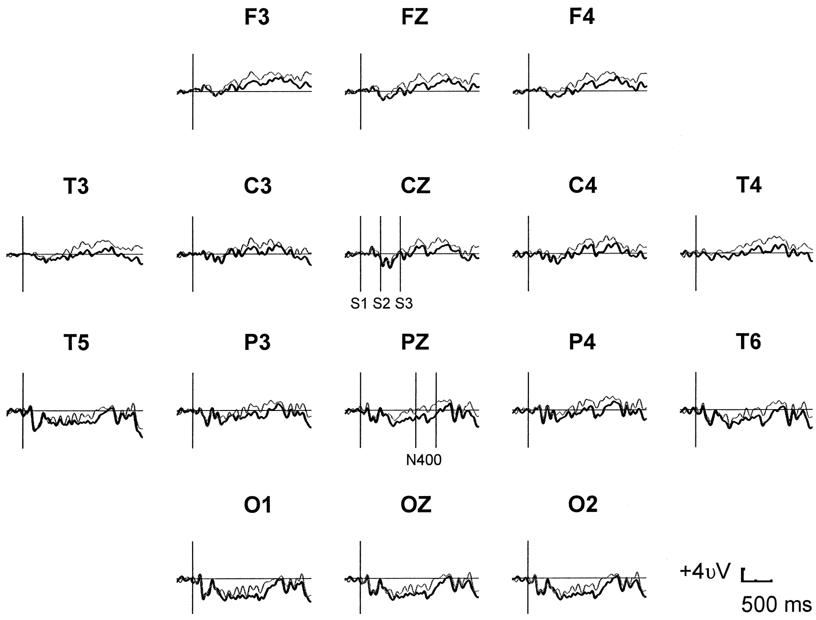

Fig. 3. The N400 priming effect when primes were unmasked. In this figure, as well as Fig. 4, the ERP printed in the thick line was recorded on trials where the third stimulus was unprimed. The ERP depicted by the thin line was recorded when the third word was primed by a related item which immediately preceded it.

rate. From the onset of the probe, the mean RT across conditions was 895 ms.

7. ERP data

In the present study the third stimulus of each trial was the critical one on which ERPs were compared. Effects of the relatedness of the third stimulus to the preceding prime (second stimulus) could be measured with minimal overlap of P3 since the subject could not make any classification until the probe (fourth stimulus) appeared.

The topography of the N400 is illustrated, for all electrodes, in Fig. 2 using the ERPs recorded during the unprimed, masked condition. The N400 was maximal at posterior sites in all conditions. The effects of the priming manipulation on its amplitude and area, however, were larger at central, frontal, and fronto-temporal sites, particularly in the masked condition (see Figs. 3 and 4). [1] ANOVA on the factors of Masking (masked, unmasked), and Electrode (F3, Fz, F4, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, 0z, 02) was performed on scaled area measures of the N400 difference waves (unprimed minus primed) in order to determine whether the N400 priming effects associated with masked and unmasked stimuli might have different topographies. There was no significant interaction, however, between Electrode and Masking, regardless of which of the two baselines the data were measured against.

7.1. Priming effects

Mean amplitudes of N400s recorded to the critical stimuli on each class of trials are presented in Table 1. A three-way ANOVA including the factors of Masking (masked, unmasked), Priming (unprimed, primed), and Electrode (F3, Fz, F4, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, 0z, 02) revealed a significant main effect of priming ($F(1,9) = 14.19$, $P = .004$). The N400 elicited by critical words was significantly larger on Unprimed trials than on Primed trials where two adjacent words were semantically related. There was no main effect of masking, nor were there any significant interactions. Two-way ANOVAs were also run separately on the Masked and Unmasked conditions, using Priming (Primed, Unprimed) and Electrode (F3, Fz, F4, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, 0z, 02) as factors. Priming was significant for the masked condition ($F(1,9) = 5.82$, $P = .039$) as well as for the unmasked condition ($F(1,9) = 9.03$, $P = .015$). There were no interactions between Priming and Electrode.

The same analyses were performed on the data derived using the average EEG activity in the -200 to 500 ms epoch as a baseline. The main effects were essentially identical to the first set of analyses and there were, again, no significant interactions. The over all three-way ANOVA including the factors of Masking (masked, unmasked), Priming (unprimed, primed), and Electrode (F3, Fz, F4, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, 0z, 02)

[1] One reviewer asked why the N400 persisted for longer than in most studies. A likely reason for the persistence of the priming effect is that there was no P3 present. In most of the extant N400 literature tasks have been used which require subjects to classify the critical word. As a result large P3s are usually elicited shortly after the N400, which overlap it, and make it appear as if the N400 has terminated.

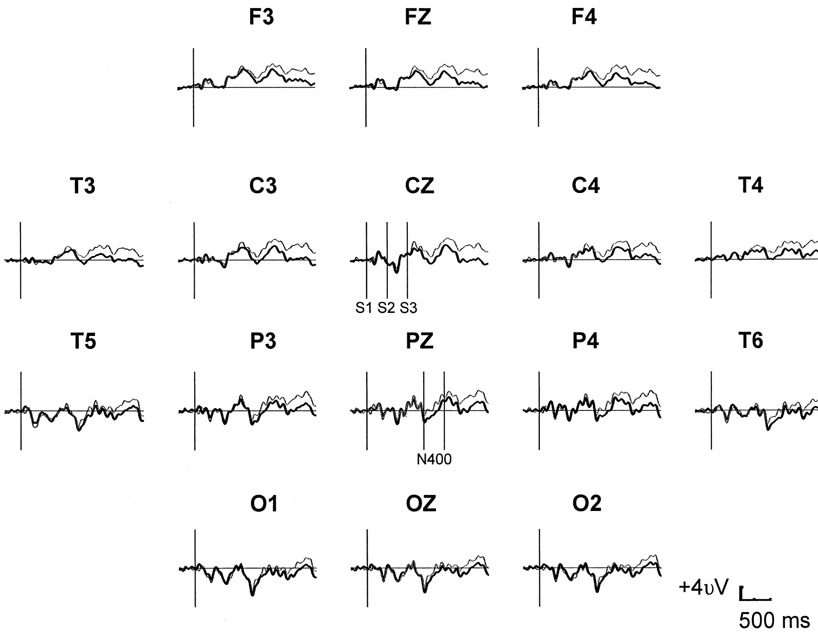

Fig. 4. The N400 priming effect when primes were masked.

revealed a significant main effect of priming on the area of N400 ($F(1,9) = 11.09$, $P = 0.009$). The N400 was significantly larger on Unprimed trials than on Primed trials. There was no main effect of masking. On two-way ANOVAs run separately on the Masked and Unmasked conditions (using Priming and Electrode as factors) priming was significant for both the masked condition ($F(1,9) = 13.98$, $P = 0.005$) and the unmasked condition ($F(1,9) = 5.11$, $P = 0.050$).

8. Discussion

In all conditions, the analysis of ERP data was limited to the critical (third) word in each trial. The main comparisons of interest were between the ERPs on trials where the third word was Primed (truck–cat–dog) and Unprimed (doctor–truck–dog) under conditions where the prime was either masked to prevent its conscious identification or was clearly visible. Regardless of which of the two baselines was used, the main findings were essentially the same. The usual priming effect was obtained on N400 mean amplitude, that is, the N400 was larger when adjacent stimuli were unrelated than when they were related, whether the prime was masked or not. These findings contrast with those of Brown and Hagoort [6] who found no priming effect on N400 amplitude when the prime was masked.

Differences in the methods of data analysis would not appear to account for the discrepancy between the two studies. In addition to an overall ANOVA, we examined Priming effects by running separate analyses on the data from the Masked and Unmasked conditions. These analyses, which were more comparable to those used by Brown and Hagoort, also indicated significant priming effects on N400, whether or not the primes were masked. Moreover, the figures presented by Brown and Hagoort evidenced no apparent priming effect in the masking condition, also suggesting that the differences in the two studies lay in the data per se, rather than the methods of data analysis.

The present study employed a repeated measures design whereas Brown and Hagoort used four separate subject groups, one group each for the masked and unmasked versions of their RT and ERP experiments and analyzed the data from each of the four groups separately. Thus, between-group differences may have accounted for the disparate results of their masked and unmasked experiments, as well as the dissociation they reported between N400 and RT. A related issue is that in the present study several subjects were excluded because they showed no priming in the unmasked condition. Our logic was that we could not determine whether masking reduced priming in subjects who showed no priming to start with. Brown and Hagoort could not have known which of their subjects in the masked ERP experiment would have demonstrated priming effects in the absence of the mask.

The fact that we obtained a masked priming effect in the present study should not have been due to the subjects having consciously processed the words to a greater extent than in the Brown and Hagoort study, since our masked stimuli were presented at much shorter durations than in their study. In this regard, our behavioral criterion for exclusion of subjects was essentially identical to theirs (i.e., subjects were excluded who could identify three or more words out of 10). However, the threshold setting stimuli used in the present study contained both primed and unprimed words, as were presented in the actual experiment. None of the threshold setting stimuli used by Brown and Hagoort were primed. On each trial of their threshold-setting task, a single test stimulus was followed by a set of three words upon which the subject performed a forced choice recognition task. To the extent that primed words would be easier to recognize than unprimed, our threshold-setting task may have been a more conservative test of the subject's ability to recognize the words, even though subjects were required to name the words rather than perform a forced choice judgement. In line with this, when we used a stimulus duration which approached that of Brown and Hagoort, during the threshold setting task, every subject tested could read the majority of the test words presented. Given these procedural differences and our observations, it is possible that more conscious processing occurred in their study. In discussing the stimulus parameters employed in their series of four behavioral experiments, Dagenbach et al. [10] concluded that priming is reduced at threshold levels of identification but *increases* as the ability to identify stimuli *decreases*. Moreover, this group has demonstrated inhibition from masked primes when the primes were presented at durations which are just above threshold [7,10]. Carr and colleagues postulated that a center-surround attentional mechanism is invoked in order to process the weakly activated masked prime. Activation of that portion of the lexicon corresponding to the prime word (the ''center'' in their model) is enhanced, whereas activation of related concepts (in the surround) is dampened in order to increase the signal/noise ratio. Given that the prime-mask SOA in the Brown and Hagoort study was similar to that used by Carr et al. to produce inhibition, it is possible that many of Brown and Hagoort's subjects showed inhibition on primed trials. If inhibitory effects were present on even some trials, this may have nullified the priming effects on N400 in the averaged ERPs for each subject. It may also have reduced the priming effects obtained from the group of subjects run on their RT experiment, since the priming effect on RT was much smaller in the masked condition (12 ms) than in the unmasked condition (70 ms). The subjects who recognized only one, or none of the 10 threshold setting stimuli used in the present study, showed more N400 priming than those who recognized two or three items. Although there were not enough subjects to make statistical group comparisons, the observation is in keeping with the possibility that inhibition may have occurred on some trials in the Brown and Hagoort study.

The long SOA used by Brown and Hagoort, it should be noted, was sufficient to allow the operation of the attentional mechanism proposed by Carr and colleagues, whereas the short SOA in the present study was not. The present study employed a 250 ms SOA between the prime and target whereas the SOA used by Brown and Hagoort was 750 ms. A further issue related to SOAs used in the two studies is that Neely [23] postulated that automatic priming decays by 700 ms after stimulus onset, whereas expectancy related priming begins to build up some time after 700 ms. It could therefore be that automatic priming effects, which would have been the only type of priming operating in the masked condition, had decayed by 750 ms. [2] On the other hand, the robust priming seen in the unmasked condition, could have been expectancy related since subjects were better able to consciously process word meanings in this condition.

Although we have demonstrated that automatic priming might endure for 2 s or beyond [15], our data were obtained under circumstances where the prime had to be semantically processed and remembered. These task demands may have been responsible for the extended lifetime of automatic priming which we reported. Thus, in the Brown and Hagoort study, the lexical decision task and long SOA might have worked in concert to produce a low level of semantic activation which resulted in little or no automatic priming. In support of this view, Fischler and Goodman [17] found facilitation of RT from masked primes during lexical decision at prime-target SOAs of 40 and 90 ms, but not at SOAs of 500 ms. The facilitation observed in the 40 and 90 ms conditions was, furthermore, limited to trials on which the prime was not identifiable. [3] On the other hand, several studies have found facilitation of RT at prime-target SOAs as long as 1500 ms when shorter prime-mask SOAs were used. Obviously the relationship between stimulus parameters which do and do not produce masked priming is complex. While it is unlikely that prime-mask SOA alone could account for the disparity between the present study and Brown and Hagoort it may have been a contributing factor.

A final potentially important difference in the two studies is that Brown and Hagoort used associatively related items in their primed conditions, whereas in the present study primed items were both categorically and associatively related. Not only were our stimulus materials more strongly related by virtue of this, but qualitative differences might exist between associative and categorical priming which interact with masking.

We are unaware of other published studies describing masked semantic priming effects on the N400. Schnyer et al. [30], however, have reported significant repetition priming effects on N400 when words were masked. Thus, there appear to be more data to suggest that N400 priming effects can indeed be obtained under conditions where subjects cannot identify the words. Collectively, the data of Schnyer et al., the data of the present study, and the

[2] This argument assumes that the stimuli did not continually activate semantic stores for the duration over which they remained on the monitor.

[3] Although Dark and Benson [11] produced seemingly opposing data (facilitation was associated only with masked primes that were recognized, regardless of whether the prime-target SOA was 1000 or 250 ms) the proportion of masked primes correctly named by subjects was too high to be considered near threshold.

studies which we have cited as showing automatic priming effects, provide evidence against the post-lexical integration hypothesis.

Three experiments conducted by Rugg et al. [29] further strengthen the argument against the post-lexical integration hypothesis. These authors examined repetition priming effects on the N400 as a function of the context within which the word was presented. Repeated words were preceded either by the same word as on the initial presentation or a different word. The N400 was significantly reduced on second presentations of words, regardless of whether the word which preceded the repeated word was also repeated or was a new word. Rugg et al. conducted these experiments believing that, in single word paradigms, a context is provided for each word by the word which precedes it. The view that the N400 reflects post-lexical integration of a word into its context was not supported by their repetition data because N400 would have been expected to be larger when the word preceding the repeated word (the context for the repeated word) was changed.

In a similar study by Besson and Kutas [4] no repetition priming effects were obtained on N400 when the repeated word was preceded by different sentence stems. In this study, which was conducted for a different purpose, subjects knew that they would later be shown the same sentence stems and asked to provide the terminal word that was originally presented with them. The most efficient strategy which subjects could have adopted in this task would have been to remember the first presentation of the word and the sentence stem which accompanied it as a unit. This strategy may have influenced the results in such a way as to make the repeated words predictable when presented with the original sentence stem and unexpected when they followed a new sentence stem. As the sentences used had low cloze probabilities, the words would not have been predictable otherwise. The sentences where words were repeated in a different context may have elicited negativity in the N400 region due the violation of the subject's rehearsed expectancy that the repeated word would appear in its original context.

While it is clear that sentential context affects the amplitude of the N400 [19,20,31], it would be more in keeping with the extant literature and the results of the present study to propose an early locus for the context effect, rather than a post-lexical one. Van Petten and Kutas came to this conclusion in a study which examined the effects of word frequency and the ordinal position of words in sentences. Low frequency words which appeared near the beginning of sentences produced larger N400s than high frequency words. The frequency effect was greatly reduced however for words appearing near the ends of sentences. Presumably, the more context that was provided before each word the less effect word frequency had. Van Petten and Kutas concluded that sentential context and word frequency interact at some early aspect of word recognition. These conclusions are thus in line with the view that the processes engendering the N400 have a lexical locus.

Although the literature which we have reviewed is somewhat ambiguous regarding the functional significance of the N400, the present study clarifies at least two issues. The first is that the N400 is sensitive to priming phenomena which are truly automatic. Moreover, as priming effects were obtained on the N400 even though subjects could not consciously perceive the stimuli, the N400 recorded in this experiment could not reflect any of the post-lexical processes described in the literature, as these are consciously governed.

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