SEMANTIC PRIMING MODULATES THE N400, N300, AND N400RP

Michael S. Franklin[1,2], Joseph Dien[1,3], James H. Neely[4], Elizabeth Huber[3], & Lauren D. Waterson[3]

[1]Department of Psychology
Tulane University

[2]Department of Psychology
University of Michigan

[3]Department of Psychology
University of Kansas

[4]Department of Psychology
State University of New York at Albany

Franklin, M. S., Dien, J., Neely, J. H., Huber, E., and Waterson, L. D. (2007). Semantic Priming Modulates the N400, N300, and N400RP. Clinical Neurophysiology, 118(5)1053-68. (https://doi.org/10.1016/j.clinph.2007.01.012)

Address requests for reprints to: Michael Franklin, Department of Psychology, The University of Michigan, 525 East University Ann Arbor, MI, 48104. Email: msfrankl@umich.edu

The research in this paper was done in partial fulfillment of the first author’s requirements for the M.S. degree at Tulane University. Portions of this research were presented at the Cognitive Neuroscience Society, April 2003 in New York City. We would like to thank Kyle Malone for assistance with the behavioral data. We would also like to thank the members of the first author’s thesis committee, Gary Dohanich, Paul Colombo, and Dave Corey for their helpful comments and support throughout the study. The preparation of this manuscript was partially supported by a Louisiana Board of Regents Research Competitiveness Subprogram grant (LEQSF-RD-A-27).

ABSTRACT

Objective: To determine whether ERP components can differentiate between the semantic priming mechanisms of automatic spreading activation, expectancy, and semantic matching.

Methods: The present study manipulated two factors known to differentiate semantic priming mechanisms: associations between words (forward, backward, and symmetrical) and prime-target stimulus onset asynchrony (SOA). Twenty-six participants were tested in each SOA condition while high-density 128-channel data were collected. Principal components analysis was applied to separate the ERP components.

Results: Priming was observed for all conditions. Three semantic components were present: 1) the standard N400 effect for symmetric and forward priming pairs at both short and long SOAs, 2) an N300 for the long SOA symmetric priming pairs, and 3) a right-lateralized posterior N400RP for long SOA backward priming pairs.

Conclusions: Results suggest that the N300 reflects expectancy, but only for categorical and/or semantic similarity priming. Results further suggest that the N400RP is a replicable ERP component that responds to semantic matching. There is also some evidence that the N400 indirectly responds to both ASA and expectancy, perhaps as part of a post-lexical updating process and that backward priming at short SOAs is different from that at long SOAs.

Significance: Improved understanding of the semantic properties of the N400 and related ERP components may increase their utility for understanding language processes and for diagnostic purposes.

Keywords: Event Related Potential (ERP), Semantic Priming, N400, Attention

INTRODUCTION

Semantic priming is the facilitated processing of a target word when it is preceded by a semantically/associatively related prime word, relative to when it is preceded by a totally unrelated prime word (McNamara, 2005; Neely, 1991). Cognitive psychologists have used semantic priming to gain insight into how people use semantic context to access a word's meaning and to shed light on how semantic memory is organized and accessed (Meyer & Schvaneveldt, 1976). A three process model of priming, consisting of automatic spreading activation (ASA), expectancy, and post-lexical semantic integration has been used to account for the wide array of effects seen in semantic priming experiments (Neely & Keefe, 1989).

One method for isolating these three processes is the manipulation of the direction of association between the prime and the target. In forward associative priming, there is an association from the prime to target, but not the other way around (e.g., prime-FRUIT, target-FLY; prime-STORK, target-BABY). Forward priming is presumably produced by ASA at short SOAs and expectancy at longer SOAs. Backward associative priming (Koriat, 1981) occurs as a result of a strong associative link from target to prime but not the other way around (e.g., prime-FLY, target-FRUIT; prime-BABY, target-STORK). Because there is a backward association from the target ***fruit*** to the prime ***fly***, the semantic matching mechanism could detect this target-prime relation, whose presence and absence is correlated with the target being a word or a nonword, thereby producing a priming effect in the lexical decision task.

Event-related potentials (ERPs) have been a useful tool in examining processes involved in priming. Of particular interest is the N400, an ERP component that appears to be sensitive to the congruity of a stimulus with the current semantic context (Kutas & Van Petten, 1994). Opinions regarding what the N400 reflects vary widely. Some argue that the N400 reflects controlled processes and not ASA (e.g., Chwilla, Hagoort, & Brown, 1998) whereas others argue that it reflects both (e.g., Deacon, Uhm, Ritter, Hewitt, & Dynowska, 1999). Overall, evidence suggests that the N400 reflects all three priming mechanisms, ASA (Deacon et al., 2004; Deacon, Hewitt, Yang, & Nagata, 2000; Kiefer, 2002; Kiefer & Spitzer, 2000; Kutas & Hillyard, 1989), expectancy (Kutas, Lindamood, & Hillyard, 1984; Silva-Pereyra et al., 1999), and semantic matching (Chwilla, Hagoort, & Brown, 1998; Holcomb, 1993), although the case for expectancy priming is not as strong. Although the relatively late time course of the N400 with respect to the presumed time course of semantic analysis (Sereno, Rayner, & Posner, 1998) might seem to tilt the evidence towards N400 being a manifestation of post-lexical semantic matching and/or integration, the P300 literature provides a clear precedent for a late acting component to index an expectancy process.

Some existing reports suggest the possibility that the different priming mechanisms are indexed by different ERP components. One such paper (Hill, Strube, Roesch-Ely, & Weisbrod, 2002) conducted a lexical decision task with both short (150 ms) and long (700 ms) SOAs. In addition to the conventional centro-parietal N400 effect, there was a frontal negativity at about 300 ms that was sensitive to semantic incongruity only at the short SOA, as might be expected for an effect that responds to ASA. Such a frontal effect has been proposed elsewhere as potentially indexing ASA (Pritchard, Shappell, & Brandt, 1991). Hill and colleagues (2002) also reported a right posterolateral N400 effect that was significant only at the long SOA, mirroring an ERP component in another study (Dien, Franklin, & May, 2006) that responded to both backward and forward associative priming and was therefore proposed to reflect semantic matching.

The first goal of this study was to try to provide more information on how the N400 (and other related components) relates to ASA, expectancy, and semantic matching. To isolate the operation of these mechanisms, this study manipulated SOA and direction of association. The empirical question to be answered is whether the four combinations of short vs. long SOA and forward vs. backward priming will be differentially associated with the N400. A long, 500-ms prime-target SOA and asymmetrically associated word pairs were used to isolate semantic matching, through backward priming, and expectancy, through forward priming. In addition, conventional symmetrically associated prime pairs were included for purposes of comparison.

A short, 150-ms SOA was also utilized to investigate whether ASA-based priming modulates the N400. This 150-ms SOA also permits us to observe the operation of a fourth potential priming mechanism that accounts for backward priming at short SOAs. It is speculated that there might be differences in the N400 effects seen for backward priming at the long and short SOAs based on behavioral evidence for different mechanisms of backward priming at short and long SOAs (Kahan, Neely, & Forsythe, 1999).

An earlier study by Chwilla and colleagues (Chwilla, Hagoort, & Brown, 1998) had much in common with the present study, including examining backward priming at both short and long interstimulus intervals (ISI) of 0 and 500 ms each, but using auditory stimuli. Reaction time and N400 priming effects occurred at both SOAs and were interpreted as supporting the position that the N400 reflects semantic matching/integration and possibly expectancy.

Although the study by Chwilla and colleagues (1998) was an important step towards better characterizing the N400, it left some issues unresolved. The present report provides new information beyond Chwilla and colleagues' (1998) original report in the following ways: 1) because visual stimuli have a discrete onset time, the present study had stronger control over SOA timing issues; 2) the present study used a high-density recording montage that could detect potentially new semantic effects; 3) the high-density montage might make it possible to separate out P300 effects.

A potential issue with the experimental design is that the lexical decision task is likely to superimpose a P300 on the resulting waveforms. The study by Chwilla and colleagues (1998) sought to minimize the presence of the P300 by replicating the experiment with the instruction to press a button to nonwords only. However, the P300 responds primarily to stimulus probability rather than target status (Donchin, 1981) so simply designating the non-words as being the target will not eliminate the P300 from the word targets, although it will reduce it. In order to maximize comparability with the published behavioral priming literature this study attempted the strategy of capitalizing on a combination of high-density topographical information and principal components analysis (PCA) to separate the P300 and the N400, an approach that has been previously reported to work (Polich, 1985).

In summary, our procedures allow us the opportunity to achieve both psychophysiological and cognitive goals. The first psychophysiological goal is to try to better characterize the N400 with respect to the three priming mechanisms, separate from the P300. The second psychophysiological goal is to identify and characterize other semantic effects, especially the frontal effect and the right posterolateral effect. The cognitive goal is to obtain further information about whether backward priming at short SOAs is mediated by the same priming mechanism that produces backward priming at long SOAs.

METHODS

Participants

Fifty-two, right-handed, native English speaking, Tulane University introductory-level psychology students, without neurological history or psychotropic medications, participated in the study for course credit. An additional 59 participants participated at the University of Kansas. Decisions were made prior to data analysis to exclude from analysis a participant's data when they were likely to be unreliable and/or invalid, due to too many trials in which there measurement problems due to excessive movement and ERP artifacts or too few trials on which correct responses were made. Data from 16 and 18 Tulane and Kansas participants, respectively, were dropped due to measurement problems and from 25 Kansas participants due to more than 40% errors in a cell, leaving 36 and 16 Tulane and Kansas participants, respectively. The final dataset contained 26 participants for each SOA group (33 women, 19 men) ranging in age from 18 to 21 years with a mean age of 18.5. Six participants reported familial left-handedness (four more were missing handedness data). Informal examination of the windowed data did not reveal any tendency for unusual lateralization patterns (e.g., Kutas, Van Petten, & Besson, 1988).

Statistical Tests

Robust test statistics using a combination of a Welch-James type approximate degrees of freedom (ADF) approach, trimmed means, and bootstrapping was used to test effects (Keselman, Wilcox, & Lix, 2003). To calculate these statistics, Keselman's SAS/IML code for conducting robust statistical tests (generously made available at http://www.umanitoba.ca/faculties/arts/psychology/) was ported to Matlab (http://www.people.ku.edu/~jdien/downloads.html). A 10% symmetric trim rule was used

(2 observations dropped at either extreme within each cell). The seed for the number generation was set at 1000. The number of simulations used for the bootstrapping routine was set at 50000. P-values are rounded to the second significant digit.

Stimuli

The experiment consisted of 360 prime-target pairs: 20 forward related, 20 unrelated matched to the forward related, 20 backward related, 20 unrelated matched to the backward related, 70 symmetric related, and 210 non-words. The relatedness proportion was .60 and the non-word ratio was .78. Half of the asymmetric associated pairs were compounds (i.e., “fruit-fly”) and half noncompound items (e.g., “stork-baby”), with 64 of these pairs being identical to those used by Kahan and colleagues (1999). The remaining 16 pairs were taken from Thompson-Schill, Kurtz, and Gabrieli (1998). As determined from the Nelson, McEvoy and Schreiber (1999) norms, the mean prime-to-target and mean target-to-prime associative strengths for these pairs were .144 (sd = .16) and .02 (sd = .05), respectively, T_{WJt}/c (1,55) = 32.34, $p<.0001$. The sets of 40 compound and 40 noncompound pairs were each used to create 10 pairs for each of the four different priming conditions: backward related, backward unrelated, forward related, and forward unrelated. To form the forward unrelated pairs, the primes and targets from half of the forward related word pairs were re-paired. Which half of the pairs served as forward related and forward unrelated pairs was counterbalanced across participants.

Four stimulus lists were constructed, such that across the four lists each asymmetrically associated pair was presented once in each of the four priming conditions. A given list contained twenty pairs in each of these four conditions. None of the primes or targets was repeated within a list. All nonwords were pronounceable and were created by replacing one letter in a word that was unassociated with the prime word with which that nonword was paired.

The backward related and backward unrelated pairs were created by reversing the prime-target order of the corresponding forward pairs, thereby guaranteeing that the strengths of the associations mediating the forward vs. backward priming effects would be identical. Because of this procedure, the targets in the forward pairs unavoidably had a higher frequency (i.e., 42.5) than the targets in the backward pairs (i.e., 16.0) with the opposite being so for the primes (Kucera & Francis, 1967). The primes and targets had a mean semantic similarity of 0.27 as determined from the latent semantic analysis website at the University of Colorado (Landauer & Dumais, 1997). The log-transformed frequencies (log of 1 plus the frequency) for the primes and targets were statistically different, T_{WJt}/c (1,63) = 19.65, $p < .0001$.

The primes and targets for the symmetric pairs had median raw Kucera-Francis (Kucera & Francis, 1967) frequencies of 28.0 and 36.5, which for log freq scores: yielded $T_{WJt}/c(1,55) = 0.56$, n.s. The median raw frequency of 36.5 for the symmetric-pair targets is comparable to the average, 29.3, of the medians for the forward and backward asymmetrical unrelated targets when tested on the log freq scores, $T_{WJt}/c(1,96.21) = 1.21$, $p = .28$. As determined from the Nelson, McEvoy and Schreiber (1999) norms, the median prime-to-target and median target-to-prime associative strengths for these symmetric pairs were .38 (sd = .23) and .18 (sd = .22), respectively, $T_{WJt}/c(1,53) = 8.38$, $p = .006$, which were higher than the corresponding .144 and .02 values for the asymmetric pairs. Finally, these primes and targets had a mean semantic similarity (Landauer & Dumais, 1997) of 0.44, which was significantly higher than that for the asymmetrically related pairs, $T_{WJt}/c(1,106.99) = 25.02$, $p < .0001$.

Priming in the symmetric condition was evaluated relative to the mean of the forward unrelated and backward unrelated conditions. Ideally, one would want to assess symmetric priming relative to an unrelated condition that contained the same targets re-paired with primes from other symmetric prime-target pairs. However, this would have required adding more unrelated trials, which would have lowered the relatedness proportion. Although adding even more symmetric buffer trials could have counteracted this, this would have made the test list too long to be administered in one sitting without fatigue becoming a factor. This comparison was justified on the grounds that the frequency of the symmetric targets was statistically comparable to the mean of the forward and backward unrelated targets.

Procedure

The subjects were seated 42 cm in front of a flat LCD monitor. At Tulane, EGIS (Electrical Geodesics, Inc.) was used to present the stimuli. At the University of Kansas, E-Prime (Psychology Software Tools) was used to present the stimuli. Oral instructions described the task and emphasized both speed and accuracy. Subjects pressed one of two outer keys on the button box to indicate “word” or “nonword,” using their index fingers. The “word”/”nonword” response button was counterbalanced across participants. A trial consisted of a prime word for 150 ms in capitalized letters followed by the target letter string in lowercase letters for 150 ms. The prime-target SOA was either 150 ms (0 ms ISI) or 500 ms (350 ms ISI). A 1000 ms intertrial interval was initiated after the end of an 850 ms response window that followed the onset of the target. Before the experimental trials began subjects went through a practice block of 30 trials with symmetrically related prime-target pairs (RP=.64, NR=.76). Subjects could ask questions before beginning the 4 experimental blocks, each consisting of 90 trials. The experimental task took about twenty minutes.

Data Collection

EEG data were gathered using a high-density 128-channel EGI system (Electrical Geodesics, Inc.). Electrode impedances were measured and the impedance criteria were 50k ohms, per manufacturer guidelines for this high impedance system. The data were recorded with a bandpass of .1 to 100 Hz and digitized at 250 Hz. The EEG was segmented 100 ms before the target stimulus onset and 1000 ms after stimulus onset, retaining only trials with correct responses. EEG data were filtered using a 30 Hz lowpass filter. The Tulane dataset was filtered after segmentation and three time points before and after the final segment were dropped to eliminate the filtering artifact. The Kansas dataset was filtered prior to segmentation, thus avoiding filtering artifact. A baseline correction was applied to the 100 ms epoch before target onset. For the short SOA, this resulted in contamination by the ERP from the prime, but inspection of the grand averages suggested such contamination did not produce confounds with the priming manipulations. An average reference transform was applied to estimate the reference-independent ERP waveforms (Bertrand, Perrin, & Pernier, 1985; Dien, 1998b).

Eye blinks were removed using an automated independent components analysis routine developed by this lab (available for download at http://www.people.ku.edu/~jdien/downloads.html) using EEGLAB (Delorme & Makeig, 2004). A channel in a given trial was marked bad if the fast average amplitude exceeded 200 μv, if the differential average amplitude exceeded 100 μv, or the channel had zero variance. A channel was marked as being bad across the entire session if it was marked bad in more than 20% of the trials. Bad channels were interpolated from neighboring channels using spherical splines. Trials were marked bad if they contained more than 10 bad channels or had EOG activity in excess of 70 μv even after the ICA procedure. These automated criteria were supplemented by visual editing. The average number and range of trials going into each average was: Backward Related (17, 10-20), Backward Unrelated (16, 7-20), Symmetric Related (59, 34-70), Forward Related (17, 10-20), Forward Unrelated (17, 9-20), Non-Word (174, 114-209). Note that the robust statistics used in these analyses is designed to account for heterogeneous error variances so the larger number of trials in the symmetric related condition should not be an issue.

Data Analysis

Regarding behavioral analyses, only data for the correct "word" responses were included for reaction time (RT) analyses. The trimmed means of individual's median RTs for each condition are reported. Data from compound and noncompound word pairs were combined to have a sufficient number of trials for analyses, as similar RT priming effects have been reported for these types of pairs (Kahan, Neely, & Forsythe, 1999). As justified earlier, priming in the symmetrical condition was evaluated relative to the mean of the forward unassociated and backward unassociated conditions.

The ERP effects associated with the different kinds of priming effects were measured as the mean amplitude between 350 and 450 ms after target onset. Based on a prior study mapping the N400 topography with the same electrode montage (Dien et al., submitted), electrodes were chosen as a region of interest. Since there is interest regarding the laterality of the N400 effect, two lateralized regions of interest bracketing Cz were defined (Left: 7, 31, 32, 38, 54 and Right: 80, 81, 88, 106, 107); see Figure 1 for electrode locations. In order to derive measures that would be more robust against individual variations in scalp topography, each set of five electrodes was averaged together to produce two lateralized measures. In addition, a frontal region of interest was defined in order to investigate the putative frontal ASA component. The four electrodes surrounding Fz (Fz itself is not represented in the current electrode montage) were chosen as the region of interest (5, 6, 11, 12). Based on an inspection of the present data and a previous report by our lab (Dien, Franklin, & May, 2006), two lateralized regions of interest between and dorsal to T3/T4 and T5/T6 were defined (Left: 42, 43, 47, 48, 50, 51, 52 and Right: 93, 94, 98, 99, 102, 103, 104). Only correct trials were included in the averaged data. To maximize trial counts, compound and non-compound cells were collapsed together.

In order to isolate the primary ERP components contributing to the N400 window semantic effects, a temporo-spatial PCA was conducted using the Matlab PCA Toolbox 1.093 (http://www.people.ku.edu/~jdien/downloads.html). Variables for the initial temporal PCA consisted of the voltage readings at each of 275 time points (25 pre-stimulus and 250 post-stimulus). Recordings from 129 electrodes for each of the 5 conditions for each of 52 participants resulted in 33,540 observations. The relational matrix was the covariance matrix. Promax rotation was used to rotate to a simple structure (Dien, 1998a; Dien, Beal, & Berg, 2005; Hendrickson & White, 1964), with Kaiser correction for the Varimax portion of the procedure. A follow-up spatial Infomax PCA was conducted on each temporal factor score to separate them (Spencer, Dien, & Donchin, 1999), using the routine from EEGlab (Delorme & Makeig, 2004). The factor scores for the 129 channels were the variables and the 5 conditions x 52 participants were the observations. Finally, the portion of the grand average accounted for by each factor was reconstructed for interpretation and analysis (Dien, Frishkoff, Cerbone, & Tucker, 2003).

Design

The experiment had a two-factor split-plot design, a two-level between-subjects factor (SOA: 150 ms and 500 ms) and a five-level within-subjects factor [Priming:

Backward Associated, Backward Unassociated, Forward Associated, Forward Unassociated, and Symmetrically Associated]. The tests of the N400 window added a third within-subjects factor (Hemisphere: Left and Right). The frontal effect was tested as a midline region since it appeared to be predominantly on the midline and no apparent laterality has been previously reported or was evident in the present dataset. A Hemisphere test was not possible for the PCA factors since the channel amplitudes are represented by factor loadings and procedures for significance testing factor loadings are not yet available to this lab.

RESULTS

Behavioral results

As seen in Table 1 and Figure 2, in the 2 (SOA) x 5 (Priming) factorial design, there was a borderline trend for the RTs to be faster for the long than for the short SOA (T_{WJt}/c [1,41.95] = 3.86, p=.055). There was also a significant main effect for priming (T_{WJt}/c [4,32.32] = 22.62, p<.0001) and a significant priming x SOA interaction (T_{WJt}/c [4,32.32] = 2.99, p=.030). However, contrasts of backward, forward, and symmetrical priming interactions with SOA were not at all significant, with all p-values > .33. Individual contrasts of each of the five priming types for SOA effects suggest that the interaction is due to a greater speeding of reaction times by the longer SOA for the symmetrical and the forward related and unrelated types, although they do not survive multiple comparison correction: backward related (T_{WJt}/c [1,41.07] = 0.30, p=n.s.), backward related (T_{WJt}/c [1,41.99] = 1.02, p=n.s.), symmetrical related (T_{WJt}/c [1,41.96] = 5.45, p=.023), forward related (T_{WJt}/c [1,41.91] = 6.63, p=.014), and forward unrelated (T_{WJt}/c [1,41.23] = 5.54, p=.023). Collapsing over SOAs, there were significant priming effects from backward primes (T_{WJt}/c [1,41.97] = 9.97, p=.0018), forward primes (T_{WJt}/c [1,41.78] = 12.78, p=.0007), and symmetric primes (T_{WJt}/c [1,39.74] = 67.14, p<.0001).

In the accuracy measures, there was a main effect for priming (T_{WJt}/c [4,32.39] = 6.28, p=.0008). There was also a trend towards a main effect of SOA (T_{WJt}/c [1,41.24] = 2.97, p=.088) with accuracy being 2% higher for the 500 ms SOA than for the 150 ms SOA. Only symmetrical priming showed a significant effect for accuracy: (T_{WJt}/c [1,40.51] = 12.60, p=.0008). Backward priming (T_{WJt}/c [1,38.36] = 2.75, p=.10) and forward priming (T_{WJt}/c [1,40.81] = 3.04, p=.082) showed trends.

ERP Windowed Results

Traditional channels of the grand average waveforms are provided in Figures 3 and 4 for comparison with previous reports. The grand average waveforms of the channels used to test the three putative semantic components are provided in Figure 5. The overall scalp topography of the difference waveforms are provided in Figure 6. Note that SOA main effects are likely to reflect the intrusion of the processing of the short SOA prime into the baseline period.

For the frontal windowed measures, there was a trend towards a priming effect (T_{WJt}/c [4,32.38] = 2.32, p=.078), as seen in Table 2 and Figure 7. Overall, it was more negative for the short SOA: T_{WJt}/c [1,40.23] = 32.95, p<.0001). The only significant priming effect was for symmetric priming: T_{WJt}/c (1,39.02) = 4.07, p = .050. The p-values for backward and forward priming were both over .56. Of interest, there was a trend towards an interaction for symmetric primes with SOA: T_{WJt}/c (1,39.02) = 3.07, p=.088. This trend reflected high significance for symmetric primes at the long SOA (T_{WJt}/c [1,21.00] = 9.81, p = .0031) but not the short SOA (p = .87). Given that the Priming by SOA interaction was only a trend, it seems appropriate to apply a Bonferroni correction on this latter contrast for all six possible combinations of SOA and priming type. Even with this strict correction it remains significant (alpha equals .0083). An examination of the difference wave (collapsed across the region of interest) for the long SOA symmetrical contrasts reveals a peak at 404 ms, although the time course is quite extended.

For the N400 windowed measure as seen in Table 3 and Figure 8, there was a main effect for priming: T_{WJt}/c [4,33.07] = 8.97, p=.0001. Overall, it was less positive for the long SOA: T_{WJt}/c [1,34.99] = 11.19, p=.0030). There was an interaction between SOA, hemisphere, and Priming: T_{WJt}/c [4,32.86] = 3.07, p=.023. This interaction reflects a significant SOA by hemisphere interaction for backward priming only: T_{WJt}/c [1,41.44] = 8.29, p=.0046. This interaction in turn reflects a significant effect for backward priming only over the right hemisphere and only at the long SOA: T_{WJt}/c [1,21] = 12.13, p=.0028. Finally, there were overall significant effects for forward priming (T_{WJt}/c [1,41.69] = 7.71, p=.0078) and symmetric priming (T_{WJt}/c [1,41.25] = 34.71, p<.0001) and a trend towards backward priming (T_{WJt}/c [1,41.58] = 3.31, p=.076). Whereas there was a very distinct SOA effect for symmetric primes for the frontal windowed measures, the specific contrasts for the N400 measures were quite similar for short (T_{WJt}/c [1,21] = 20.61, p=.0004) and long (T_{WJt}/c [1,21] = 14.13, p=.0010) SOAs. An examination of the difference wave (collapsed across the region of interest) for the long SOA symmetrical contrast reveals a clear single peak at 400 ms.

For the posterior windowed measures, there was a significant effect of Priming (T_{WJt}/c [4,32.96] = 2.86, p=.036), as seen in Table 4 and Figure 9. The right side was overall more positive: T_{WJt}/c [1,41.77] = 16.69, p=.0003. The long SOA was less positive overall: T_{WJt}/c [1,41.48] = 10.52, p=.0022. This long SOA negativity was more distinct over the left hemisphere: T_{WJt}/c [1,41.77] = 4.51, p=.038. Despite the apparently strong lateralized effect for backward primes visible in the grand average, for the posterior windowed measures there was only a trend towards an SOA by hemisphere interaction for backward priming only (T_{WJt}/c [1,41.73] = 1.98, p=.16), with p-values of over .90 for forward and symmetric primes. Finally, there were overall significant effects for backward priming (T_{WJt}/c [1,41.83] = 4.26, p=.044), forward priming (T_{WJt}/c [1,41.90] = 4.89, p=.030) and symmetric priming (T_{WJt}/c [1,41.86] = 7.32, p=.0080). In the backward priming condition, the much longer time course for the semantic difference at these channels and in the N400 channels suggest that these condition differences reflect different ERP components. An examination of the difference wave (collapsed across the region of interest) for the long SOA backward contrast yields a peak at 364 ms.

Finally, in order to determine if there was a double-dissociation between apparent N300 symmetrical priming effects in the frontal channels and the apparent right-lateralized N400RP backward priming effects in the P300/N400 channels (see Discussion), a targeted contrast was conducted for the long SOA (for which both effects appeared to be strongest). For the frontal region, the symmetric priming effect was stronger (T_{WJt}/c [1,21] = 5.08, p=.032) whereas for the P300/N400 lateralized channels (right hemisphere minus left hemisphere), there was a trend for the backward priming effect to be stronger (T_{WJt}/c [1,21] = 2.10, p=.16).

ERP PCA Results

As described in the methods section, a principal components analysis was conducted to further elucidate the componentry of the N400 window activity. The Scree plot suggested the retention of 11 factors for the initial temporal PCA, accounting for 76% of the variance. The second temporal factor, peaking at 460 ms, appeared to represent the N400 window activity. A Scree plot suggested the retention of five factors for the subsequent spatial ICA of this N400 window temporal factor, accounting for 67% of the variance of this temporal factor.

Of the five ICA factors, three had topographies appearing to correspond to the frontal effect, the P300/N400, and the posterior effect. The frontal factor displayed a significant Priming effect: T_{WJt}/c (4,31.49) = 5.78, p=.0021. The frontal factor also was more negative for the short SOA: T_{WJt}/c (4,36.97) = 7.36, p=.010. The frontal factor displayed a significant symmetric priming contrast: T_{WJt}/c (1,38.92) = 16.16, p=.0002.

The P300/N400 factor displayed a significant Priming effect: T_{WJt}/c (4,32.45) = 3.66, p=.~~019~~018. The P300/N400 factor also was more negative for the short SOA: T_{WJt}/c (4,40.48) = 6.69, p=.013. The forward priming contrast (T_{WJt}/c [1,39.19] = 5.47, p=.023) and the symmetric priming contrast (T_{WJt}/c [1,41.10] = 11.57, p=.0016) were significant. The backward priming contrast was not significant with a p-value of .80.

None of the posterior factor effects were significant. ~~The posterior factor was larger for the short SOA: T_{WJt}/c (1,39.42) = 5.73, p=.019. There was also a trend towards a Priming effect: T_{WJt}/c (4,32.97) = 2.30, p=.075.~~

~~Finally, in order to determine if there was a double-dissociation between the symmetric and backward priming effects on the frontal and N400RP factors, a targeted contrast was conducted for both factors. For the frontal factor, the symmetric priming effect was stronger (T_{WJt}/c [1,33.86] = 11.36, p=.0017) whereas for the N400RP factor, the backward priming effect was stronger (T_{WJt}/c [1,41.47] = 7.64, p=.0079).~~

DISCUSSION

The behavioral results reveal significant RT priming effects for all conditions. The forward and backward priming RT priming effects were roughly numerically equivalent at the 500-ms and 150-ms SOAs. These data are similar to the significant effects found in a larger sample tested by Kahan and colleagues (1999) and allow an investigation of the ERPs with the knowledge that priming was indeed occurring in all conditions. As for the three goals, the effort to separate the N400 from the P300 appears to have failed, precluding conclusions about the N400 in this dataset. On the other hand, the data do suggest the successful detection of the two semantically sensitive components other than the N400, a frontal effect (an N300) and a right parietal effect (the N400RP, meaning right parietal N400). This paper will argue that the former reflects an aspect of expectancy whereas the latter reflects semantic matching. Finally, the ERP results suggest that there is indeed a qualitative difference between backward priming at the short and long SOAs.

One caveat is that the ERP from the prime overlapped into the baseline period for the short SOA condition. This overlap meant that main effects of SOA could not be interpreted. Potentially, this overlap could also produce confounds with the priming manipulations. However, examination of the grand averages suggest no such confound was present as the ERP components of the prime appear to be equivalent across the different prime types.

There are also some caveats to keep in mind regarding differences between the conditions. First, there are a larger number of symmetric trials than asymmetric trials (70 vs. 40). Second, the associative strength between the symmetric pairs was higher than between the asymmetric pairs.

The key response to such potential concerns is that the N300 and the N400RP effects ~~constitute~~ suggest a double dissociation pattern (Teuber, 1968). In the case of this study, the N300 effect is stronger for the symmetric priming contrast and the

N400RP ~~is~~ tends to be stronger for the backward priming contrast. Although the latter contrast did not reach significance, the N400RP effect was indeed significant for backward priming and not for symmetric priming when evaluated separately. Thus, whether one accepts this argument depends on how stringent a criterion is required. We further suggest that the observation of an isolated N400RP (Dien, Franklin, & May, 2006) and a successful fMRI replication (O'Hare, Dien, Waterson, & Savage, submitted) of the N300 effect, described later, provide further support that these two effects constitute separate ERP components.

I~~n such a case~~f the argument of a double-dissociation is accepted, differential sensitivity cannot account for both effects. For example, if the symmetric priming contrast was more sensitive to semantic effects (because it has more trials and because it has a stronger association strength) then these differences could explain why the N300 effect was significant for the symmetric priming contrast but not the backward priming contrast; however, this same explanation cannot simultaneously account for why the N400RP is significant in the backward priming contrast but not the symmetric priming contrast. If there is only one semantic effect, then only one condition can overall be more sensitive to it than the other. This paper will therefore consider both effects on the basis that at least one of them must represent something other than a simple difference in sensitivity to a basic semantic effect.

The N300

The windowed measure suggests the presence of a separate frontal effect other than the N400 that was only sensitive to symmetric primes. The conclusion that a frontal effect is present is further supported by the finding of an independent PCA factor for the frontal N400 effect; nonetheless, there is a need to establish a functional double-dissociation to be fully confident of this conclusion. Note also the differing time course evident for the putative N300 effect from the more posterior N400 effect in Figure 5. The collapsing of the two into a single temporal factor can be understood by an observed tendency of temporal PCA to divide the epoch into windows such that components that span multiple windows are split, contributing to the need for the two-step PCA procedure to separate multiple activities in each window. Further confidence that this factor represents a distinct ERP component is provided by an fMRI replication (O'Hare, Dien, Waterson, & Savage, submitted) which found that this factor source localizes to a posterior cingulate region that co-registers with an fMRI activation which similarly is significant only for the symmetric priming contrast.

Contrary to a previous proposal of a frontal N4a that reflects ASA (Pritchard, Shappell, & Brandt, 1991), our frontal semantic effect was found to be significant only for long SOA symmetrical prime pairs (although the interaction with SOA was only a trend, the specific contrasts for short and long SOAs show a distinct difference with p-values of .0031 for long and .87 for short). Given the current understanding that ASA should be stronger at short than long SOAs (McNamara, 2005; Neely, 1991), this observation would seem to weigh against this frontal effect reflecting ASA. Furthermore, the original report (Pritchard, Shappell, & Brandt, 1991) was in regards to a category membership task in which low typicality exemplars yielded a stronger effect than high typicality exemplars and the inference that the N400a reflected ASA was based solely on the reasoning that judging typicality was not a part of the task and hence the priming difference for high and low typicality members was based on an automatic process.

Alternatively, the N400a component may be the same as the N300 seen for picture priming experiments (Barrett & Rugg, 1990; Ganis, Kutas, & Sereno, 1996; McPherson & Holcomb, 1999). Indeed, a prior study using the same electrode montage has reported a very similar scalp topography for word-picture priming (Hamm, Johnson, & Kirk, 2002). Note that this N300 is different from the lateral N300 effect that has also been reported (Dien, Frishkoff, Cerbone, & Tucker, 2003).

The picture study (Hamm, Johnson, & Kirk, 2002) reported that the picture N300, unlike the N400, only responded to between-category mismatches (e.g., "robin" - picture of collie) as opposed to within-category mismatches (e.g., "poodle" - picture of collie). Another study of picture priming (Federmeier & Kutas, 2002) also reported an N300 that only responded to categorical relatedness and not associative relatedness. Neither study controlled for semantic similarity. These reports suggest that the N300 represents a cognitive process that is especially sensitive to either categorical or semantic similarity.

Although it has thus far been thought that the N300 is only elicited by picture stimuli, a parsimonious account of the putative N4a (Pritchard, Shappell, & Brandt, 1991) is that it was an N300 that was also being sensitive to categorical membership (and/or semantic similarity); however, this report was pilot data that was never fully peer-reviewed. Further evidence that this N300 can be elicited by word stimuli is provided by two prior studies where they were termed respectively an N330 (Nobre & McCarthy, 1994) and a midfrontal negativity (Frishkoff, Tucker, Davey, & Scherg, 2004).

The present manuscript is the first peer-reviewed study that not only reports an apparent N300 to word stimuli but also provides evidence that it too may be sensitive to category membership and/or semantic similarity, since the symmetric priming pairs were both more semantically similar and shared more category membership than the associative pairs (although further study will be needed to rule out the possibility that in this case it was due to the stronger associations of the symmetric pairs).

Some further evidence for a distinction between associative relationships and category membership/semantic similarity for word stimuli is a classic behavioral study (Becker, 1980) which reported that relative to a neutral priming condition (in which the prime was a string of XXXs), associative pairs produced facilitation for the related priming condition but little inhibition for the unrelated priming condition whereas categorically related pairs produced inhibition for unrelated targets. This research also demonstrated that these effects were strategically mediated since associative pairs in a list containing mostly categorically related pairs or categorical pairs in a list containing mostly associatively related pairs displayed the priming pattern of the list type. Likewise, in the present study the effect of greater semantic similarity/category membership (for the symmetric pairs) on the N300 was seen only in the long SOA condition (which favors controlled priming). Although Becker's pattern of results was used to support a Verification model that emphasized the size of the search sets generated from different kinds of primes, his data could also be interpreted as supporting a qualitative difference between these two types of relationships (Dien, submitted). Hence, further study is required to validate our speculation that the N300 is elicited by both word and picture stimuli and that it reflects an expectancy process that is sensitive to category membership and/or semantic similarity.

N400

The most pronounced semantic effect was a posterior midline relative negativity. One concern is to what extent it represents a P300 (Linden, 2005; Polich & Kok, 1995). The P300 is thought to mark the end of a decision process (Donchin & Coles, 1988), which is certainly present in the current experiment, although there are some continuing disputes regarding the relationship between P300 latency and reaction time measures (Dien, Spencer, & Donchin, 2004; Verleger, 1997). Because the P300 latency reflects decision-making time (Kutas, McCarthy, & Donchin, 1977), it is possible that the relative negativity in the N400 window is due to a delayed P300 peak; however, if this were so, there should have been such an effect in the backward priming condition too. The P300 is very sensitive to probability and is largely absent when no stimulus category can be considered rare, although there is also a small effect of target status (Donchin, 1981). In the present study the two categories were nearly equal (58% non-word) and participants responded to all stimuli, which means the P300 should have been minimal, accounting perhaps for the failure to separate it from the N400. The present authors therefore suggest that the posterior effect mostly reflects the N400 and that it reflects ASA (because it appears at the short SOA) and possibly expectancy as well (because it does not display a reduced priming effect at the long SOA, although conclusions based on this null effect at the long SOA must be tentative).

N400RP

The backward priming effects were right-lateralized unlike the other two effects, suggesting that backward priming was due to a different component. The PCA results support this interpretation, showing effects in the posterior midline factor for symmetrical and forward priming pairs but not backward priming pairs. The double-dissociation pattern between the two effects supports the contention that they are different components sensitive to different experimental manipulations. Since the right posterior component appears to be different from the N400 proper, it will be termed an N400RP (for right parietal). This N400RP appears to be a replication of a right posterior effect reported in a previous study (Dien, Franklin, & May, 2006). The present results suggest that it reflects semantic matching and not ASA or expectancy, since it seems to be specific to backward priming in this dataset.

Of additional interest is the observation that in a previous study (Dien, Franklin, & May, 2006) the N400RP responded to forward primes as well as backward primes, although there was a trend for the effect to be larger for backward primes. One possible reason for this change is that in the present dataset the relatedness proportion was much higher, inducing a greater reliance on expectancy processes. Alternatively, the SOA was shorter in both conditions (250 and 500 ms versus 1000 ms) and so ASA should be stronger in the present study too. In any case, the data suggests that expectancy (N400) and semantic matching (N400RP) can be deployed in parallel since both effects are seen in this dataset. Furthermore, because these two processes occur in the same, relatively late, time frame, they may both be post-lexical in nature. One way in which the N400 "expectancy" process could be post-lexical is if it reflected an updating process much like that of the P300 (Donchin & Coles, 1988), but restricted to semantics. Furthermore, because the N400RP was not elicited by forward priming unlike in the prior experiment (Dien, Franklin, & May, 2006), it suggests that the N400RP can be suppressed in favor of the N400 on a trialwise basis. This observation suggests a scenario in which both expectancy (N400) and semantic matching (N400RP) can be deployed in parallel, with semantic matching only being applied on trials in which expectancy has failed.

As for why these effects differed from the Chwilla and colleagues' (1998) findings, there are a number of possible reasons. First of all, since the words and non-words were equiprobable and in their second experiment the non-words were designated the targets, it is expected that the P300 to the words would be minimal in their study as well so their effects will be interpreted as being due to the N400. The most likely interpretation is that the discrepancy is due to differences seen in unimodal versus cross-modal stimulus presentations (Anderson & Holcomb, 1995; Holcomb &

Anderson, 1993). It appears that backward priming operates differently for auditory prime-visual target pairs. Such a hypothesis would also account for a prior report (Peterson & Simpson, 1989) that backward priming could occur at longer SOAs for auditory primes in a word pronunciation task; a task that is normally found to preclude semantic matching (Seidenberg, Waters, Sanders, & Langer, 1984).

Cognitive Issues

In the present study, the absence vs. presence of right-lateralized N400RP backward priming effects at the 150-ms and 500-ms SOAs, respectively, suggests that separate mechanisms may be producing backward priming under automatic and strategic conditions. In the present study, the fact that significant backward priming effects in RTs were not accompanied by any significant ERP effects at a 150-ms SOA suggests that “automatic” backward priming is produced by a mechanism other than post-lexical semantic integration, which was the likely source for the backward priming effects that yielded both N400RP and RT differences at the 500-ms SOA.

As previously noted, a study by Kahan and colleagues (1999) provides converging evidence that backward priming at a short SOA is produced by a mechanism other than ASA or post-lexical semantic matching. Their study revealed that at a 150-ms SOA backward priming caused facilitation in both pronunciation and lexical decision tasks, whereas at a 500-ms SOA significant backward priming occurred only for lexical decisions. Because the pronunciation task seems to minimize post-lexical integrative processing (de Groot, 1985; Keefe & Neely, 1990; Seidenberg, Waters, Sanders, & Langer, 1984), to account for short-SOA backward priming effects, one must either postulate a new priming mechanism or modify the assumptions regarding how ASA can produce a priming effect.

Because the present study and Kahan and colleagues (1999) demonstrated *similar* facilitation for backward priming for RTs at 150-ms and 500-ms SOAs in the lexical decision task, it is argued that the difference in N400RP effects indicates differences in cognitive processing rather than differences in statistical power. Because no ERP effects were seen for the 150-ms SOA backward priming effect, further research must be done to better characterize this automatic process, which could be considered to be a fourth priming mechanism.

Conclusions

This paper yielded four novel contributions to the literature: 1) confirmation of an N300 effect that, as for pictorial stimuli, seems to be sensitive to expectancy for category membership and/or semantic similarity, promising potential insights into these aspects of semantics; 2) confirmation of the N400RP by providing a double-dissociation with the N400 and stronger evidence that it is specific to semantic matching; 3) some evidence that the N400 might indirectly reflect ASA and expectancy via some type of post-lexical updating process; 4) evidence that backward priming processes in lexical decision tasks are different at short and long SOAs.

REFERENCES:

Anderson, J. E. & Holcomb, P. J. (1995). Auditory and visual semantic priming using different stimulus set asynchronies: An event-related brain potential study. *Psychophysiology*, *32*, 177-190.

Barrett, S. E. & Rugg, M. D. (1990). Event-related potentials and the semantic matching of pictures. *Brain and Cognition*, *14*, 201-212.

Becker, C. A. (1980). Semantic context effects in visual word recognition: An analysis of semantic strategies. *Memory and Cognition*, *8*(6), 493-512.

Bertrand, O., Perrin, F., & Pernier, J. (1985). A theoretical justification of the average reference in topographic evoked potential studies. *Electroencephalography and Clinical Neurophysiology*, *62*, 462-464.

Chwilla, D. J., Hagoort, P., & Brown, C. M. (1998). The mechanism underlying backward priming in a lexical decision task: Spreading activation versus semantic matching. *Quarterly Journal of Experimental Psychology*, *51A*(3), 531-560.

de Groot, A. M. B. (1985). Word-context effects in word naming and lexical decision. *Quarterly Journal of Experimental Psychology*, *37A*, 281-297.

Deacon, D., Grose-Fifer, J., Yang, C.-M., Stanick, V., Hewitt, S., & Dynowska, A. (2004). Evidence for a new conceptualization of semantic representation in the left and right cerebral hemispheres. *Cortex*, *40*, 467-478.

Deacon, D., Hewitt, S., Yang, C.-M., & Nagata, M. (2000). Event-related potential indices of semantic priming using masked and unmasked words: Evidence that the N400 does not reflect a post-lexical process. *Cognitive Brain Research*, *9*, 137-146.

Deacon, D., Uhm, T.-J., Ritter, W., Hewitt, S., & Dynowska, A. (1999). The lifetime of automatic semantic priming effects may exceed two seconds. *Cognitive Brain Research*, *7*, 465-472.

Delorme, A. & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis*. Journal of Neuroscience Methods*, *134*, 9-21.

Dien, J. (1998a). Addressing misallocation of variance in principal components analysis of event-related potentials*. Brain Topography*, *11*(1), 43-55.

Dien, J. (1998b). Issues in the application of the average reference: Review, critiques, and recommendations*. Behavior Research Methods, Instruments, and Computers*, *30*(1), 34-43.

Dien, J. (submitted). Looking both ways through time: the Janus model of lateralized cognition.

Dien, J., Beal, D. J., & Berg, P. (2005). Optimizing principal components analysis of event-related potential analysis: Matrix type, factor loading weighting, extraction, and rotations*. Clinical Neurophysiology*, *116*(8), 1808-1825.

Dien, J., Franklin, M., & May, C. (2006). Is "blank" a suitable neutral prime for event-related potential experiments? *Brain and Language*, *97*, 91-101.

Dien, J., Franklin, M. S., Michelson, C. A., Lemen, L. C., Adams, C. L., & Kiehl, K. A. (submitted). Localizing the N400 Semantic Cloze Effect: Parametric ERP and fMRI Analysis.

Dien, J., Frishkoff, G. A., Cerbone, A., & Tucker, D. M. (2003). Parametric analysis of event-related potentials in semantic comprehension: Evidence for parallel brain mechanisms*. Cognitive Brain Research*, *15*, 137-153.

Dien, J., Spencer, K. M., & Donchin, E. (2004). Parsing the "Late Positive Complex": Mental chronometry and the ERP components that inhabit the neighborhood of the P300*. Psychophysiology*, *41*(5), 665-678.

Donchin, E. (1981). Surprise, surprise*. Psychophysiology*, *18*, 493-513.

Donchin, E. & Coles, M. G. H. (1988). Is the P300 component a manifestation of context updating? *Behavioral and Brain Sciences*, *11*, 357-374.

Federmeier, K. D. & Kutas, M. (2002). Picture the difference: electrophysiological investigations of picture processing in the two cerebral hemispheres. *Neuropsychologia*, *40*(7), 730-747.

Frishkoff, G. A., Tucker, D. M., Davey, C., & Scherg, M. (2004). Frontal and posterior sources of event-related potentials in semantic comprehension. *Cognitive Brain Research*, *20*, 329-354.

Ganis, G., Kutas, M., & Sereno, M. I. (1996). The search for "common sense": An electrophysiological study of the comprehension of words and pictures in reading. *Journal of Cognitive Neuroscience*, *8*, 89-106.

Hamm, J. P., Johnson, B. W., & Kirk, I. J. (2002). Comparison of the N300 and N400 ERPs to picture stimuli in congruent and incongruent contexts. *Clinical Neurophysiology*, *113*, 1339-1350.

Hendrickson, A. E. & White, P. O. (1964). Promax: A quick method for rotation to oblique simple structure. *The British Journal of Statistical Psychology*, *17*, 65-70.

Hill, H., Strube, M., Roesch-Ely, D., & Weisbrod, M. (2002). Automatic vs. controlled processes in semantic priming - differentiation by event-related potentials. *International Journal of Psychophysiology*, *44*(3), 197-218.

Holcomb, P. J. (1993). Semantic priming and stimulus degradation: Implications for the role of the N400 in language processing. *Psychophysiology*, *30*, 47-61.

Holcomb, P. J. & Anderson, J. E. (1993). Cross-modal semantic priming: A time-course analysis using event-related brain potentials. *Language and Cognitive Processes*, *8*, 379-412.

Kahan, T. A., Neely, J. H., & Forsythe, W. J. (1999). Dissociated backward priming effects in lexical decision and pronunciation tasks. *Psychonomic Bulletin & Review*, *6*(1), 105-110.

Keefe, D. E. & Neely, J. H. (1990). Semantic priming in the pronunciation task: The role of prospective prime-generated expectancies. *Memory and Cognition*, *18*(3), 289-298.

Keselman, H. J., Wilcox, R. R., & Lix, L. M. (2003). A generally robust approach to hypothesis testing in independent and correlated groups designs. *Psychophysiology*, *40*, 586-596.

Kiefer, M. (2002). The N400 is modulated by unconsciously perceived masked words: Further evidence for an automatic spreading activation account of N400 priming effects. *Cognitive Brain Research*, *13*, 27-39.

Kiefer, M. & Spitzer, M. (2000). Time course of conscious and unconscious semantic brain activation. *NeuroReport*, *11*(11), 2401-2407.

Koriat, A. (1981). Semantic facilitation in lexical decision as a function of prime-target association. *Memory and Cognition*, *9*(6), 587-598.

Kucera, H. & Francis, W. N. (1967). *Computational analysis of present-day American English.* Providence: Brown University Press.

Kutas, M. & Hillyard, S. A. (1989). An electrophysiological probe of incidental semantic association. *Journal of Cognitive Neuroscience*, *1*(1), 38-49.

Kutas, M., Lindamood, T., & Hillyard, S. A. (1984). Word expectancy and event-related brain potentials during sentence processing. In S. Kornblum & J. Requin (Eds.), *Preparatory states and processes*. (pp. 217-238). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Kutas, M., McCarthy, G., & Donchin, E. (1977). Augmenting mental chronometry: The P300 as a measure of stimulus evaluation time. *Science*, *197*, 792-795.

Kutas, M., Van Petten, C., & Besson, M. (1988). Event-related potential asymmetries during the reading of sentences*. Electroencephalography and Clinical Neurophysiology*, *69*, 218-233.

Kutas, M. & Van Petten, C. K. (1994). Psycholinguistics electrified: Event-related brain potential investigations. In M. A. Gernsbacher (Ed.), *Handbook of Psycholinguistics*. (pp. 83-143). San Diego, CA: Academic Press.

Landauer, T. K. & Dumais, S. T. (1997). A solution to Plato's problem: The Latent Semantic Analysis theory of acquisition, induction, and representation of knowledge*. Psychological Review*, *104*, 211-240.

Linden, D. E. J. (2005). The P300: Where in the brain is it produced and what does it tell us? *New Scientist*, *11*(6), 563-576.

McNamara, T. P. (2005). *Semantic Priming: Perspectives from Memory and Word Recognition.* New York, NY: Taylor & Francis.

McPherson, W. B. & Holcomb, P. J. (1999). An electrophysiological investigation of semantic priming with pictures of real objects*. Psychophysiology*, *36*(1), 53-65.

Meyer, D. & Schvaneveldt, R. (1976). Meaning, memory structure, and mental processes*. Science*, *192*, 27-33.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G. W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition*. (pp. 264-336). Hillsdale, NJ: Lawrence Erlbaum Associates.

Neely, J. H. & Keefe, D. E. (1989). 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(24)*. (pp. 207-248). New York: Academic Press.

Nelson, D. L., McEvoy, C. L., & Schreiber, T. A. (1999). The University of South Florida Word Association, Rhyme and Fragment Norms.

Nobre, A. C. & McCarthy, G. (1994). Language-related ERPs: Scalp distributions and modulations by word type and semantic priming. *Journal of Cognitive Neuroscience*, *6*(3), 233-255.

O'Hare, A. J., Dien, J., Waterson, L., & Savage, C. R. (submitted). Activation of the Posterior Cingulate by Semantic Priming: A co-registered ERP/fMRI Study.

Peterson, R. R. & Simpson, G. B. (1989). Effect of backward priming on word recognition in single-word and sentence contexts. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*(6), 1020-1032.

Polich, J. & Kok, A. (1995). Cognitive and biological determinants of P300: an integrative review. *Biological Psychology*, *41*(2), 103-146.

Polich, J. (1985). Semantic categorization and event-related potentials. *Brain and Cognition*, *26*, 304-321.

Pritchard, W. S., Shappell, S. A., & Brandt, M. E. (1991). Psychophysiology of N200/N400: A review and classification scheme. *Advances in Psychophysiology*, *4*, 43-106.

Seidenberg, M. S., Waters, G. S., Sanders, M., & Langer, P. (1984). Pre- and postlexical loci of contextual effects on word recognition. *Memory and Cognition*, *12*(4), 315-328.

Sereno, S. C., Rayner, K., & Posner, M. I. (1998). Establishing a time-line of word recognition: evidence from eye movements and event-related potentials. *Neuroreport*, *9*, 2195-2200.

Silva-Pereyra, J., Harmony, T., Villanueva, G., Fernández, T., Rodríguez, M., Galán, L., et al. (1999). N400 and lexical decisions: Automatic or controlled processing? *Clinical Neurophysiology*, *110*, 813-824.

Spencer, K. M., Dien, J., & Donchin, E. (1999). A componential analysis of the ERP elicited by novel events using a dense electrode array. *Psychophysiology*, *36*, 409-414.

Teuber, H.-L. (1968). Alteration of perception and memory in man. In L. Weiskrantz (Ed.), *Analysis of behavioral change.* New York: Harper and Row.

Thompson-Schill, S. L., Kurtz, K. J., & Gabrieli, J. D. E. (1998). Effects of semantic and associative relatedness on automatic priming. *Journal of Memory and Language*, *38*, 440-458.

Verleger, R. (1997). On the utility of P3 latency as an index of mental chronometry. *Psychophysiology*, *34*(2), 131-156.

Figure Captions

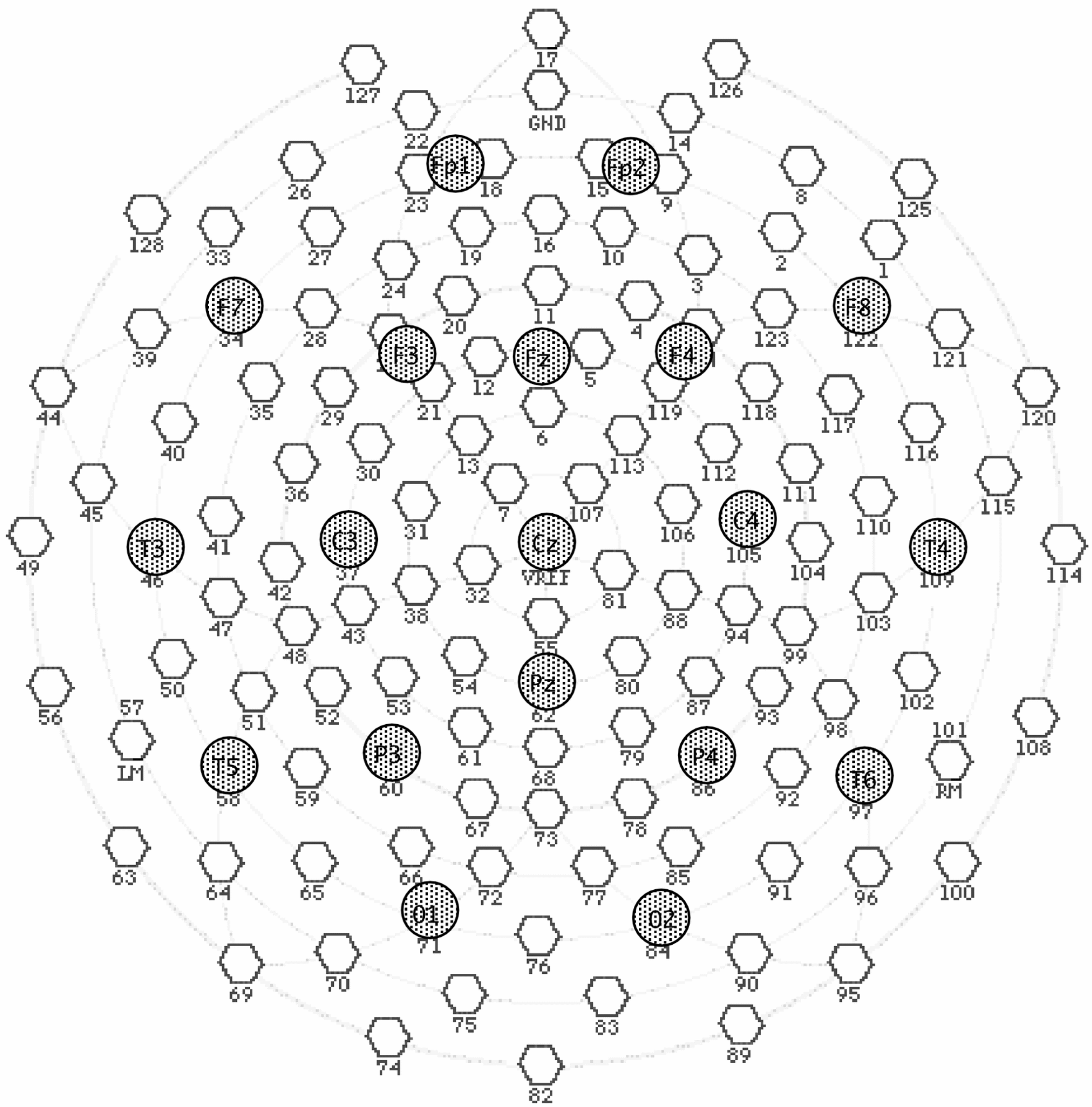

Figure 1. Electrode locations. Standard 10-20 locations are marked in gray.

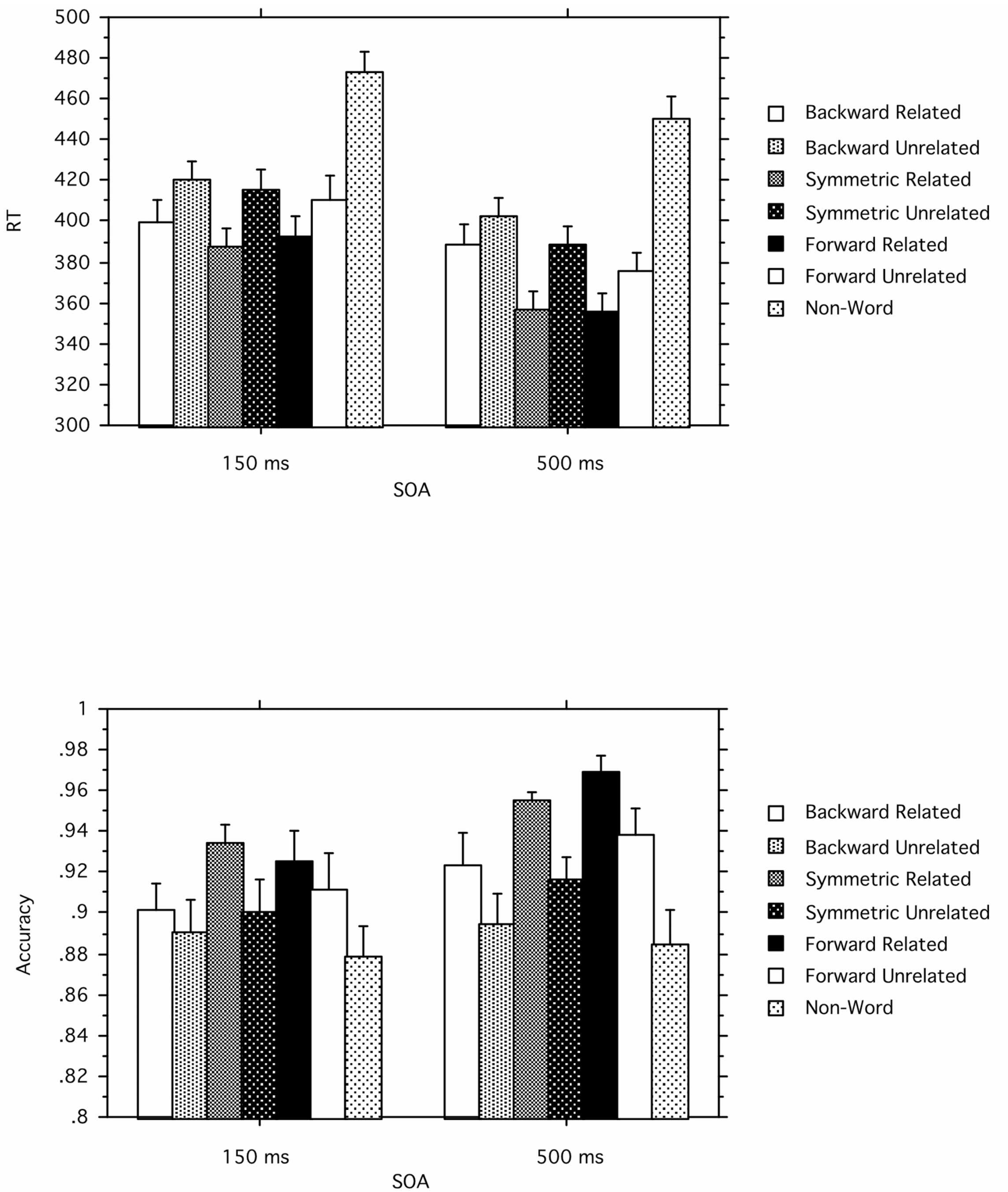

Figure 2. Bar chart for behavioral data. The equal unrelated condition is the average of the backward and forward unrelated conditions. The height of the bars represents the mean of the conditions. The error bar is the standard error.

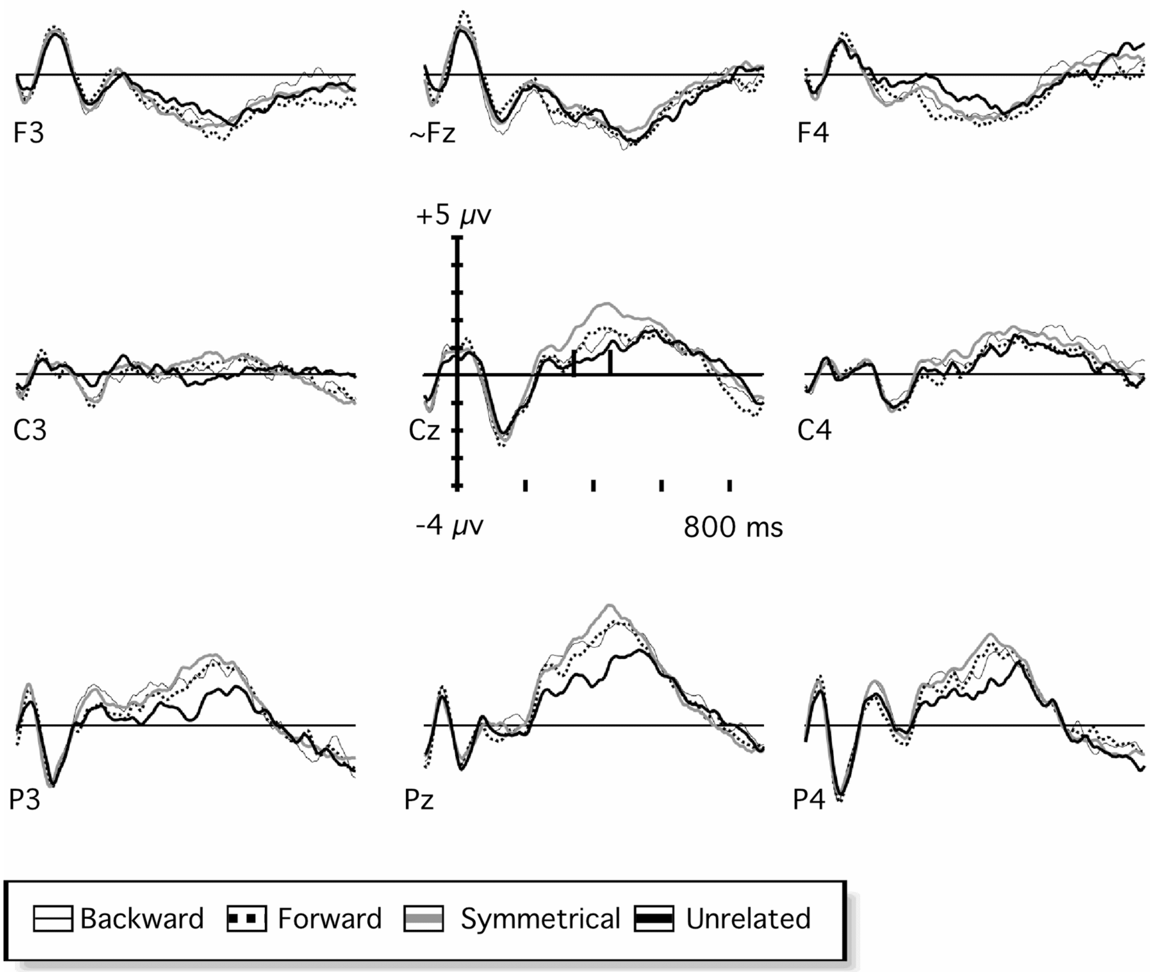

Figure 3. Grand average waveforms of the short SOA condition. The unrelated condition is the average of the backward and forward unrelated conditions. Two vertical lines in each plot indicate the boundaries of the windowed measure (350-450 ms).

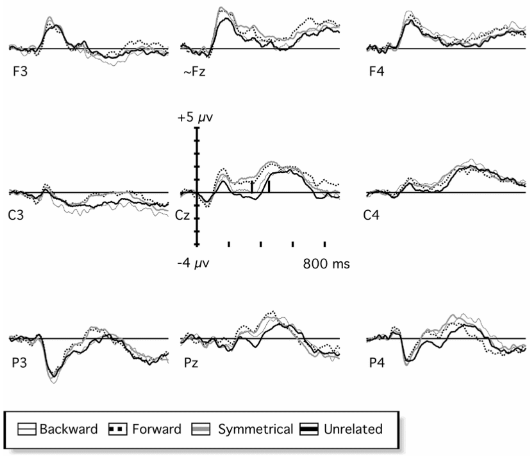

Figure 4. Grand average waveforms of the long SOA condition. The unrelated condition is the average of the backward and forward unrelated conditions. Two vertical lines in each plot indicate the boundaries of the windowed measure (350-450 ms). The plots are from -100 to 900 ms.

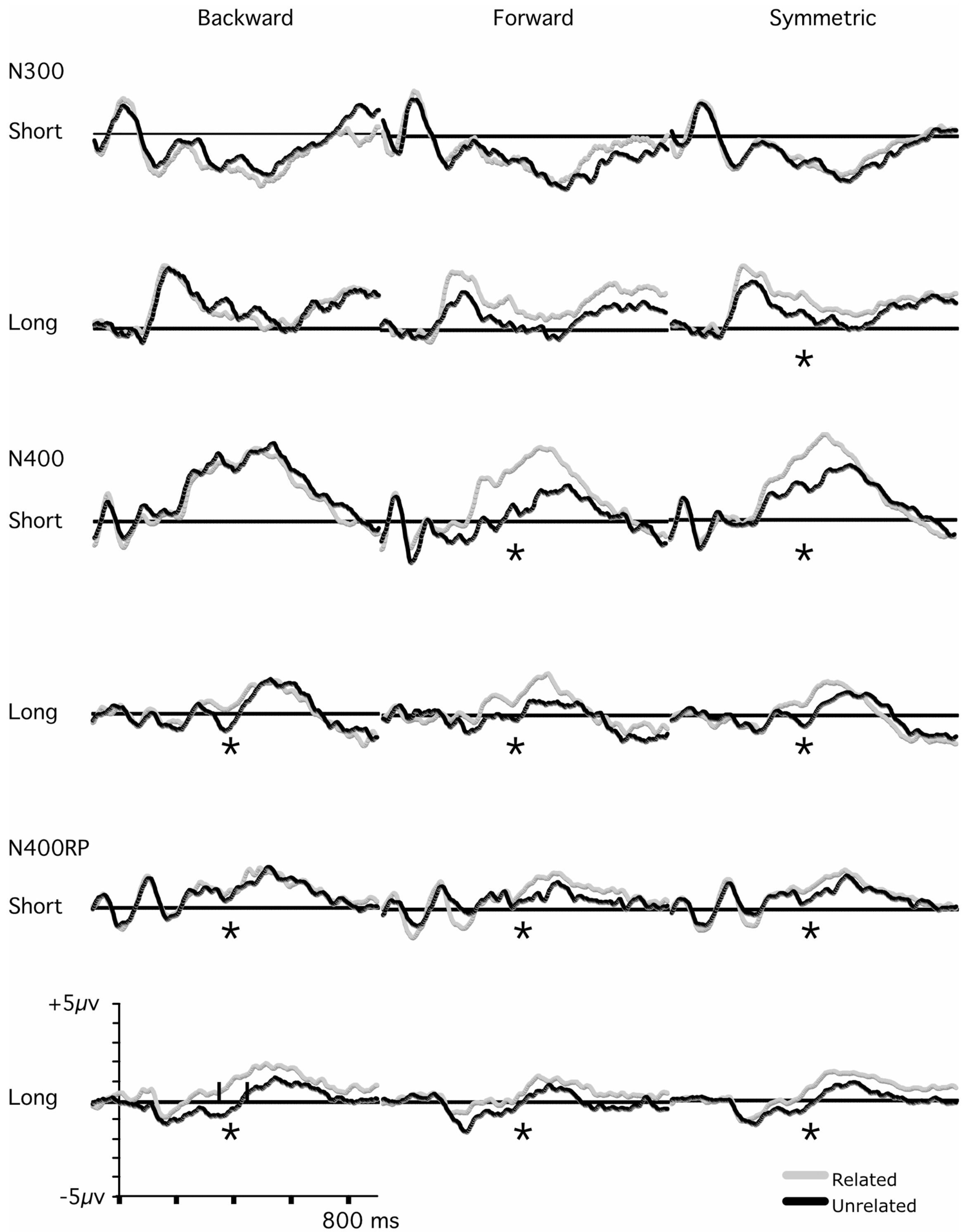

Figure 5. Grand average waveforms of the semantic priming effects. The channels representative of the N300 (e11, just anterior to Fz), N400/P300 (e62, Pz), and the N400RP (e99, C4-P4) are shown. The short and long SOA conditions are displayed

separately. The two vertical lines in the lower left plot indicate the boundaries of the windowed measure (350-450 ms). An asterisk marks significant effects. The plots are from -100 to 900 ms.

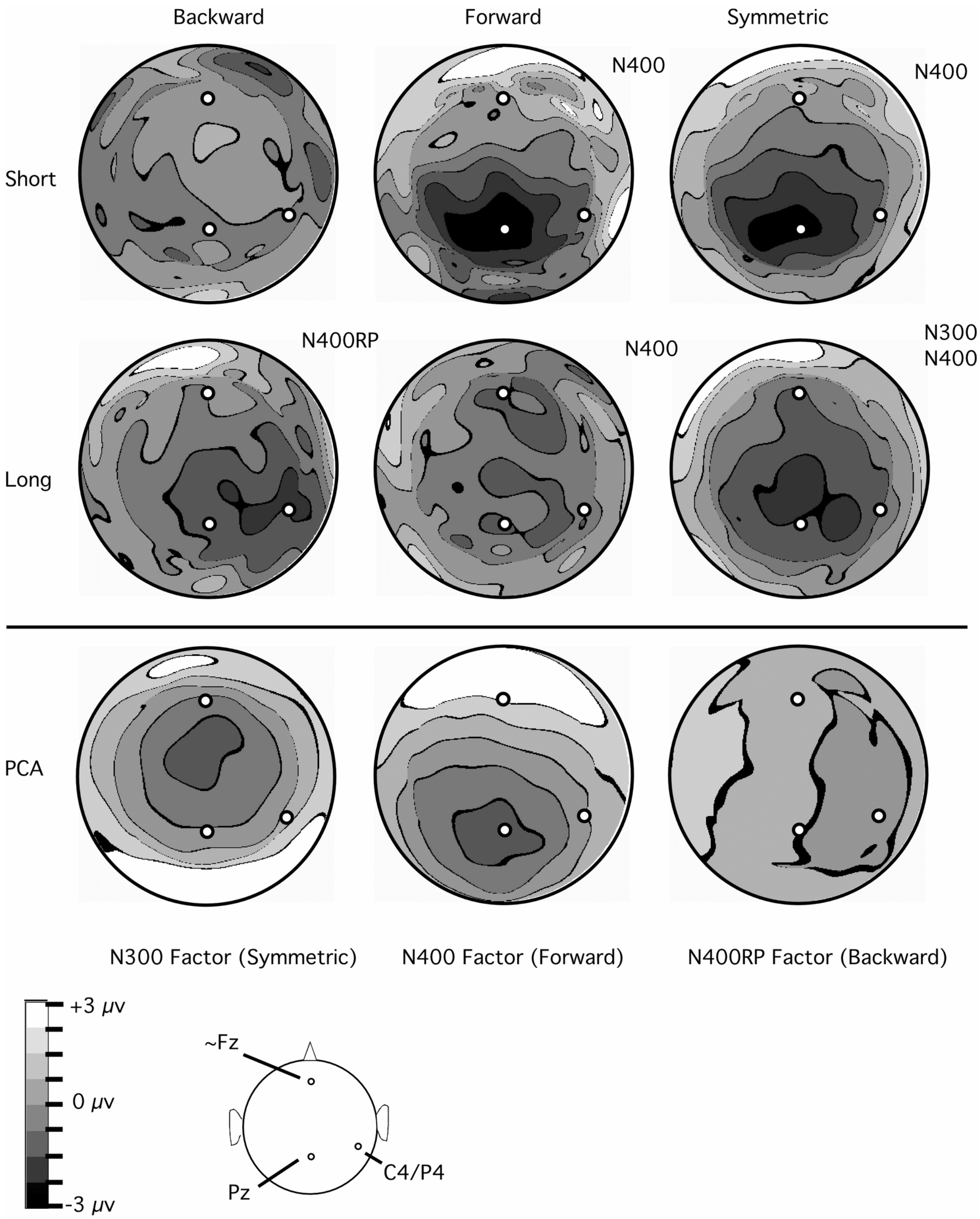

Figure 6. Difference wave scalp topographies of the semantic priming effects at 400 ms. The difference waves are the unrelated condition minus the related condition. The white dots indicate the location of the three channels displayed in the waveform figure. Also

shown are the difference wave plots for the three relevant PCA factors (collapsed over SOA).

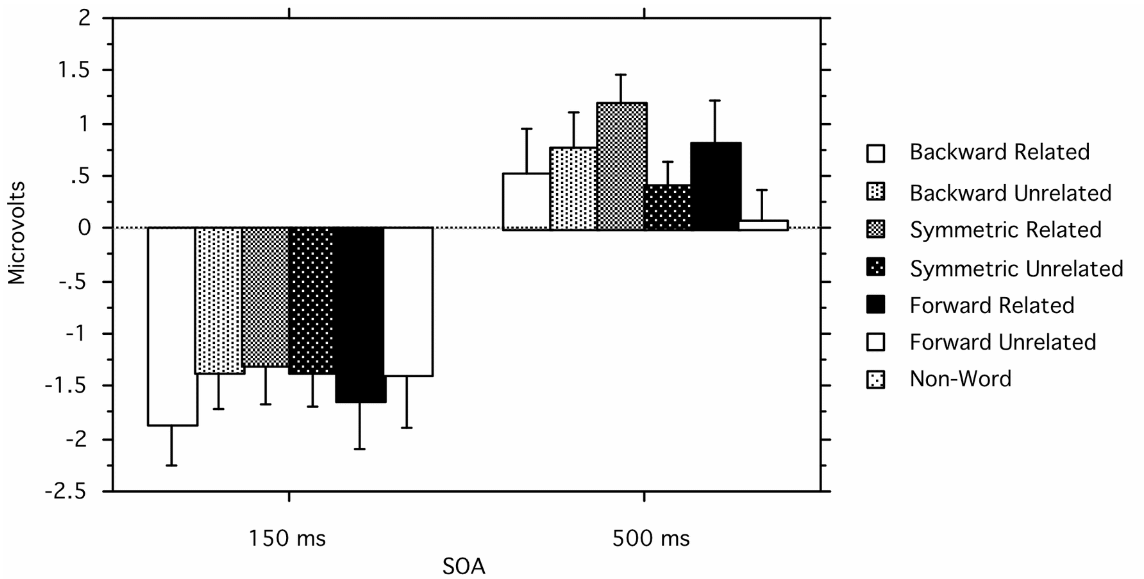

Figure 7. Bar chart for the windowed N300 measures. The equal unrelated condition is the average of the backward and forward unrelated conditions. The height of the bars represents the mean of the conditions. The error bar is the standard error.

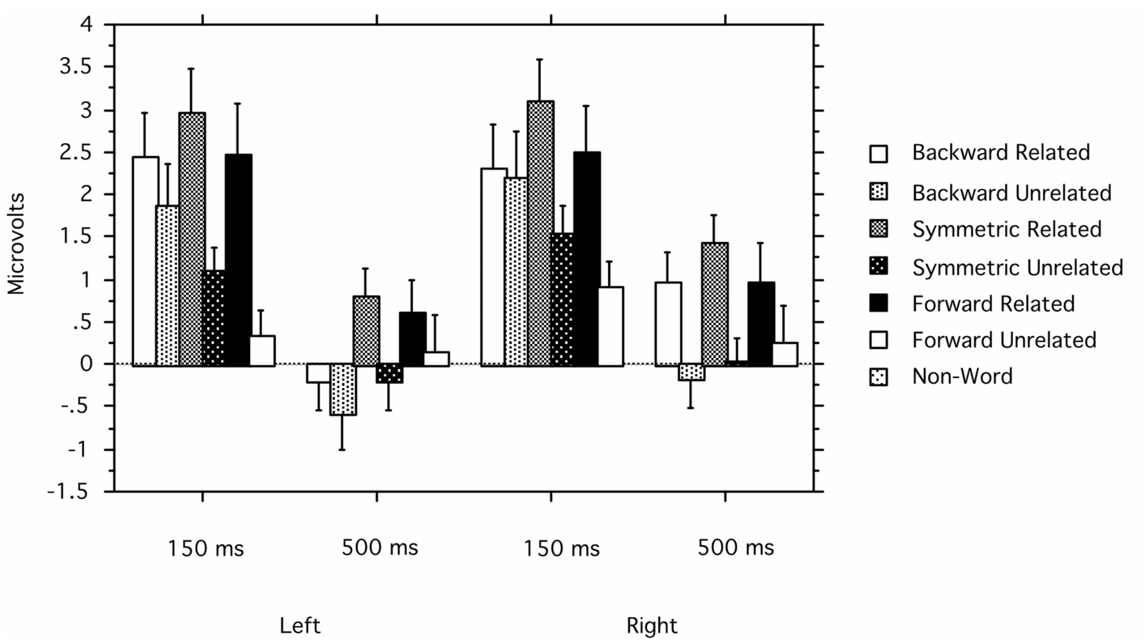

Figure 8. Bar chart for the windowed N400 measures. The equal unrelated condition is

the average of the backward and forward unrelated conditions. The height of the bars represents the mean of the conditions. The error bar is the standard error.

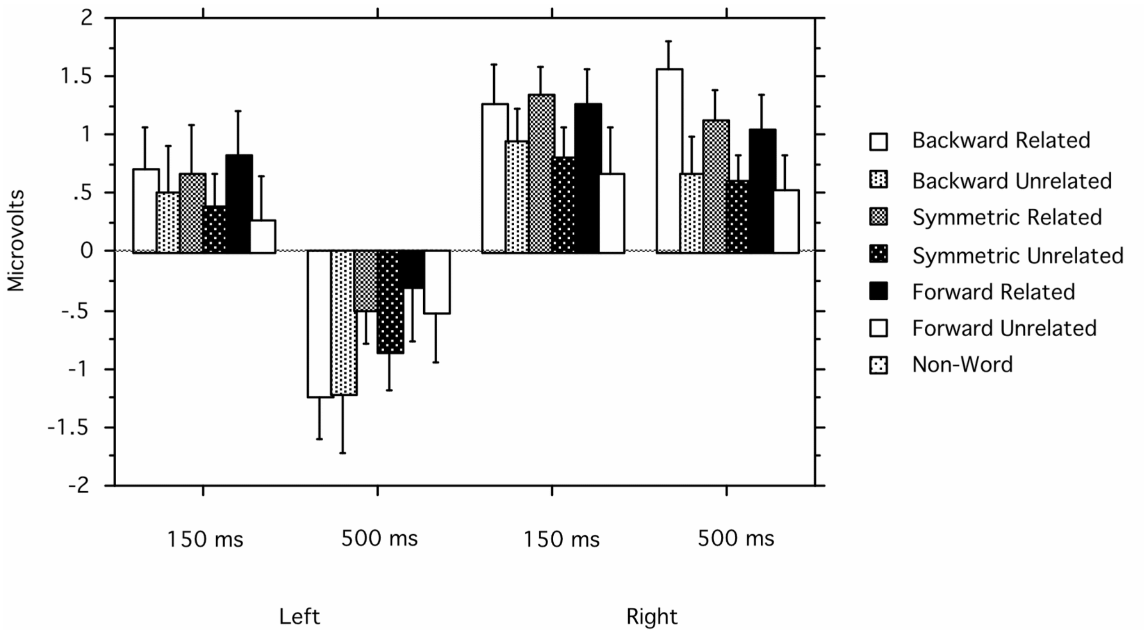

Figure 9. Bar chart for the windowed N400RP measures. The equal unrelated condition is the average of the backward and forward unrelated conditions. The height of the bars represents the mean of the conditions. The error bar is the standard error.

Table 1. Trimmed RTs and Accuracy (in parentheses) with Priming Effects and Corresponding ERP effect

		Prime-Target SOA (in ms)->	**150**	**500**
Forward Associated			390 (.93)	357 (.97)
Forward Unassociated			408 (.92)	375 (.94)
PRIMING			+18* (.01)	+18* (.03)
ERP Window			N400	N400
Backward Associated			397 (.90)	389 (.93)
Backward Unassociated			417 (.90)	404 (.90)
PRIMING			+20* (0)	+15* (.03)
ERP Window			None	N400RP
Symmetrically Associated			387 (.94)	356 (.95)
Unassociated[a]			413 (.91)	390 (.92)
PRIMING			+26* (.03*)	+34* (.03*)
ERP Window			N400	N300, N400
Non-Word			474 (.88)	449 (.90)

* p<.05 (two-tailed)

[a] These data represent the means of the forward and backward unassociated conditions.

Table 2. Trimmed means of the windowed N300 mean amplitudes.

	Backward Related	Backward Unrelated	Symmetric Related	Forward Related	Forward Unrelated
Short	-1.21	-0.82	-0.55	-1.11	-1.32
Long	0.70	0.77	1.33	0.99	0.24

Table 3. Trimmed means of the windowed N400 mean amplitudes.

	Backward Related	Backward Unrelated	Symmetric Related	Forward Related	Forward Unrelated
Short LH	2.19	1.76	2.86	2.26	0.38
Short RH	2.11	2.07	2.95	2.31	0.82
Long LH	-0.22	-0.48	0.92	0.80	0.26
Long RH	0.99	-0.22	1.42	0.88	0.36

Table 4. Trimmed means of the windowed N400RP mean amplitudes.

	Backward Related	Backward Unrelated	Symmetric Related	Forward Related	Forward Unrelated
Short LH	0.72	0.41	0.70	0.71	0.29
Short RH	1.28	1.01	1.29	1.35	0.56
Long LH	-1.20	-1.05	-0.45	-0.24	-0.47
Long RH	1.54	0.68	1.15	1.07	0.54