# Neurophysiological Correlates of Comprehending Emotional Meaning in Context

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## Abstract

■ Although the neurocognitive mechanisms of nonaffective language comprehension have been studied extensively, relatively less is known about how the emotional meaning of language is processed. In this study, electrophysiological responses to affectively positive, negative, and neutral words, presented within nonconstraining, neutral contexts, were evaluated under conditions of explicit evaluation of emotional content (Experiment 1) and passive reading (Experiment 2). In both experiments, a widely distributed Late Positivity was found to be larger to negative than to positive words (a ''negativity bias''). In addition, in Experiment 2, a small, posterior N400 effect to negative and positive (relative to neutral) words was detected, with no differences found between N400 magnitudes to negative and positive words. Taken together, these results suggest that comprehending the emotional meaning of words following a neutral context requires an initial semantic analysis that is relatively more engaged for emotional than for nonemotional words, whereas a later, more extended, attention-modulated process distinguishes the specific emotional valence (positive vs. negative) of words. Thus, emotional processing networks within the brain appear to exert a continuous influence, evident at several stages, on the construction of the emotional meaning of language. ■

## INTRODUCTION

During language comprehension, the final representation of meaning that is generated is dependent on multiple neurocognitive processes that come into play at different time points. The meaning of each incoming word is initially integrated with that of its preceding context and with respect to preexisting knowledge, and then, under some circumstances, additional cognitive processes are engaged to more fully evaluate the meaning constructed. However, the mechanisms underlying the construction of meaning of emotionally evocative language are poorly understood. The present study used event-related potentials (ERPs)—a direct index of on-line neural activity—to examine the neurocognitive processes underlying the comprehension of emotional language, both when participants paid explicit attention to emotional content and under more passive reading conditions. Our focus was on the modulation by emotion of two ERP components—the N400 and the Late Positivity. Below we review these two components in relation to both the comprehension of language and emotional information.

### Building Up Meaning during Language Comprehension

#### *The N400 and Semantic Memory*

It has been known since the early 1980s that there is a distinct neural measure that is sensitive to the semantic contextual relationship between an eliciting word and its preceding context: the N400 (Kutas & Hillyard, 1980, 1984). The N400 is a centro-posteriorly distributed, negative-going waveform that starts at approximately 300 msec and peaks at approximately 400 msec after the onset of a critical word. The amplitude of this waveform is larger (more negative) to critical words that are semantically unassociated (vs. associated) with preceding single words in semantic priming paradigms (Bentin, McCarthy, & Wood, 1985; Rugg, 1985) and that are incongruous (vs. congruous) with their preceding sentence contexts (Kutas & Hillyard, 1980, 1984) or global discourse contexts (Van Berkum, Hagoort, & Brown, 1999). In addition to being evoked by frank semantic anomalies (Kutas & Hillyard, 1980), the amplitude of the N400 is larger to plausible words that are unpredictable (vs. highly predictable) with respect to their preceding context (Kutas & Hillyard, 1984), to implausible words that are categorically unrelated (vs. categorically related) to a predicted word (Federmeier & Kutas, 1999; Kutas & Hillyard, 1984), and to words that are inconsistent (vs. consistent) with our knowledge of what is commonly encountered in the world (Hagoort, Hald, Bastiaansen, & Petersson, 2004; Kuperberg, Sitnikova, Caplan, & Holcomb, 2003). Taken together, this previous work suggests that the N400 reflects, at least in part, the process of directly mapping an evolving representation of meaning on to stored knowledge, whether this be stored associations about what we know to be true (Hagoort et al., 2004), what types of events we think are likely to occur (Kuperberg et al., 2003), or stored

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semantic associations (Van Petten, 1993) and categorical and featural relationships (Federmeier & Kutas, 1999) between individual words—a process that has been referred to, generally, as a semantic memory-based analysis (Kuperberg, 2007; Kutas, Van Petten, & Kluender, 2006; Kutas & Federmeier, 2000).

### *Late Positivities in Language Processing*

In addition to a semantic memory-based analysis, under certain conditions, additional cognitive processes may be engaged in a further effort to integrate and evaluate a word with respect to its preceding context. This additional analysis is often manifested by a centro-posteriorly distributed Late Positive component that onsets and peaks at a later time point than the N400 and that can extend until approximately 800 or 900 msec after stimulus onset. The Late Positivity is evoked by words that violate the syntactic or thematic structure of their preceding context (the P600) (Kuperberg, 2007; Hagoort, 1993; Osterhout & Holcomb, 1992), and is also seen in various other situations, such as during the comprehension of metaphor (Coulson & Van Petten, 2002) and jokes (Coulson & Kutas, 2001). In all of these cases, a continued analysis (or reanalysis) of the relationship between the eliciting stimulus and the context are required in order to recover a full and accurate representation of meaning.

The degree to which the Late Positivity reflects particular linguistic processes (Kuperberg, 2007; Osterhout & Hagoort, 1999) or more general processes (Kolk & Chwilla, 2007; Coulson, King, & Kutas, 1998) is debated. Late Positivities have often been viewed as part of the P300 family of ERP components that are modulated by the subjective probability of the eliciting stimuli (with more positive amplitudes with greater task relevance) and index the degree to which a working model of the environment requires updating (Donchin & Coles, 1988). Nonetheless, although the Late Positivity, like the P300, is modulated by task and, in some situations, by the probability of the eliciting stimulus, it can be present and modulated even during passive reading and listening, without additional task requirements, suggesting that the processes it reflects can be inherent to naturalistic on-line comprehension. In sum, although it is not clear whether the linguistic and nonlinguistic Late Positivities index the same or overlapping cognitive processes, what is not controversial is that the Late Positivity reflects additional cognitive processing that continues after the N400 time window and that such processes are distinct from the semantic memory-based analysis reflected by the N400.

## Building Up and Evaluating Emotional Meaning

### *Semantic Memory and Emotion*

How representations of emotional meaning are stored within semantic memory remains poorly understood (Niedenthal, 2007). Studies examining patterns of evaluative ratings of words have found evidence for a structure of emotion knowledge that includes dimensions of valence, arousal, and potency or dominance (Kissler, Assadollahi, & Herbert, 2006; Osgood, Suci, & Tannenbaum, 1957). Because valence and arousal appear to account for much of the variance in these ratings, a two-dimensional model of affective meaning has been largely adopted (Feldman, 1995; Russell, 1980; Lang, 1979). These dimensions of word meaning also apply to nonlinguistic representations, such as pictures and sounds (Bradley, Codispoti, Cuthbert, & Lang, 2001; Bradley & Lang, 2000), suggesting that they may be represented amodally within semantic memory. An additional source of evidence that emotion concepts are stored and structured within semantic memory comes from affective semantic priming studies in which the processing of target words with emotional meaning is facilitated by the presence of prime words of similar affective valence, and slowed by the presentation of words with a dissimilar valence (Bargh, Chaiken, Raymond, & Hymes, 1996; Fazio, Sanbonmatsu, Powell, & Kardes, 1986), although the precise mechanisms by which this occurs are debated (Spruyt, Hermans, De Houwer, Vandromme, & Eelen, 2007; Klinger, Burton, & Pitts, 2000).

Other studies have suggested that emotional information is represented in the brain in a distributed, ‘‘embodied’’ manner—the meaning of emotional information is retrieved via a simulation of the emotionally evocative stimulus or overall experience (Niedenthal, 2007; Glenberg, Havas, Becker, & Rinck, 2005). Evidence in support of this model comes from studies showing that mood and bodily states can ‘‘prime’’ the comprehension (Glenberg et al., 2005) and classification (Niedenthal, Halberstadt, & Innes-Ker, 1999) of representations that are emotionally congruent with the body or mood state. For example, in one study, reading times of emotionally laden sentences were faster when participants were induced to have mood-congruent (vs. mood-incongruent) facial expressions without their awareness (Havas, Glenberg, & Rinck, 2007), suggesting that such emotion knowledge can rapidly influence on-line language comprehension.

Despite this evidence for a structured organization of emotion knowledge that can interact with language comprehension, and the known sensitivity of the N400 to semantic memory-based processes, there have been relatively few studies examining the relationship between emotional meaning and the N400 ERP component. A number of studies have observed an N400 effect in response to words that are emotionally incongruous (vs. congruous) with the emotional prosody of a preceding, spoken sentence (Schirmer, Kotz, & Friederici, 2002, 2005) or with the prosody of how the word itself was spoken (Schirmer & Kotz, 2003). In another study, subjects, having undergone a mood induction procedure, read short, highly constraining, emotionally evocative stories that ended with a word that was either positive or negative in valence, or highly incongruous with the preceding story (Chung et al., 1996). Participants in a negative mood state produced a more negative N400 to positive than to negative words, whereas the opposite pattern was observed in subjects in a positive mood. In addition, an overall facilitatory effect of positive mood state on general semantic retrieval has been found (Federmeier, Kirson, Moreno, & Kutas, 2001), providing further evidence for an influence of mood state on semantic processing within the N400 time window. However, prior studies have not attempted to isolate emotional processing by comparing the modulation of the N400 by emotional and affectively neutral (but otherwise semantically congruous) words within a neutral context; thus, it is unclear whether previous findings of N400 effects to emotional words reflect unique aspects of affective semantic processing, or represent additional instances of N400 effects to more general semantic incongruity.

### *The Late Positivity and Emotional Processing*

A Late Positivity is evoked in response to a variety of emotional (relative to nonemotional) stimuli including emotionally evocative pictures (Schupp et al., 2000; Palomba, Angrilli, & Mini, 1997; Johnson, Miller, & Burleson, 1986), photographs of human faces with emotional expressions (Schupp, Ohman, et al., 2004; Krolak-Salmon, Fischer, Vighetto, & Mauguiere, 2001; Vanderploeg, Brown, & Marsh, 1987), and words with affective meanings (Kanske & Kotz, 2007; Herbert, Kissler, Junghofer, Peyk, & Rockstroh, 2006; Kiehl, Hare, McDonald, & Brink, 1999; Naumann, Maier, Diedrich, Becker, & Bartussek, 1997; Naumann, Bartussek, Diedrich, & Laufer, 1992). Because the emotional Late Positivity is modulated by the degree of emotional similarity between the eliciting stimuli and its surrounding stimuli (Cacioppo, Crites, Gardner, & Bernston, 1994), as well as by the task relevance of the stimuli (Schupp, Stockburger, Bublatzky, et al., 2007; Naumann et al., 1997; Carretie, Iglesias, Garcia, & Ballesteros, 1996), it has often been considered part of the P300 family. Consistent with this notion is its modulation by the amount of attention allocated to the emotional content of the stimuli, which is, in turn, influenced by how arousing (and intrinsically attention-grabbing) the stimuli are (Schupp, Stockburger, Codispoti, et al., 2007; Schupp, Junghofer, Weike, & Hamm, 2004). However, there is some evidence that the emotional Late Positivity represents a more specific index of emotional processing. Several studies have reported that the Late Positivity to negatively valenced stimuli is larger than to positively valenced stimuli (Kanske & Kotz, 2007; Bernat, Bunce, & Shevrin, 2001; Kiehl et al., 1999; Ito, Larsen, Smith, & Cacioppo, 1998), even in situations in which attention to affective meanings is limited or absent (Bernat et al., 2001), or when the arousing quality of the positive and negative stimuli are equated (Ito et al., 1998).

This sensitivity of the Late Positivity to affective valence (negative vs. positive) has been demonstrated in experiments measuring responses to emotional words (Kanske & Kotz, 2007; Bernat et al., 2001; Kiehl et al., 1999), faces (Schupp, Ohman, et al., 2004), and pictures (Ito et al., 1998). It supports a more general hypothesis about affective processing that emerged initially from findings in social psychology: that negatively valenced information gives rise to more complex representations and requires more cognitive processing than positively valenced information, leading to a ''negativity bias'' (Dahl, 2001; Ito et al., 1998; Pratto & John, 1991). This negativity bias has been defined as the increased output from the negative motivational system, relative to the positive one, given a comparable amount of motivational input (Ito et al., 1998). It has been observed in numerous behavioral studies reporting longer response latencies to negative than to positive words (Dahl, 2001; Kiehl et al., 1999; Pratto & John, 1991; Strauss, 1983; Graves, Landis, & Goodglass, 1981). Some of these studies found that this bias is only present when subjects are explicitly attending to the emotional meaning of the words (Dahl, 2001; White, 1996), whereas others have found this effect even when subjects are performing nonaffective operations such as lexical decisions or Stroop interference tasks (Wurm & Vakoch, 1996; Pratto & John, 1991; Strauss, 1983).

As is the case with the Late Positivity evoked by affectively neutral language stimuli, it is unclear exactly what cognitive process(es) are reflected by the emotional Late Positivity. It has usually been interpreted as an allocation of attentional resources to the emotional stimulus and, consistent with its conceptualization as part of the P300 family, as reflecting a re-evaluation of the eliciting stimulus with respect to its surrounding context. Such a re-evaluation may be particularly important in processing emotional stimuli, given the importance of emotional responses for signaling changes in strategy during the pursuit of rewards and avoidance of harm (Williams, Mathews, & MacLeod, 1996; Mathews & MacLeod, 1994). It has been proposed that, in general, negatively valenced stimuli are prioritized over positively valenced stimuli because, in a short time frame, it is more important to avoid harmful events, such as injury or death, than to pursue pleasurable ones (Taylor, 1991).

## The Present Study

In the present study, we used ERPs to elucidate the neurocognitive mechanisms mediating the processing of emotional information during the comprehension of short, two-sentence scenarios. Participants read pairs of sentences in which negative, positive, and neutral words were preceded by a neutral, ambiguous, and nonconstraining context, for example, ''Sandra's old boyfriend stopped by her apartment today. This time he brought a *rose/gun/letter* (positive, negative, neutral word, respectively) with him.'' All of the sentences were plausible, and the critical word was not predictable in any of the three conditions. Two experiments were conducted: one in which participants made explicit valence categorization judgments (Experiment 1) and one in which ERPs were measured as participants processed affective information incidentally, passively reading the sentence pairs with occasional checks for comprehension (Experiment 2). In both experiments, ERPs were time-locked to the emotional or neutral words (e.g., rose/gun/letter—the critical word) within the second sentence.

Based on the evidence suggesting that emotion-related knowledge has a specific organization within the brain, such that emotionally laden information is segregated from (or prioritized with respect to) nonemotional information (Innes-Ker & Niedenthal, 2002; Bower, 1981), we predicted that encountering an affectively valent word (vs. a neutral word), following a neutral (and therefore affectively inconsistent) context, would lead to increased difficulty of semantic processing and an increased N400, even if the overall meaning was plausible.

Based on previous evidence (as described above) for Late Positivities elicited during the processing of neutral language and emotional stimuli across several modalities, we also predicted that, in addition to an N400 effect, the motivational significance of emotional words, within a nonconstraining neutral context, would lead to additional prolonged processing, reflected by a Late Positivity effect (larger Late Positivity amplitudes for negative and positive words relative to neutral words).

We also aimed to determine whether the amplitude of the Late Positivity would be modulated by the type of affective valence of the critical word. Based on previous electrophysiological evidence (Kanske & Kotz, 2007; Bernat et al., 2001; Kiehl et al., 1999), we hypothesized that we would find a more positive Late Positivity to negatively valenced than to positively valenced words in context.

## EXPERIMENT 1

### Methods

*Participants*

Eighteen Tufts psychology undergraduate students participated (9 men; mean age = 22.4 ± 3.5 years). Individuals with histories of psychiatric or neurological disorders, who had learned languages other than English before age 5, or who were left-handed were excluded. Each participant provided written informed consent in accordance with the procedures of the Institutional Review Board of Tufts University. Prior to the ERP experiment, demographic information was collected about each participant and levels of trait anxiety were measured using the Spielberger State and Trait Anxiety Assessment Inventory (STAI) (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983).

*Stimuli*

Two-sentence descriptions of scenarios which described a situation involving one person or more (see Table 1 for examples) were generated for each of three experimental conditions. For each sentence pair, the first sentence

**Table 1.** Example Sentence Pairs

| *First Sentence* | *Second Sentence (Without the Critical Word)* | *Neutral Critical Word* | *Positive Critical Word* | *Negative Critical Word* |
|---|---|---|---|---|
| Nancy's son ended up just like his father. | He was already a ____ by age 25. | husband | millionaire | criminal |
| Stephen owned a lot of nineteenth century art. | Everyone knew that he ___ paintings of old masters. | bought | loved | forged |
| An unfamiliar man rang Lenora's doorbell one day. | He had come to _____ her. | register | congratulate | arrest |
| Every day, the local newspaper wrote about the mayor. | They always said ____ things about him. | factual | marvelous | damaging |
| Mr. Jenners planned to move his family to New York. | The reason for this was _____ to the children. | obvious | reassuring | hidden |
| Cheryl's baby cried when she took him to bed. | She quieted him with a ____ that night. | pacifier | lullaby | drug |

(8–11 words long) was affectively neutral and ambiguous in content, providing a nonconstraining context for the second sentence. There was a neutral, positively valenced, or negatively valenced word (the critical word) in the second sentence. The second sentence was six to nine words long, and the critical word was either the fourth, fifth, or sixth word in the sentence and was never the sentence-final word.

### *Pretests of Stimuli*

Pretests were conducted in participants who did not participate in the ERP experiments in order to obtain more objective measures of whether the sentence pairs were positive, negative, or neutral in valence (24 raters), and to collect cloze probabilities (24 raters) and plausibility ratings (15 raters), as well as concreteness, valence, and arousal measurements of the critical words (10–12 raters for each). Concreteness, valence, arousal, and plausibility ratings were made using 7-point Likert scales (7 = most concrete, most pleasant, most arousing, and most likely). For cloze probability ratings, raters were presented with each scenario without the critical word and the words that followed it and were asked to produce the most likely next word. The cloze probability for each critical word reflected the proportion of times that the word was used to complete the sentence. For plausibility ratings, raters were presented with each sentence pair, ending with the critical word, and were asked to rate how likely it was that this situation would happen in real life.

Using the sentence-pair average valence ratings, scenarios for which all three conditions met criteria for affective valence (positive condition: valence >5; negative condition: valence <3; neutral condition: valence ≥3 and ≤5) were selected. Within this subset, additional scenarios were eliminated so that the three conditions were matched with respect to the concreteness, number of letters, and Kucera–Francis frequency of the critical word (see Table 2). This left a final stimulus set of 405 sentence pairs. As expected, the three conditions differed significantly with respect to the mean affective valence of the sentence pairs and critical words (positive > neutral > negative) (see Table 2). They also differed with respect to subjective arousal level (negative > positive > neutral) of the critical words, consistent with relative arousal levels of negative and positive stimuli found in nature (Lewis, Critchley, Rotshtein, & Dolan, 2007) and the increased slope of activation of the negative (relative to the positive) motivational system (Ito et al., 1998). Overall, the critical words were unpredictable (with an overall average cloze probability of 2%), but all the sentences were rated as plausible (with an overall average plausibility rating of 5.4). However, the three conditions differed slightly with respect to mean cloze probability [positive (3.5) > negative (1.4) and neutral (1.1)] and mean plausibility [negative (4.7) < positive (5.8) and neutral (5.6)]. These differences among the conditions in arousal, cloze probability, and plausibility likely reflect inherent, naturalistic aspects of emotional processing (see Discussion of Experiment 2), but to investigate their role, we conducted additional analyses, in addition to the main analyses, in which these different factors were matched across conditions by excluding a subset of the stimuli.$^1$

For the ERP experiments, the final stimuli set was divided into three lists, using a Latin square design, which were counterbalanced between participants such that no participant encountered the same sentence pair more than once and such that, across subjects, all two-sentence scenarios were seen in all three conditions. Each of the three lists included 135 sentence pairs, with 45 sentence pairs for each condition.

### *Stimulus Presentation*

Participants sat in a comfortable chair in a dimly lit room. Stimuli were presented to participants on a computer monitor, in white font, centered on a black background, and subtended at a visual angle of about 5°. Participants

**Table 2.** Results of Pretest Ratings for the Sentence Pairs and Their Critical Words

| | *Positive Mean (SD)* | *Negative Mean (SD)* | *Neutral Mean (SD)* |
|---|---|---|---|
| Affect of the sentence pair* | 5.73 (0.4) | 2.11 (0.5) | 4.21 (0.5) |
| Affect of the critical word* | 5.43 (0.8) | 2.19 (0.7) | 4.30 (0.7) |
| Arousal of the critical word* | 4.26 (1.1) | 4.64 (0.9) | 3.37 (0.9) |
| Concreteness of the critical word | 3.76 (1.3) | 3.85 (1.1) | 4.03 (1.1) |
| Cloze probability percentage* | 3.52 (7.93) | 1.42 (5.12) | 1.14 (4.21) |
| Plausibility* | 5.82 (1.56) | 4.72 (1.55) | 5.63 (1.12) |
| Number of letters in the critical word | 7.30 (2.4) | 6.76 (2.3) | 7.27 (2.2) |
| K–F Frequency of the critical word | 46.55 (101.4) | 38.42 (99.6) | 54.44 (57.4) |

Differences among means were not significant (all *p*s > .1) except for those marked with an * (*p*s < .05, see text).

were randomly assigned to one of the six lists. All trials began with a white fixation cross (500 msec, interstimulus interval [ISI] = 100 msec). Then the first sentence was presented as a whole (3.5 sec, ISI = 100 msec). The second sentence was presented one word at a time (500 msec, ISI = 100 msec). A 750-msec blank-screen interval followed the final word of the second sentence, followed by the next trial. The subjects' task was to press one of three buttons with their right thumb (button order was counterbalanced across subjects), depending on their judgment of whether the sentence pair depicted a pleasant, unpleasant, or neutral person, place, or situation.

### *Data Analysis*

*Behavioral data analysis.* The percentage of participants' responses, which were consistent with the prior classifications of the three conditions (obtained during the pretests of the stimuli, see above), was compared across conditions and between the two groups using ANOVAs, and significant main effects and Condition by Group interactions were followed up by planned, paired Student's $t$ tests ($\alpha = .05$).

*ERP data analyses.* All analyses were conducted on the mean amplitudes of ERPs evoked by critical words (using a 100-msec prestimulus baseline), within selected time windows (see Results).

Repeated measures ANOVAs were performed on the midline, medial, lateral, and peripheral electrode columns (see Figure 1) as previously described (Kuperberg, Kreher, Sitnikova, Caplan, & Holcomb, 2007; Kreher, Holcomb, & Kuperberg, 2006; Kuperberg et al., 2003). In all analyses, AP distribution (electrode position along the anterior–posterior plane) and affect (positive, negative, and neutral) were entered as within-subjects factors. For the medial, lateral, and peripheral column analyses, hemisphere (left, right) was an additional within-subjects factor. Overall ANOVAs were followed up with simple effects ANOVAs comparing each sentence type with one another, and follow-up $t$ tests at individual electrode sites. A Greenhouse–Geisser correction was applied to all analyses with more than one degree of freedom in the numerator (Greenhouse & Geisser, 1959). In these cases, we report the original degrees of freedom with the corrected $p$ value.

## Results

The percentage of sentence pairs in which the participants' valence classifications corresponded to those of the pretest conducted in a separate sample (see Methods), for the positive, negative, and neutral sentence pairs was 90.7%, 94.9%, and 77.9% (*SD*s: 5.5, 3.8, 13.39), respectively. A repeated measures ANOVA revealed a highly significant effect of Affect for the rate of correspondence between the participants' classifications and those of the prior pretests [$F(2, 34) = 20.53, p < 1 \times 10^{-6}$]. Participants' classifications of the negative sentence pairs were significantly more likely to correspond to those of the pretests than their classifications of the neutral [$t(17) = 4.96, p = .0001$] and positive [$t(17) = 3.09, p = .006$] sentence pairs, and participants' classifications of the positive sentence pairs were significantly more likely to correspond to those of the pretests than their classifications of the neutral sentence pairs [$t(17) = 4.18, p = .0006$].

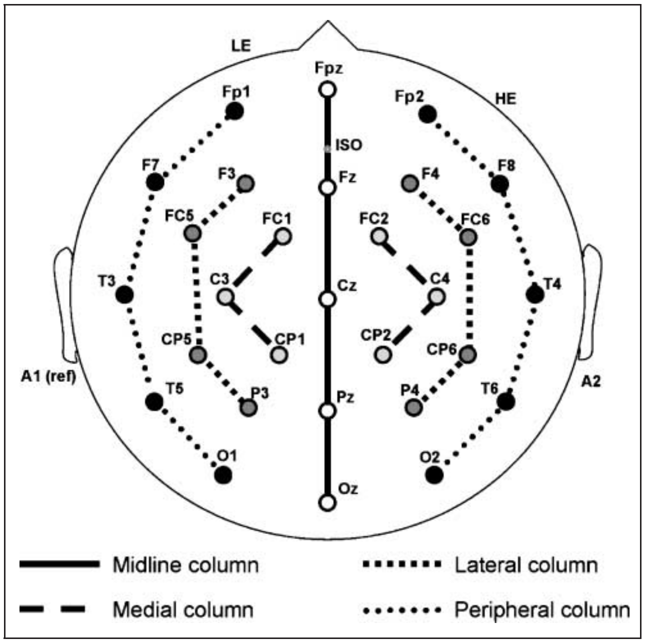

**Figure 1.** Electrode montage with columns used in the analyses.

Grand-average ERPs elicited by the critical words in the three types of sentence pairs and maps of voltage differences between the conditions are shown in Figure 2. An N1–P2 complex can be seen in the first 300 msec after word onset. There was little evidence for modulation of this complex across the three conditions, as reflected by the absence of a main effect of Affect or Affect by AP distribution interaction in the first 300 msec (with analyses carried out at separate 0–100 msec, 100–200 msec, and 200–300 msec time windows). However, there was an Affect by Hemisphere interaction for the 0–100 msec time window for the negative versus positive contrast in the peripheral column only, which was due to a greater positivity in response to the negative words than the positive words at T5 [$t(17) = 2.187, p = .043$; $p$s $> .12$ for other electrodes in the peripheral columns].

These early components were followed by a negativity and then a large Late Positivity, which began at ~375 msec, peaking between 500 and 700 msec.[2] Because of the dominance of the Late Positivity and its onset within the N400 time window, an N400 effect could not be evaluated statistically (see Figure 2A). For the Late Positivity, overall

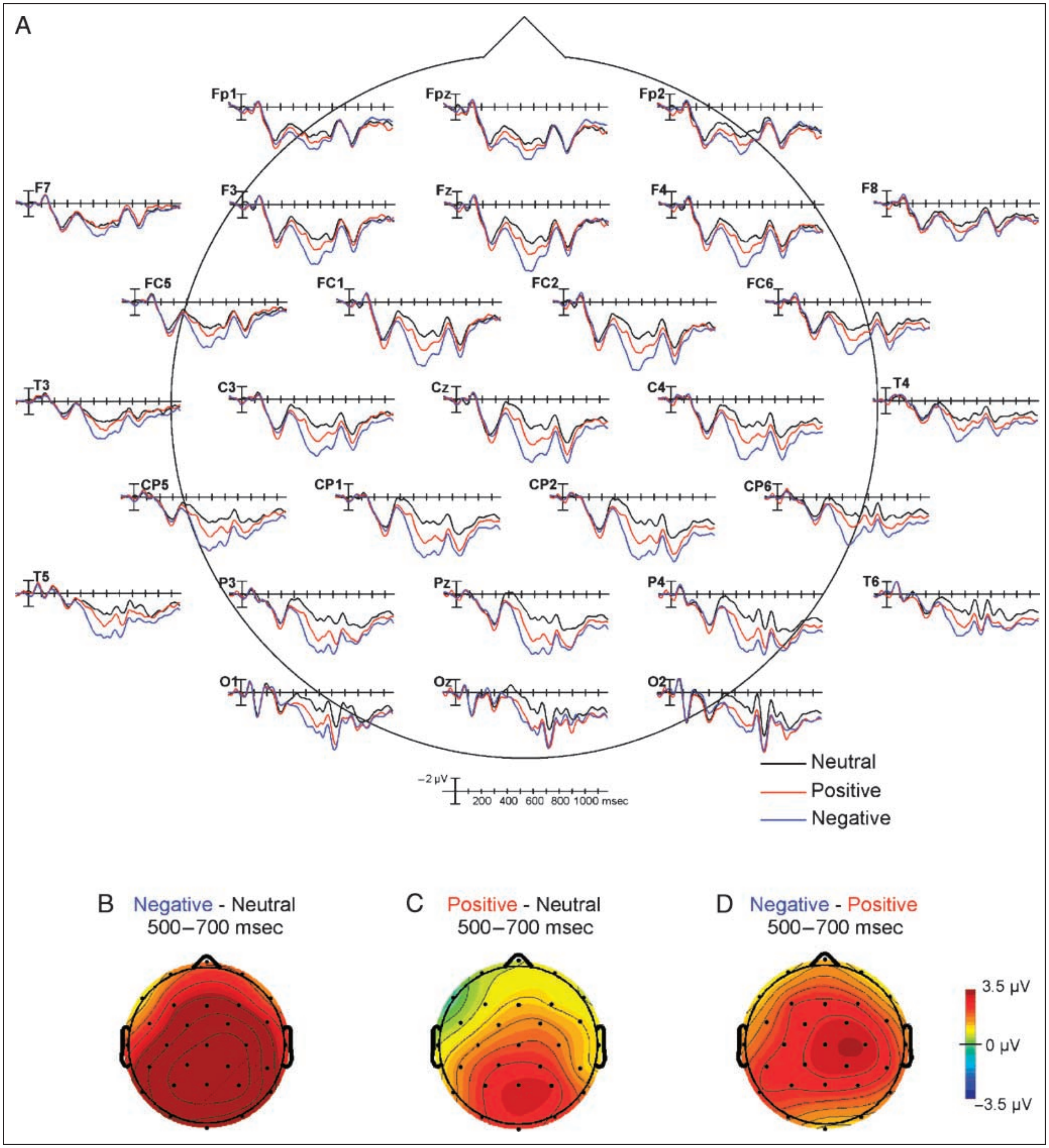

**Figure 2.** Grand-averaged waveforms (A) and voltage maps showing the average voltage differences, in the Late Positivity (500–700 msec) time window, between responses to negative and neutral (B), positive and neutral (C), and negative and positive (D) critical words in Experiment 1.

ANOVAs revealed significant main effects of Affect, and Affect by AP distribution interactions at all electrode columns (see Table 3). Planned, pairwise simple effects ANOVAs also revealed significant main effects of Affect and Affect by AP distribution interactions, reflecting significantly larger Late Positivities to the negative relative to the positive critical words that were, in turn, significantly larger than to the neutral critical words, particularly at posterior sites. An Affect by Hemisphere interaction for the negative vs. neutral comparison was found in the medial column [$F(1,34) = 3.303$, $p = .028$], which reflected a relatively larger Late Positivity to the negative (versus neutral) critical words in the right than in the left hemisphere. There were no other Affect by Hemisphere interactions, or any Affect by Hemisphere by AP distribution interactions.

**Table 3.** Main Effects of Affect and Affect by AP Distribution Interactions for the Late Positivity (500–700 msec) Time Window in Experiment 1

| | *Main Effect of Affect* | | *Interactions between Affect and AP Distribution* | |
|---|---|---|---|---|
| | *F (Degrees of Freedom)* | *p* | *F (Degrees of Freedom)* | *p* |
| *A. Overall Effects* | | | | |
| Midline | 17.093 (2, 34) | $1.29 \times 10^{-5}$ | 8.386 (8, 136) | $4.00 \times 10^{-5}$ |
| Medial | 18.382 (2, 34) | $6.78 \times 10^{-6}$ | 5.868 (4, 68) | .004 |
| Lateral | 16.228 (2, 34) | $2.47 \times 10^{-5}$ | 9.337 (6, 102) | $2.23 \times 10^{-5}$ |
| Peripheral | 13.868 (2, 34) | $6.88 \times 10^{-5}$ | 8.685 (8, 136) | $4.16 \times 10^{-4}$ |
| *B. Negative versus Neutral* | | | | |
| Midline | 31.537 (1, 17) | $3.09 \times 10^{-5}$ | 14.368 (4, 68) | $7.23 \times 10^{-6}$ |
| Medial | 31.631 (1, 17) | $3.04 \times 10^{-5}$ | 9.963 (2, 34) | .003 |
| Lateral | 25.073 (1, 17) | $1.08 \times 10^{-4}$ | 15.298 (3, 51) | $1.05 \times 10^{-5}$ |
| Peripheral | 22.205 (1, 17) | $2.01 \times 10^{-4}$ | 17.314 (4, 68) | $4.02 \times 10^{-5}$ |
| *C. Positive versus Neutral* | | | | |
| Midline | 6.669 (1, 17) | .019 | 6.441 (4, 68) | .003 |
| Medial | 5.535 (1, 17) | .031 | 10.211 (2, 34) | $5.45 \times 10^{-4}$ |
| Lateral | 4.865 (1, 17) | .041 | 12.386 (3, 51) | $3.96 \times 10^{-5}$ |
| Peripheral | 5.191 (1, 17) | .036 | 12.402 (4, 68) | $6.87 \times 10^{-4}$ |
| *D. Negative versus Positive* | | | | |
| Midline | 12.479 (1, 17) | .003 | 4.899 (4, 68) | .022 |
| Medial | 16.871 (1, 17) | $7.34 \times 10^{-4}$ | 0.096 (2, 34) | .812 |
| Lateral | 16.347 (1, 17) | $8.44 \times 10^{-4}$ | 0.894 (3, 51) | .397 |
| Peripheral | 11.718 (1, 17) | .003 | 1.589 (4, 68) | .225 |

Significant ($p < .05$) effects are highlighted with gray shading.

The statistical results for the analyses of the three datasets that were matched for arousal, cloze probability, and plausibility were the same as those of the original analyses, with the exception that for the plausibility-matched analysis, the neutral versus positive contrast showed Affect by AP distribution interactions at all columns but no main effects of Affect. Grand-average ERPs and voltage maps for these arousal, cloze, and plausibility-matched analyses are shown in Figures S1, S2, and S3 in Supplementary Materials (see www.nmr.mgh.harvard.edu/kuperberglab/materials.htm).

## Discussion

In this first experiment, specific modulation of the N400 by emotion could not be measured due to the presence of a large overlapping positivity which began at about 375 msec. This Late Positivity was found to be largest to the negative words, smaller to the positive words, and smallest to the neutral words. Both the valence categorization task and the emotional content of the words likely contributed to this pattern of modulation, as each alone can elicit positivities. Although it is not possible to determine definitively whether the categorization task and emotional content influenced the same or distinct neural mechanism(s), studies examining the effects of varying attention on neurophysiological responses to emotional faces have found evidence for interactions between attention and emotion within the Late Positivity window (Vuilleumier & Pourtois, 2007), suggesting that attention and emotional content engage the same or overlapping neural circuitry.

The fact that the relative magnitudes of the Late Positivities to the three conditions patterned with the differences among the conditions in mean arousal levels in the original dataset suggests a role for arousal in the emotional Late Positivity: The intrinsic motivational significance of affective material may be reflected in its capacity to elicit physiologic arousal, and explicit, top–down attention to emotional meaning may have further increased arousal levels. This explanation would also be consistent with a simulation-based comprehension mechanism (Glenberg et al., 2005); a bodily state of arousal may reflect a rapid activation of limbic networks and the peripheral autonomic nervous system that occurs when the emotionally salient event or object depicted by the word or text is re-experienced. However, previous studies have been contradictory with respect to this issue, with some support for an arousal modulation of the Late Positivity that is independent of valence (Schupp, Junghofer, et al., 2004) and also for the reverse relationship (Kanske & Kotz, 2007; Ito et al., 1998). In the present study, differences in arousal between the positive and negative stimuli cannot fully explain the differences in modulation of the Late Positivity to these stimuli, as this affect-mediated difference in modulation of the Late Positivity was not altered when these two conditions were equated for arousal. Future studies which measure physiologic arousal directly, using skin conductance or pupillary responses, may help to clarify this issue further.

Our finding of a larger Late Positivity to negative than to positive words, even within the arousal, plausibility, and cloze-matched datasets, suggests that additional processing resources are recruited to re-evaluate and integrate the meaning of negative words within a neutral context, relative to those required for positive words. This finding of a ''negativity bias'' during the rapid online evaluation of emotional information is consistent with the results of previous work using nonlinguistic stimuli (Schupp, Ohman, et al., 2004; Ito et al., 1998) and single words (Bernat et al., 2001; Kiehl et al., 1999). In the current study, the negativity bias may have been additionally influenced by the preceding neutral context. The magnitude of the Late Positivity elicited by emotional stimuli has been found to correlate with its ''affective distance'' from contextual stimuli, that is, the difference between the affect ratings of the target and context (Cacioppo et al., 1994). Thus, a difference in affect or arousal between the neutral context and critical word that is greater for the negative relative to the positive critical words could produce a differential neural response, reflected in the Late Positivity. Alternatively, because the slope of the valence versus arousal function of the negative motivational system is steeper than that of the positive motivational system (Ito et al., 1998), this bias may be present even when the affective distance from the context is equated for negative and positive stimuli. In the current study, the affective content and arousal level of the context were not manipulated; the relative contributions to the emotional Late Positivity of the affective distance between context and target and the intrinsic emotional meaning of the stimuli can be explored further in follow-up experiments which systematically vary these two components.

Also, in the current study, we focused on the neurophysiological effects of general affect categories (negative and positive) rather than on the effects of specific emotion categories within a general affect category (i.e., within the negative affect category: angry, sad, fearful, etc.). The perception of specific emotion may be particularly influenced by contextual information (Barrett, Lindquist, & Gendron, 2007); thus, it will be important in future work to determine whether there is further modulation of the emotional Late Positivity by specific emotion categories.

In order to dissociate the role of explicit attention to affective meaning from the effects of affective meaning itself on ERPs during the comprehension of emotional words, we conducted a second experiment in which a separate set of participants passively read these same sentence pairs for comprehension. Based on the results of numerous previous studies, we predicted that the absence of an evaluative task would lead to smaller magnitudes of Late Positivities to emotional (vs. neutral) words. However, given behavioral (Wurm & Vakoch, 1996; Pratto & John, 1991; Strauss, 1983) and ERP (Bernat et al., 2001) evidence for the persistence of the negativity bias even when participants are not explicitly attending to affective content, we predicted that this bias would be preserved under passive reading conditions. Finally, we also predicted that, because the intrinsic salience of emotional words increases the demands of semantically integrating their meanings, we would detect, during passive comprehension, an N400 effect to emotional (vs. neutral) words.

## EXPERIMENT 2

### Methods

#### *Participants*

Eighteen Tufts psychology undergraduate students participated (9 men; mean age ± *SD* = 21.1 ± 3.2 years). None had participated in the first experiment. Inclusion and exclusion criteria, as well as the characterization procedure, were identical to those of the first experiment.

#### *Stimuli and Procedure*

The sentence pairs were the same as those in Experiment 1, except that probe trials were now included (see below). The experimental procedure was identical to that of Experiment 1, except for the task.

*Construction of probes.* After a variable number of trials, participants viewed a ''probe'' in order to ensure that they attended to the sentences and read them for comprehension. In each of the three original lists, 24 probe phrases, that each was either congruous (12) or incongruous (12) with a theme or concept described in the preceding sentence pair, were inserted. For example: After many years Barbara finally telephoned her father. She wanted to forgive him now. Probe phrase: "talking to family" (congruous) or "interested in politics" (incongruous).

The probes were then counterbalanced across the three original lists such that, across all subjects, a probe that was incongruous in one list was used as a congruous probe for the same condition in a different list, as well as the reverse, giving rise to six lists. These probes were rated for congruency in 10 raters who did not participate in the ERP experiment; these raters were 98% accurate in identifying the congruous and incongruous probes.

After a variable number of trials (on average, after every 6 trials), participants viewed the probe phrase in yellow. Participants were told to read all of the sentences and, when they saw a probe phrase, to decide whether this phrase was congruous or incongruous in meaning with the preceding sentence pair. The probe phrase remained on the screen until the subject made a response with their right or left thumb (counterbalanced across participants) at which point the next trial started.

### *Data Acquisition and Analysis*

Data acquisition and analysis were identical to that in Experiment 1.

Also, Spearman's correlations were used to conduct exploratory analyses in order to determine whether participants' level of trait anxiety impacted modulation of the N400 by emotion at Pz (the electrode which has shown the largest N400 effects in previous studies). Alpha was set at .05.

## Results

The mean accuracy rate (averaged over the 18 subjects) in correctly identifying the congruous and incongruous probes was 89% ($SD = 23$). No participant showed less than 70% accuracy.

Grand-average ERPs elicited by the critical words in the three types of sentence pairs and maps of voltage differences between conditions are shown in Figure 3. An N1–P2 complex can be seen in the first 300 msec after word onset. In both the 0–100 msec time window and the 100–200 msec time window, there were no differences between the three conditions. In the 200–300 msec time window, the P2 appeared to be slightly smaller to the positive relative to both the neutral and the negative critical words at lateral sites, reflected by interactions between Affect and AP distribution [positive vs. neutral: $F(6, 102) = 4.426$, $p = .035$], and Affect, AP distribution, and Hemisphere [positive vs. negative: $F(6, 102) = 4.281$, $p = .023$]. However, follow-up at individual electrode sites failed to reveal any significant effects (all $p$s $> .13$).

The N1–P2 was followed by a distinct negativity—the N400. This was immediately followed by a Late Positivity at many of the same posterior electrode sites where the N400 appeared largest. To characterize the modulation of the N400 across the three conditions, and yet minimize overlap from this later positivity, we selected a relatively early time window for statistical analysis of the N400: 325–425 msec. This encompassed the peak of the N400 as seen on the grand-average waveforms.[3]

Overall ANOVAs showed no main effects of Affect, but there were significant Affect by AP distribution interactions at the midline, medial, and lateral electrode columns (see Table 4). Planned pairwise ANOVAs were carried out to follow up these effects. These again revealed significant Affect by AP distribution interactions: The negative words evoked a larger negativity than the neutral words at the midline and lateral columns, particularly at central and posterior sites[4] (CP5, $p = .03$; T5, $p = .03$; trends at CP1, P3, Pz, P4, O1, Oz, O2, T6, $p$s $< .12$). The positive words also evoked a slightly larger negativity than the neutral words at the midline, medial, lateral, and peripheral columns, particularly at occipital sites (Oz, $p = .03$; O2, $p = .03$; O1, $p = .07$), but a slightly larger, but nonsignificant, positivity than to the neutral words at more anterior sites. There were no significant differences in amplitude between the N400 evoked by negative and positive words at any electrode column. There were also no Affect by Hemisphere, or Affect by Hemisphere by AP distribution interactions.

The large positivity which followed the N400 peaked between 500 and 700 msec.[5] For this Late Positivity, the overall ANOVAs revealed main effects of Affect at all columns except the peripheral column (see Table 5), but no significant interactions involving AP distribution or hemisphere in any electrode column. Follow-up pairwise ANOVAs revealed a larger Late Positivity to the negative words relative to the neutral words at the midline column. In contrast, there were no differences between Late Positivity amplitudes elicited by the positive and neutral words. Finally, planned pairwise simple effects ANOVAs comparing the negative and positive words revealed main effects of Affect at all columns, reflecting significantly larger Late Positivities to the negative than to the positive words.

Analyses of the plausibility-matched dataset indicated that differences between the negative and neutral conditions in levels of plausibility did not account for the negative (vs. neutral) N400 effect; in this dataset, all of the previously found interactions remained significant, with an additional significant effect found in the medial column. Similarly, in the arousal-matched dataset, all of the original Affect by AP distribution interactions for the N400 time window remained significant, with additional significant effects in the medial and peripheral columns for both the negative versus neutral and positive versus

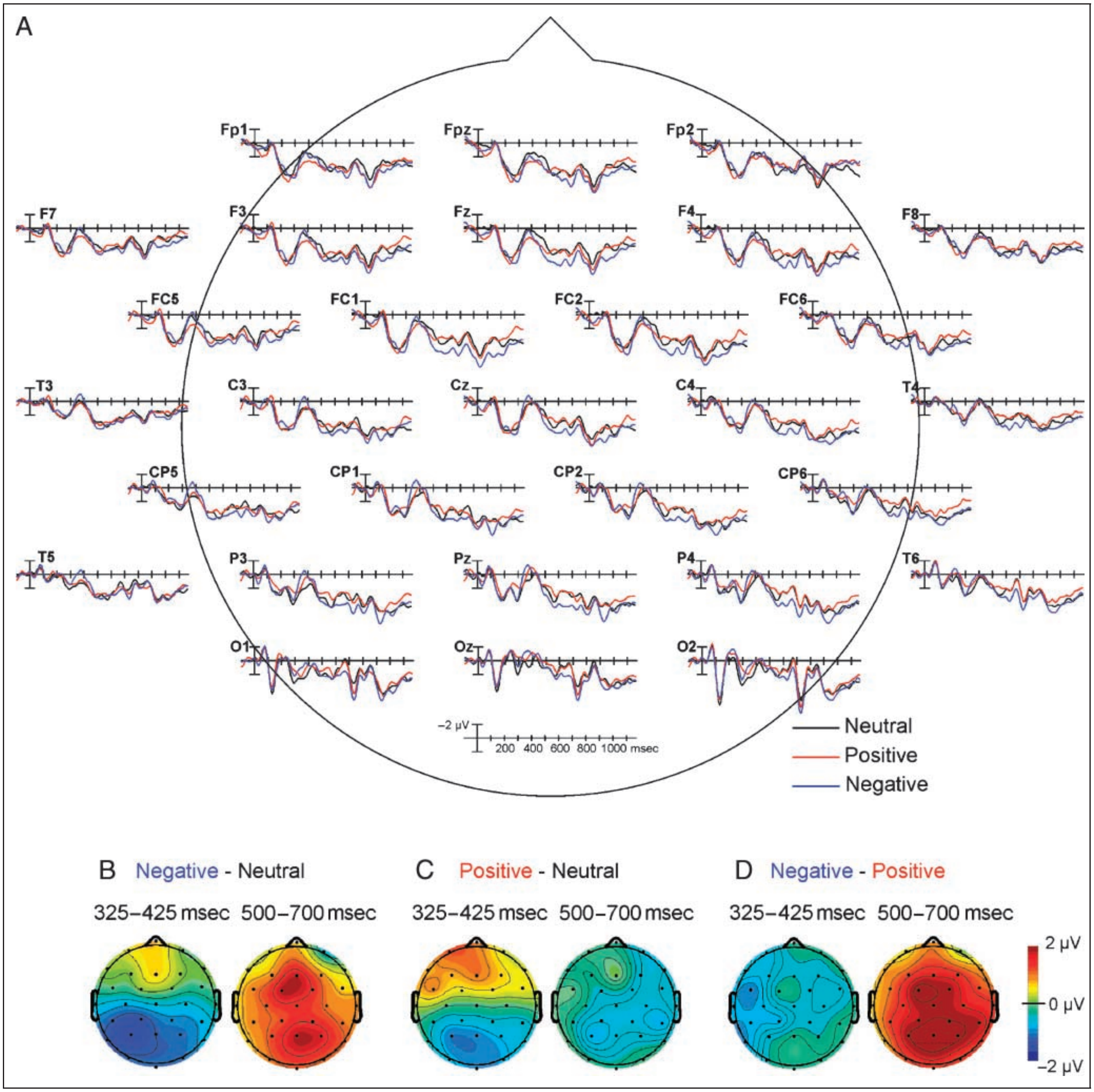

**Figure 3.** Grand-averaged waveforms (A) and voltage maps showing the average voltage differences, in the N400 (325–425 msec) and Late Positivity (500–700 msec) time windows, between the responses to the negative and neutral (B), positive and neutral (C), and negative and positive (D) critical words in Experiment 2.

neutral contrasts, with no significant differences between the negative and positive conditions in any column. Finally, the analysis of the cloze-matched dataset indicated that the slightly increased cloze probability of the positive relative to the negative and neutral critical words was not likely to account for the original findings; the contrast between positive and neutral words in the cloze-matched dataset revealed Affect by AP distribution interactions for the N400 time window that approached significance in the midline, medial, and lateral columns (all *F*s > 3.5, *p*s < .07).

Also, analyses conducted in the datasets matched for arousal, cloze probability, and plausibility demonstrated that the negative versus positive Late Positivity effect was not due to differences in these factors; the original pattern of results remained intact, with main effects of Affect in all columns, with the exception of the peripheral column for the arousal-matched analysis which showed an Affect by Hemisphere by AP distribution interaction instead. Similarly, the negative versus neutral Late Positivity effect was not affected by the difference in plausibility between the negative and neutral words because this

**Table 4.** Main Effects of Affect and Affect by AP Distribution Interactions for the N400 (325–425 msec) Time Window in Experiment 2

| | *Main Effect of Emotion* | | *Interactions between Affect and AP Distribution* | |
|---|---|---|---|---|
| | *F (Degrees of Freedom)* | *p* | *F (Degrees of Freedom)* | *p* |
| *A. Overall Effects* | | | | |
| Midline | 0.266 (2, 34) | .768 | 4.302 (8, 136) | .012 |
| Medial | 0.771 (2, 34) | .469 | 3.938 (4, 68) | .043 |
| Lateral | 1.070 (2, 34) | .353 | 4.745 (6, 102) | .018 |
| Peripheral | 1.104 (2, 34) | .342 | 2.578 (8, 136) | .066 |
| *B. Negative versus Neutral* | | | | |
| Midline | 0.337 (1, 17) | .569 | 6.088 (4, 68) | .011 |
| Medial | 1.156 (1, 17) | .297 | 4.217 (2, 34) | .053 |
| Lateral | 1.433 (1, 17) | .248 | 5.088 (3, 51) | .030 |
| Peripheral | 1.310 (1, 17) | .268 | 3.242 (4, 68) | .068 |
| *C. Positive versus Neutral* | | | | |
| Midline | 0.001 (1, 17) | .973 | 5.283 (4, 68) | .020 |
| Medial | 0.014 (1, 17) | .908 | 6.356 (2, 34) | .016 |
| Lateral | 0.000 (1, 17) | .992 | 5.801 (3, 51) | .019 |
| Peripheral | 0.012 (1, 17) | .912 | 3.804 (4, 68) | .046 |
| *D. Negative versus Positive* | | | | |
| Midline | 0.420 (1, 17) | .526 | 0.088 (4, 68) | .896 |
| Medial | 1.090 (1, 17) | .311 | 0.527 (2, 34) | .504 |
| Lateral | 1.610 (1, 17) | .222 | 0.531 (3, 51) | .548 |
| Peripheral | 1.755 (1, 17) | .203 | 0.104 (4, 68) | .892 |

Significant ($p < .05$) effects are highlighted with gray shading.

effect became more robust in the plausibility-matched analysis (attaining significance in the medial, lateral, and peripheral columns). Grand-average ERPs and voltage maps for these arousal, cloze, and plausibility-matched analyses are shown in Figures S4, S5, and S6 in Supplementary Materials (see www.nmr.mgh.harvard.edu/kuperberglab/materials.htm).

The difference between N400 amplitudes to the negative and neutral words at Pz (as well as at CP5 and T5, where the N400 effect to negative vs. neutral words was largest) correlated with levels of trait anxiety (Pz: $\rho = .51$, $p = .030$; CP5: $\rho = .53$, $p = .023$; T5: $\rho = .48$, $p = .042$) (see Figure 4), that is, higher levels of trait anxiety led to smaller (less negative) N400 effects. There were no other significant correlations between Pz N400 amplitudes and trait anxiety (all *p*s > .12).

## Discussion

In this second experiment, we found that, during the passive comprehension of emotional words following a neutral, nonconstraining context, a localized, posteriorly distributed N400 to negative and positive words was larger (more negative) than the N400 to neutral words. However, there was no significant difference between the amplitude of the N400 to positive and negative words. Also, similar to Experiment 1, a Late Positivity was significantly larger (more positive) to negative words than to both neutral and positive words. However, during passive reading conditions, there were no differences between the amplitudes of the Late Positivity to positive and neutral words. The same pattern of results was obtained when differences between the conditions in

**Table 5.** Main Effects of Affect and Affect by AP Distribution Interactions for the Late Positivity (500–700 msec) Time Window in Experiment 2

| | *Main Effect of Affect* | | *Interactions between Affect and AP Distribution* | |
|---|---|---|---|---|
| | *F (Degrees of Freedom)* | *p* | *F (Degrees of Freedom)* | *p* |
| *A. Overall Effects* | | | | |
| Midline | 5.226 (2, 34) | .012 | 1.326 (8, 136) | .236 |
| Medial | 4.621 (2, 34) | .018 | 1.017 (4, 68) | .373 |
| Lateral | 4.142 (2, 34) | .028 | 1.356 (6, 102) | .270 |
| Peripheral | 2.296 (2, 34) | .127 | 1.182 (8, 136) | .325 |
| *B. Negative versus Neutral* | | | | |
| Midline | 4.866 (1, 17) | .041 | 1.859 (4, 68) | .175 |
| Medial | 4.278 (1, 17) | .054 | 1.279 (2, 34) | .279 |
| Lateral | 2.849 (1, 17) | .110 | 1.447 (3, 51) | .251 |
| Peripheral | 1.336 (1, 17) | .264 | 2.898 (4, 68) | .072 |
| *C. Positive versus Neutral* | | | | |
| Midline | 0.406 (1, 17) | .533 | 0.610 (4, 68) | .535 |
| Medial | 0.639 (1, 17) | .435 | 0.348 (2, 34) | .676 |
| Lateral | 0.866 (1, 17) | .365 | 0.371 (3, 51) | .617 |
| Peripheral | 0.584 (1, 17) | .455 | 0.113 (4, 68) | .887 |
| *D. Negative versus Positive* | | | | |
| Midline | 12.186 (1, 17) | .003 | 1.441 (4, 68) | .252 |
| Medial | 10.822 (1, 17) | .004 | 1.164 (2, 34) | .316 |
| Lateral | 10.697 (1, 17) | .005 | 2.134 (3, 51) | .155 |
| Peripheral | 6.656 (1, 17) | .019 | 1.035 (4, 68) | .356 |

Significant ($p < .05$) effects are highlighted with gray shading.

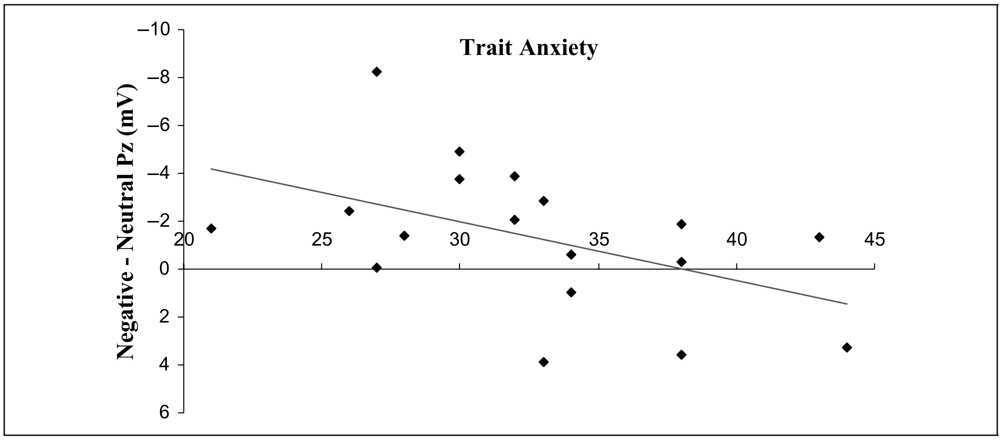

**Figure 4.** A scatterplot of the correlation between trait anxiety (measured using the Spielberger Trait and State Anxiety Inventory) and the N400 effect to negative versus neutral words at Pz ($r$ = .51, $p$ = .03). Note that on the $y$-axis, negative values are plotted upward in order to be consistent with the waveform plots.

arousal, cloze probability, or plausibility were taken into account.

One possible interpretation of the N400 effect to negative and positive words is that it arose from a lower predictability and/or plausibility of emotionally laden events. Pretests of the stimuli used here showed that the positive endings to the sentence pairs were slightly more predictable than the neutral and negative ones, and that the negative endings were slightly less plausible than both the neutral and positive endings. These differences may reflect naturalistic aspects of processing emotional meaning, particularly because they are consistent with evidence that healthy people tend to, on average, expect positive outcomes and to believe that unpleasant events are relatively unlikely to occur (an ''optimism bias'' about future events) (Sharot, Riccardi, Raio, & Phelps, 2007; Armor & Sackett, 2006; Hoch, 1984; Weinstein, 1980). However, these differences are unlikely to fully explain the observed pattern of findings for two reasons. First, the pattern of N400 modulation across the three conditions did not pattern with the small differences in cloze probability or plausibility ratings across the three conditions: given the ratings, the N400 to the positive words should have been smaller or equal to that of the neutral words—not larger at some posterior sites. Second, the N400 effect to negative and positive (vs. neutral) words remained evident in the analyses of datasets which were matched across the conditions for cloze probability and plausibility.

We therefore suggest that this small, localized modulation of the N400 by emotion arose from a more specific influence of emotion on semantic integration and that, as soon as the affective meaning of the critical words was decoded, the consequent activation of emotional processing networks increased the demands of integrating their meanings within their neutral contexts. This might occur simply because distinct neural representations were activated by the emotional critical words and the neutral context (Schupp et al., 2000; Cacioppo et al., 1994). Alternatively, it may have been driven by the greater capacity of the emotional words to elicit arousal and attract attention (Lang, 1995), directly recruiting additional processing resources for more detailed semantic analysis of emotionally salient stimuli (also see Van Berkum, in press for a similar interpretation). Note that both these explanations assume that decoding the meaning of emotional words leads to a rapid activation of emotional processing networks within the brain, consistent with embodied frameworks of semantic memory (Glenberg et al., 2005; Zwaan & Radvansky, 1998).

Both of the explanations outlined above also assume an important role of the neutral context in modulating the N400 to the emotional words in the present study—a role that is illuminated by a comparison with previous studies presenting emotional words either in isolation or in emotionally congruous contexts: Kanske and Kotz (2007) demonstrated, in contrast to these findings, *less negative* N400 amplitudes (as well as shorter reaction times) to emotional words relative to neutral words presented in isolation as participants performed a lexical decision task. Also, several studies have found reductions in N400 amplitudes to emotional words when they were primed by sentences spoken in congruent emotional prosody (Schirmer et al., 2002, 2005); in contrast to the present study, in these studies, the automatic activation of emotional processing networks by the emotionally congruent context may have facilitated integration.

We also found an inverse correlation between the size of the N400 effect to negative words and trait anxiety, that is, a smaller (less negative) N400 effect to negative versus neutral words in participants with more trait anxiety. This finding should be considered preliminary as we did not find a complementary enhancement by trait anxiety of the N400 effect to positive words, and we did not explicitly manipulate participants' mood or examine the role of positive affect. However, it does support the possibility that predominant trait mood can influence the semantic mapping process within the N400 time window: Participants with predominantly negative mood may have either perceived the negative (vs. the neutral) events as more expected, and/or the neutral context may have been interpreted as negative, decreasing any affective mismatch between the context and the negative critical word. Consistent with this explanation, an N400 effect has been reported to words within sentence contexts that are morally inconsistent (versus consistent) with a participant's individual belief system (Van Berkum, Holleman, Nieuwland, Otten, & Murre, in press) and also to words which are inconsistent (vs. consistent) with a positive self-view (Watson, Dritschel, Obonsawin, & Jentzsch, 2007). Taken together, these findings support the hypothesis that current mood state influences the processing of emotional input in a manner that is analogous to the influence of the immediate context on general, on-line language comprehension (Kutas & Federmeier, 2000), and that the comprehension of emotionally salient information is also influenced by deeply ingrained, emotionally laden beliefs about the self and the world that are rapidly retrieved from memory stores specialized for emotional and/or autobiographical information. Follow-up studies, which specifically manipulate mood state, characterize long-standing affective dispositions and belief systems of participants, and then examine the effects of these factors on predictability and plausibility (and ease of semantic integration) of emotionally laden events, can more fully explore the roles of mood, temperament, and autobiographical knowledge in the comprehension of emotional language.

Also, in this experiment, like in Experiment 1, we found a larger Late Positivity to negative words, compared to positive and neutral words. However, unlike in Experiment 1, under conditions of passive reading, there were no differences between the Late Positivities to positive and neutral words. This suggests that, in Experiment 1, there was an interaction between the task and the intrinsic salience of the stimuli, augmenting the Late Positivity overall and leading to differentiation between the positive and neutral conditions. Interestingly, the magnitude of the negativity bias (the difference between the negative and positive conditions) was not markedly affected by task, with a similar, widespread distribution in both experiments. Thus, the negativity bias may represent a manifestation of the intrinsic, attention-attracting capacity of emotional information (which is greater for negative than positive stimuli) relative to a neutral context.

## GENERAL DISCUSSION

The overall goal of these two experiments was to study the neurocognitive mechanisms governing the comprehension of the emotional meaning of language. We asked whether encountering an emotional word within a neutral context (a) influences a semantic memory-based process, as indexed by the N400, and (b) leads to the engagement of additional cognitive processes that are known to be recruited during the processing of emotional stimuli, as indexed by the Late Positivity. We found that, during passive comprehension of sentences that built up an affectively neutral context, words with emotional meaning (relative to affectively neutral words) evoked a small, posterior N400 effect, providing evidence for an intensified or more difficult process of mapping the evolving representation of meaning. However, the amplitude of the N400 elicited by emotional words was not significantly modulated by the specific valence of the words (i.e., by whether their affective content was positive versus negative). Rather, a Late Positivity showed such valence sensitivity, with a larger amplitude to negative than to positive words, during both conditions of explicit affective evaluation and passive reading. Taken together, these findings suggest that a semantic memory-based mechanism (indexed by the N400) was influenced by the overall emotional salience of a word relative to its neutral context, whereas the precise valence of the word modulated a later stage of evaluation (indexed by the Late Positivity).

Here we have shown that a word which is generally semantically plausible (i.e., makes sense) but affectively incongruous (vs. congruous) with its preceding context evokes an N400 effect. The ease of semantic integration, as reflected by the N400, is thought to be determined both by the degree to which the preceding context paves the way toward a word's meaning and the accessibility of the word's meaning within long-term semantic memory stores (Kutas & Federmeier, 2000). We have suggested that the increased N400 to emotional (relative to neutral) words embedded in a neutral context may reflect the increased demands of mapping the emotional meaning of a word with the neutral meaning of the preceding sentence, with respect to long-term semantic knowledge (including emotionally laden associations), either because of the relative distance between emotional and neutral semantic knowledge stores (Osgood et al., 1957) (each subserved by distinct neural networks, with emotional processing networks centered in the amygdala and medial prefrontal cortex) and/or because emotion or arousal rapidly focuses attention for more in-depth or intensified semantic memory-based analysis. This intensified, early analysis may be followed by a more detailed evaluation of the emotional event or situation depicted, during the Late Positivity time window.

Several previous studies have not observed modulation of the Late Positivity by emotion during the incidental processing of emotional words (Naumann et al., 1997; Carretie et al., 1996), arguing that explicit attention to emotional meaning is necessary to evoke a Late Positivity. However, here we found, during passive reading conditions, a Late Positivity to negative words that was significantly larger than the Late Positivity to both positive and neutral words in a neutral context. These findings suggest that, at least when embedded in a neutral context, the intrinsic motivational significance of negatively valenced information attracts attentional resources. Of note, however, during passive comprehension, emotional content per se did not lead to a general emotional modulation of the Late Positivity because only negatively valenced information led to amplification of the Late Positivity. In contrast, during the explicit evaluation of affective meaning, both a general emotion effect (emotional greater than neutral) and a valence effect (negative greater than positive) were demonstrated. This observation is consistent with the findings of ERP studies that have varied task-related attention to the emotional content of emotionally evocative pictures or human faces with emotional expressions (Schupp, Stockburger, Codispoti, et al., 2007; Vuilleumier & Pourtois, 2007), providing evidence for attention–emotion interactions during later stages of processing.

Our finding of a negativity bias in the Late Positivity to emotional words is consistent with a large body of previous evidence indicating that negatively valenced information typically consumes more processing resources than positively valenced information. Like the emotional Late Positivity overall, the negativity bias here was not task dependent—it was seen in both experiments. This task independence is inconsistent with the findings of some behavioral studies, which found that response latencies were longer to negative than to positive words only when their meaning was explicitly processed (Dahl, 2001; White, 1996). However, our result is in line with the ERP findings of Bernat et al. (2001), who demonstrated a negativity bias in the Late Positivity during subliminal as well as during supraliminal exposures to emotional words. Taken together, it is likely that the greater temporal sensitivity and greater proximity to the relevant neural processes of ERPs, relative to reaction times, provided the power to detect differences between responses to negative and positive words regardless of task. Our finding of a negativity bias to emotional words during the appraisal of social vignettes is consistent with evidence from social psychology (Taylor, 1991) that this bias is present during the comprehension of affectively meaningful, real-world events.

The demonstration of a Late Positivity to emotional words in a neutral context adds to our growing understanding of Late Positivities which are evoked by different triggers during the comprehension of sentences and discourse. Although it is likely that the continued analyses reflected by such positivities represent multiple different cognitive processes that are subserved by different neural networks, it has been suggested that they may share a common function—to re-evaluate or monitor the input (Kolk & Chwilla, 2007). This model is in line with the present findings; a trigger to re-evaluate a neutral context after encountering an emotionally meaningful stimulus (leading to an alternative and possibly more accurate interpretation of the input) clearly serves a primary goal of the emotional response system—to maximize perceptual or interpretive accuracy in certain, prioritized situations, for the purpose of promoting survival.

The fact that we found little evidence for early modulation of ERPs by affective meaning is inconsistent with reports of effects of the emotional content of words on amplitudes of the P1, N1, and P2 components (Kissler et al., 2006; Smith, Cacioppo, Larsen, & Chartrand, 2003; Bernat et al., 2001). However, these early effects have been reported inconsistently and may be more likely to emerge if stimuli are repeated or presented transiently (Kissler et al., 2006). Also, in the current study, the overall greater comprehension demands of evaluating whole sentences, relative to single words, may have delayed the impact of emotional content on semantic processing. In light of this possibility, the emotion-related enhancement of an early posterior negativity to single words and nonlinguistic stimuli, which occurs between 150 and 350 msec (Herbert, Junghofer, & Kissler, 2008; Kissler, Herbert, Peyk, & Junghofer, 2007; Schupp, Stockburger, Codispoti, et al., 2007; Schupp, Junghofer, Weike, & Hamm, 2003; Junghofer, Bradley, Elbert, & Lang, 2001), may be related to the N400 effect found here. Additional studies, which compare the neurophysiological effects of emotional meaning on words presented alone to words presented in context, will be able to clarify the relationships among these effects further.

## Summary

We have shown evidence that the passive comprehension of emotional, plausible words within a neutral context involves an intensified process of semantic integration, which likely results from an interaction between the neural circuits subserving emotional and other types of semantic memory-based retrieval during the comprehension of emotional language. In addition, both passive and active comprehension of such words led to a subsequent, attention-modulated, prolonged analysis of emotional words, similar to that found during the processing of nonlinguistic emotional information.

We have suggested that the earliest stages of mapping the meaning of an incoming word on to its context, as reflected by the N400, can be modulated by an initial assessment of whether the meaning of a stimulus is emotionally significant or not. Stimuli that are assessed as aversive, or potentially harm-inducing, then trigger more extensive processing, as reflected by an augmented Late Positivity. This distinction between neurocognitive responses that are sensitive to "emotion" (the N400) and more specifically to "valence" (the Late Positivity) is broadly reminiscent of results of functional imaging studies which have described brain regions that respond to overall emotional salience, such as the amygdala and the ventral striatum (Zald, 2003; Zink, Pagnoni, Martin, Dhamala, & Berns, 2003), and valence-sensitive areas of the ventral prefrontal cortex (Kringelbach, 2005; Small et al., 2003). In future studies, it will be interesting to determine, using combined ERP/fMRI or magnetic encephalography methods, whether the rapid modulation of language processing by emotional meaning demonstrated here using ERPs is mediated by the same emotion-sensitive subcortical and valence-sensitive prefrontal networks.

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## Notes

1. In order to match the conditions for arousal, cloze probability, and plausibility, we excluded 12, 17, and 47 scenarios, respectively, of the original 135. In the arousal matched set, only the positive and negative conditions were matched (the neutral condition remained lower in arousal than the other two conditions).
2. The grand-average difference waveform calculated between the negative and neutral conditions peaked at 520 msec.
3. This was confirmed by constructing a grand-average difference waveform for the negative minus neutral critical words at Pz and calculating the peak latency of this difference waveform from 300 to 500 msec. The mean peak latency fell at 375 msec.
4. Although examination of the voltage map suggested that the interaction may have, in part, been driven by an anterior positivity to the negative versus the neutral critical words, post hoc analyses revealed no significant effects at any anterior sites.
5. The grand-average difference waveform calculated between the negative and neutral conditions peaked at 520 msec.

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