Early emotion word processing: Evidence from event-related potentials

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Abstract

Behavioral and electrophysiological responses were monitored to 80 controlled sets of emotionally positive, negative, and neutral words presented randomly in a lexical decision paradigm. Half of the words were low frequency and half were high frequency. Behavioral results showed significant effects of frequency and emotion as well as an interaction. Prior research has demonstrated sensitivity to lexical processing in the N1 component of the event-related brain potential (ERP). In this study, the N1 (135–180 ms) showed a significant emotion by frequency interaction. The P1 window (80–120 ms) preceding the N1 as well as post-N1 time windows, including the Early Posterior Negativity (200–300 ms) and P300 (300–450 ms), were examined. The ERP data suggest an early identification of the emotional tone of words leading to differential processing. Specifically, high frequency negative words seem to attract additional cognitive resources. The overall pattern of results is consistent with a time line of word recognition in which semantic analysis, including the evaluation of emotional quality, occurs at an early, lexical stage of processing.

How we process written emotion words is an important issue for word recognition as well as affective neuroscience. Emotion words can either express an emotional state (angry, happy) or elicit one (snake, puppy). Such words are characterized by having high arousal values and either high (positive) or low (negative) valence. Although most research has measured behavioral responses (e.g., reaction time), more recent research has used brain electrophysiological and hemodynamic imaging methodologies to more precisely specify the temporal and spatial loci, respectively, of emotion processing. Our focus was to determine whether the emotionality of a word drives early lexical processes. Such evidence would indicate that a word’s affective semantics is not a consequence of but, rather, a component of its lexical activation. To this end, we not only manipulated the emotionality of words (positive vs. negative vs. neutral), but also their frequency of occurrence (high vs. low frequency). As the word frequency effects are considered to be inextricably linked to the moment of lexical access (e.g., Balota, 1990; Sereno and Rayner, 2003), a significant interaction between emotion and frequency would establish a lexical locus of emotional processing.

Despite the amount of research in emotion word processing, a clear picture has yet to emerge. Two main points of concern across studies are inconsistencies in stimuli and task. First, most studies have selectively compared negative and neutral words; fewer have compared positive and negative words, while still others have examined a particular emotional state. Second, while most studies have employed a lexical decision task (LDT) or some version of an emotional decision (or categorization) task, others have utilized recollection tasks (e.g., Van Strien and Luipen, 1999), odd-ball paradigms (e.g., De Pascalis et al., 2004), forced-choice tasks (e.g., Kakolewski et al., 1999), and self-referential judgments (e.g., Lewis et al., 2007). Additionally, studies often utilize experimental manipulations such as masking (e.g., Windmann et al., 2002), priming (e.g., Wentura, 2000), mood induction (e.g., Olafson and Ferraro, 2001), lateralized presentation (e.g. Kanske and Kotz, 2007; Windmann et al., 2002), stimulus repetition (e.g., Ortigue et al., 2004), and/or blocked presentation of each condition (e.g., Hamann and Mao, 2002). Although these studies typically find emotion effects, their use of different methodologies – while clearly employed to investigate specific research questions – nevertheless make it difficult to generalize across studies. For example, Tabert et al. (2001) showed better memory for unpleasant vs. neutral...
words; Kakolewski et al. (1999) showed increased right visual field attention to euphoric vs. dysphoric and neutral words; and Wurm et al. (2003) showed that naming speed to heard words was related to their relative danger and usefulness. Notably, to our knowledge, none of the behavioral or electrophysiological studies of emotion word processing have manipulated word frequency. If emotion and frequency effects are interactive, this may explain the mixed pattern of results across studies where word frequency has not been explicitly examined. The only study to date which has directly manipulated frequency, using negative and neutral words, was an fMRI study by Nakic et al. (2006) which also employed an LDT. Word stimuli were ‘high’ negative (highly unpleasant), ‘low’ negative (less unpleasant), or neutral words which were either high frequency (HF) or low frequency (LF) words (40 words in each of the 6 conditions). Pseudowords were pronounceable nonwords that differed by one letter from target words. Behaviorally, they found main effects of frequency (LF < HF) and emotion (‘high’ negative < ‘low’ negative = neutral), but no interaction. In terms of fMRI activation, LF ‘high’ and ‘low’ negative words elicited increased activation relative to HF negative words in bilateral inferior frontal gyri. The frequency effect for neutral words showed a different pattern, with greater activation for HF vs. LF words in cingulate and inferior parietal regions. For the emotion effect, ‘high’ negative words produced greater activations than ‘low’ negative and neutral words in bilateral middle temporal gyri and in the anterior and posterior cingulate gyri. Both ‘high’ and ‘low’ negative words showed greater activation than neutral words in the right amygdala; only ‘high’ negative words showed greater activation than neutral words in the left amygdala. Nakic et al. (2006) postulated that negative words become conditioned stimuli which acquire a significant association with amygdala activation; speeded responses to ‘high’ negative words were attributed to reciprocal feedback from the amygdala. However, because the relative timings of these activations were not specified (because fMRI does not provide the required high temporal resolution), it is not clear whether this feedback could directly guide early lexical processing.

Other recent fMRI studies have also demonstrated amygdala involvement in processing emotion words (Lewis et al., 2007; Strange et al., 2000). Hamann and Mao (2002) had participants emotionally evaluate blocks of the same-affect words and found increased left amygdala activity for negative as well as positive lexical affect vs. a neutral condition. Tabert et al. (2001) showed an increased right amygdala activity for unpleasant vs. neutral words during an emotional decision task in which participants selected the most unpleasant (or neutral) word from a set of three unpleasant (or neutral) words. However, no such activation difference occurred during a recognition memory task. They suggested that a correlation of amygdala and occipital cortex activity indicated that the amygdala mediates early visual processing. Although fMRI studies have identified specific neural loci related to particular tasks, they cannot in general capture the moment-to-moment temporal course of such activity. Using intracranial recording, for example, Naccache et al. (2005) showed amygdala involvement during subliminal presentation of emotion words, but only from 800 ms post-stimulus. Such activation is quite delayed in relation to word recognition, estimated to take place within the first 200 ms (Sereno and Rayner, 2003).

Electrophysiological studies are better suited to capture the real-time perceptual and cognitive processes of emotion word recognition. Several studies have examined different components of the event-related potential (ERP) for emotionality effects (for a review, see Kessler et al., 2006). Most, however, use many repetitions of the experimental materials (e.g., Bernat et al., 2001; Ortigue et al., 2004). Repetition priming has known effects in word recognition including, for example, greater facilitation for LF vs. HF words. In an event-related fMRI study, Luo et al. (2004) used a masked repetition priming paradigm with positive, negative, and neutral words in which participants judged whether the target appeared in normal or in italics font. They found behavioral repetition priming effects for positive and negative but not neutral words. In terms of fMRI activation, they found greater repetition priming for positive compared to negative words in the left mid-fusiform gyrus. Because word repetition can produce differential effects depending on particular lexical characteristics, results of such studies cannot be easily generalized to the conditions in which words are normally identified (without repetition).

Three recent ERP studies have found emotion word effects in the time range of 180–300 ms post-stimulus. All three studies, however, employ complex methodologies which may limit their generalizability. Kanske and Kotz (2007) presented abstract and concrete words which were affectively positive (N = 60), negative (N = 60), or neutral (N = 120) for 200 ms either to the left or right hemifield in an LDT. Each target was presented twice, once to each hemifield. In addition, a blocked presentation was used with either positive and neutral or negative and neutral words occurring in the same block. They found faster RTs in conjunction with larger P2s (210–300 ms) for positive vs. neutral words and for right- vs. left-hemifield words. The P2 positive emotion effect disappeared, however, when the LDT was changed to a go/no-go (pseudoword) word LDT. Herbert et al. (2006) presented pleasant, unpleasant, and neutral adjectives (60 words of each type) for 5 s each. Participants were instructed to emotionally evaluate and memorize the words. They found a larger P2 (180–250 ms) for each pleasant and unpleasant vs. neutral adjectives which they attributed to conscious processing of affective content. However, on one-third of the trials, a 90 dB acoustic probe was introduced (2.5–4 s after word onset) to induce a startle response. This manipulation presumably increased participants’ anxiety levels throughout the task (as with mood induction procedures). Finally, Kissler et al. (2007) presented a set of 180 words – 60 pleasant, 60 unpleasant, and 60 neutral words – 10 times to participants for passive viewing, 5 times at a rate of three words per second (3 Hz) and 5 times at a rate of one word per second (1 Hz). They found increased negativity for high arousal words (positive and negative) vs. low arousal (neutral) words over posterior sites from 200–300 ms post-stimulus for both presentation rates. Although words were repeated across the 10 experimental blocks, the emotion effect was stable across blocks and hence cannot be attributed to stimulus repetition (possibly because the task was passive viewing). Kissler et al. suggested the emotion effect reflects post-lexical feedback from the amygdala which enhances the processing of a high arousal stimulus regardless of its valence. Although all three studies found effects of emotionality, the use of elaborate experimental procedures (e.g., lateralized presentation, induced startle response, repetition with passive viewing) makes it more difficult to generalize these findings to normal reading. Finally, since these studies did not use word frequency as an experimental variable, they are less capable of interpreting emotion-related influences on lexical access.

As mentioned above, lexical access can be indexed by the presence of word frequency effects. A word frequency effect represents the differential response to commonly used HF words vs. LF words that occur much less often. Reliable word frequency effects have been reported in the posterior N1 (~130–190 ms post-stimulus), with LF words eliciting a greater amplitude than HF words (Sereno et al., 1998, 2003). Other ERP and MEG studies have confirmed an early time course for lexical processing (Dien et al., 2003; Hauk and Pulvermüller, 2004; Neville et al., 1992; Nobre and McCarthy, 1994; Pulvermüller et al., 2001). Lexical effects

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occurring within the exogenous components of the ERP are consistent with what has been inferred from eye movement studies of normal reading. That is, because the duration of a single fixation on a word (~225 ms) varies with the psycholinguistic complexity of that word (Rayner, 1998), a temporal window can be specified within which lexical processing must occur; corresponding electrophysiological differences within this time period can both confirm and pinpoint an early lexical time course (Sereno et al., 1998; Sereno and Rayner, 2003).

Our hope was to more clearly establish the early temporal dynamics of emotion word processing by anchoring them to frequency effects. We used a 3 (Emotion: Positive, Negative, Neutral) × 2 (Frequency: LF, HF) design (40 words of each type). Word stimuli and an equal number of pseudowords were randomly presented in an LDT while ERPs were recorded. Notably, we did not repeat stimuli, use lateralized presentation, blocking, priming, or masking, nor make use of self-referential judgments or mood induction. Behaviorally, we expected to find clear word frequency effects. We were less certain about emotion effects, as past research has demonstrated an advantage sometimes for negative words (e.g., Wurm et al., 2003) and other times for positive words (e.g., Dahl, 2001). Likewise, we were uncertain whether to expect an interaction. Nakic et al. (2006) did not find one, but they only used negative and neutral words. Electrophysiologically, our strategy was to examine effects in the N1 component, occurring before the P2 and EPN components where differences have previously been reported (Herbert et al., 2006; Kanske and Kotz, 2007; Kessler et al., 2007). Reliable word frequency effects have been demonstrated in the N1, linking this component to the processes of lexical access (Hauk and Pulvermüller, 2004; Sereno et al., 1998, 2003). We expected to find N1 frequency effects at least for Neutral words (comparable to stimuli in the earlier studies). If the arousal and valence of emotion words affect lexical access, differential effects should also be evident in the N1. In addition to examining N1 effects, we were also interested in delineating a time course of activation. To this end, we also examined the earlier P1 component and later, post-N1 time windows.

1. Method

1.1. Participants

Twenty-six members of the University of Glasgow community (15 females, 11 males; mean age 21, range: 17–24) were paid £10 for their participation. An additional four participants were run in the experiment, but were not included in the analyses because of excessive EEG artifacts which resulted in a data loss of more than 70% of the trials. All participants were native English speakers, had not previously been diagnosed as dyslexic, and were strongly right-handed (mean score approximately 1 character shorter on average than LF words (6.9 vs. 5.8 characters, respectively) [F(2,78) = 12.79, p < .001; and Neutral vs. Positive: F(2,78) = 7.19, p < .01; and Positive vs. Neutral: F(2,78) = 13.92, p < .001]. In addition, all had normal or corrected-to-normal vision and were naïve concerning the purpose of the experiment. In accordance with the guidelines set by the University’s ethics committee, written informed consent was obtained prior to experiment participation.

1.2. Materials and design

A 3 (Emotion: Positive, Negative, Neutral) × 2 (Frequency: LF, HF) design was used. Word stimuli varied in terms of arousal, valence, and word frequency. Arousal and valence values were taken from the Affective Norms for English Words (ANEW), a database of 1000 words (Bradley and Lang, 1999). Each word in ANEW has associated ratings both for arousal, from 1 (low) to 9 (high), and for valence, from 1 (negative) to 9 (positive). The following criteria for word selection were employed. Arousal values for Positive and Negative words were greater than 6.00, while those for Neutral words were less than 5.45. Valence values were greater than 6.00 for Positive words, less than 4.00 for Negative words, and between those values for Neutral words. Word frequencies were taken from the British National Corpus (BNC), a database comprising 90 million written word tokens (http://www.natcorp.ox.ac.uk/).

A total of 80 sets of word triples (Positive, Negative, and Neutral) were generated with words within each set matched for length and frequency. Forty sets were LF and 40 were HF. All word stimuli are listed in Appendix A and their specifications are listed in Table 1.1 In addition, three sets of 80 pseudowords were created, with each set length-matched to its corresponding word set. The pseudowords were orthographically legal pronounceable nonwords (e.g., blimble), and none were pseudohomophones (i.e., pseudowords matching in phonology to real words). Each participant was presented with all 480 items—240 words and 240 pseudowords.

1.3. Apparatus

Participants were tested in the Psychology Department in an electrically shielded booth with low-level ambient light. Experimental Run Time System (ERTS) software was used to control stimulus presentation (cf. Dutta, 1995). Participants were seated at a viewing distance of approximately 65 cm from the monitor, maintained throughout the experiment by means of a chin rest. Stimuli were presented centrally in 20-point Helvetica font on a Sony 15” monitor in white letters on a black background. Approximately three characters subtended 1 of visual angle. A keypad registered word and nonword responses (right and left index fingers, respectively) with millisecond accuracy. Keys were mounted about 35 cm apart on a board aligned to the body’s midline.

1.4. Procedure

Before the experiment, participants were informed about the nature of electrophysiological recording and were given specific task instructions. They were told that half of the stimuli were words and half were nonwords and that they should respond as quickly and as accurately as possible. For each trial, the sequence of events was as follows. A central fixation cross was presented for 750 ms followed by a blank interval of 500 ms. A letter string was then presented centrally until response onset. After the response (or if no response occurred within 2 s of stimulus onset), a variable blank interval of 1.5 s mean duration (range: 1.25–2.50 s) followed. Experimental trials were presented in a different random order for each participant.

Participants were first presented with a practice block of 24 trials to become accustomed to the task. Experimental trials were then presented in 10 blocks with short rest periods in between. Each experimental block consisted of 50 trials and...
lasted approximately 3.5 min. The first two trials of each block were filler items and were not recorded. After each block, participants were given feedback about their performance.

1.5. Electrophysiological recording

A BIOSEMI Active-Two amplifier system was used for continuous recording of electroencephalographic (EEG) activity from 72 Ag/AgCl electrodes (see Fig. 1): (a) midline electrodes: Fpz, AFz, Fz, FCz, Cz, CPz, Pz, POz, Oz, and Iz; (b) left hemisphere electrodes: IO1, Fp1, AF3, AF7, F1, F3, F5, F7, F9, FC1, FC3, FC5, FT7, C1, C3, C5, M1, T7, CP1, CP3, CP5, TP7, P1, P3, P5, P7, PO3, PO7, O1, including two nonstandard positions PO9' and O9' (located at 33% and 66% of the M1-Iz distance, respectively); and (c) homologous right hemisphere electrodes. Two additional electrodes (the Common Mode Sense (CMS) active electrode and Driven Right Leg (DRL) passive electrode) were used as reference and ground electrodes, respectively (cf. www.biosemi/faq/cms&drl.htm). EEG and EOG recordings were sampled at 256 Hz. All EEG channels were recalculated off-line to an average mastoid reference. Trials containing blinks were corrected using a dipole approach (BESA, Version 5.1.8). The analysis epoch started 200 ms prior to stimulus onset and lasted for a total duration of 1.5 s.

1.6. EEG data analysis

Trials with non-ocular artifacts (drifts, channel blockings, EEG activity exceeding ±75 μV) and incorrect responses were discarded, resulting in an average data loss of about 30% per participant. After artifact rejection, there remained on average 28 trials of 40 (minimally 20) per participant per condition. The signal at each electrode site was averaged separately for each of the six experimental word conditions, time-locked to word onset, band-pass filtered (0.05–30 Hz, 6 dB/oct), and aligned to a 100-ms pre-stimulus baseline. The mean amplitudes of specific ERP deflections were measured for the following time intervals: the P1 from 80–120 ms; the N1 from 135–180 ms; the Early Posterior Negativity (EPN; e.g., Schupp et al., 2006) from 200–300 ms; and the P300 from 300–450 ms. For time windows occurring before 300 ms (P1, N1, and EPN), mean voltages were computed across four posterior electrodes over right hemisphere (RH) sites (P6, P8, PO8, PO10) and four homologous electrodes over left hemisphere (LH) sites (P5, P7, P07, PO9) (see Fig. 1). The mean P300 amplitude in a 300–450 ms time interval was measured across three parietal midline electrodes (CPz, Pz, POz). In addition, a computerized peak-picking program was used to measure P300 peak latency at Pz (i.e., the time point, from 250–800 ms, when the voltage at Pz was maximally positive).

2. Results

The mean RT, mean ERP amplitude during the time intervals defined above, and P300 latency data are presented in Table 2. These data are also graphically depicted with standard error bars in Fig. 2 (RT and P300 peak latency) and Fig. 3 (P1, N1, EPN, and P300). ERP waveforms from posterior electrodes PO7 (left) and PO8 (right), and from the midline electrode Pz are shown in Fig. 4. Scalp topographies of mean ERP amplitudes in each time window are displayed in Fig. 5.

Table 2

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<th>Latency (ms)</th>
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<td>RT</td>
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<td>P300 peak</td>
<td>574</td>
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<td>Voltage (μV)</td>
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<td>1.79</td>
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<td>1.5</td>
<td>1.70</td>
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<tr>
<td>N1</td>
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<td>-2.61</td>
<td>-2.03</td>
<td>-2.27</td>
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<tr>
<td>P300</td>
<td>5.95</td>
<td>5.32</td>
<td>5.85</td>
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Note: LF, low frequency; HF, high frequency. For the P1, N1, and EPN windows, electrode areas comprise posterior sites shown in Fig. 1. For the P300 window, midline electrodes were used. The P300 peak latency was calculated from electrode Pz.

Fig. 1. Electrode arrangement. Homologous left and right posterior electrodes are indicated for analysis of average voltage amplitude in the P1, N1, and EPN windows. Midline electrodes are indicated for analysis of average voltage amplitude in the P300 window.

Fig. 2. (A) Mean RT (ms) with standard error bars indicated for LF and HF Negative, Neutral, and Positive words. (B) Mean P300 peak latency (ms) from electrode Pz with standard error bars for LF and HF Negative, Neutral, and Positive words.
2.1. RT data

Trials in which participants made errors were excluded from the RT data analysis (4.92%). The RT data were subjected to two trimming procedures. Items with RTs less than 250 ms or greater than 1500 ms were excluded from further analysis. For each participant in each condition, items with RTs beyond two standard deviations of that mean were also excluded. These procedures resulted in an average data loss of 4.78%.

A two-way analysis of variance (ANOVA) was performed on the participant data. The main effect of Emotion was significant \( F(2,50) = 11.53, p < .001 \). Follow-up contrasts revealed that responses to Positive words (525 ms) were only marginally faster than those to Negative words (532 ms) \( F(1,50) = 3.83, p = .056 \). However, responses to both Positive and Negative words were significantly faster than those to Neutral words (541 ms) \( F(1,50) = 22.82, p < .001 \); \( F(1,50) = 7.95, p < .01 \). The main effect of Frequency was highly significant, with faster responses to HF vs. LF words (511 ms vs. 555 ms) \( F(1,25) = 86.20, p < .001 \). The interaction was also significant \( F(2,50) = 4.10, p < .05 \). For LF words, both Positive and Negative words (which did not differ from each other) were faster than Neutral words \( F(1,50) = 22.29, p < .001 \); and Negative vs. Neutral:

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**Fig. 3.** Mean voltage amplitude (μV) with standard error bars for LF and HF Negative, Neutral, and Positive words for the following time windows: (A) P1 (80–120 ms); (B) N1 (135–180 ms); (C) EPN (200–300 ms); and (D) P300 (300–450 ms).

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**Fig. 4.** ERP waveforms from posterior electrodes PO7 (left) and PO8 (right), and from the midline electrode Pz. Each plot depicts the grand average ERPs to Positive, Neutral, and Negative word conditions for either LF or HF words.

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For HF words, Positive words were faster than both Negative and Neutral words (which did not differ from each other) [Positive vs. Negative: $F(1,50) = 7.40, p < .01$; Positive vs. Neutral: $F(1,50) = 8.82, p < .01$; and Negative vs. Neutral: $F < 1$].

2.2. ERP data

We performed a 3 (Emotion: Positive, Negative, Neutral) × 2 (Frequency: LF, HF) × 2 (Hemisphere: RH, LH) repeated measures ANOVA, using the Huynh-Feldt correction, on the average voltage data in the P1, N1, and EPN windows. For the P300, we performed a similar ANOVA but instead of Hemisphere as a factor, we used electrode (comprising the three midline electrodes CPz, Pz, and POz). Finally, we examined P300 peak latency at a single electrode (Pz) using a two-way ANOVA.

2.3. P1 window (80–120 ms)

As can be seen in Fig. 5, mean P1 amplitude was larger over right than left posterior electrodes (2.2 μV vs. 1.3 μV) [Hemisphere: $F(1,25) = 7.86, p < .01$]. The main effect of Emotion was significant [$F(2,50) = 4.41, p < .05$] and tended to be modulated by Frequency, as indicated by an Emotion × Frequency interaction [$F(2,50) = 2.61, p = .084$]. Further comparisons revealed that P1 amplitude was influenced by Emotion only for HF words [$F(2,50) = 5.48, p < .01$], and not for LF words [$F < 1$]. As can be seen in Table 2 and Fig. 3A, P1 amplitude was smaller for HF Negative words (1.30 μV) than either HF Positive (1.93 μV) or HF Neutral (1.94 μV) words [all $Fs(1,25) > 6.45, ps < .05$]. Negative LF words tended to elicit a larger P1 than Negative HF words (1.79 μV vs. 1.30 μV) [$F(1,25) = 4.08, p = .054$]; frequency effects, however, were not reliable for either Positive or Neutral words [all $Fs(1,25) < 1.48, ps > .20$]. No other effects were significant in the analysis of mean P1 amplitude [all $Fs < 1$]. Overall, the pattern of effects in the P1 seems to arise mainly from the very early effect of word frequency for Negative words. The established, later N1 frequency effect comes from studies using, notably, emotionally neutral words. Thus, it seems that HF Negative words are processed at an earlier stage.

2.4. N1 window (135–180 ms)

No main effects were significant, nor were most of the interactions [for Emotion, Frequency, Hemisphere, and Frequency × Hemisphere: all $Fs < 1$; Emotion × Frequency: all $Fs < 1$; Emotion × Hemisphere: $F(2,50) = 1.92, p > .15$; and Emotion × Frequency × Hemisphere: $F(2,50) = 1.35, p > .25$]. Only the Emotion × Frequency interaction was significant [$F(2,50) = 7.01, p < .01$]. Follow-up contrasts revealed a significant effect of Frequency for Neutral words, replicating prior studies (e.g., Sereno et al., 1998, 2003), with LF Neutral words eliciting a larger N1 than HF Neutral words ($-2.03 μV$ vs. $-2.61 μV$) [$F(1,25) = 4.42, p < .05$]. As can be seen in Table 2 and Fig. 3B, the effect of Frequency was not significant for Positive words [$F < 1$], but was significant in the opposite direction for Negative words, with HF Negative words eliciting a larger N1 than LF Negative words ($-2.61 μV$ vs. $-2.06 μV$) [$F(1,25) = 9.07, p < .01$]. Within LF words, similar to the pattern in the RT data, Neutral words tended to elicit a larger N1 than either Positive or Negative words (which did not differ from each other) [Positive vs. Negative: $F < 1$; Positive vs. Neutral: $F(1,25) = 2.70, p = .113$; and Negative vs. Neutral: $F(1,25) = 5.89, p < .05$]. Within HF words, Negative words elicited a significantly larger N1 than either Positive or Neutral words (which did not differ from each other) [Positive vs. Negative: $F(1,25) = 4.39, p < .05$; Positive vs. Neutral: $F(1,25) = 1.97, p > .15$; and Negative vs. Neutral: $F(1,25) = 5.72, p < .05$]. In sum, the N1 frequency effect found in prior studies (which used emotionally neutral words) was replicated with Neutral words. The different pattern of results for Positive and Negative words seems to indicate that the frequency effect is influenced by a word’s arousal and valence.

2.5. EPN window (200–300 ms)

The main effect of Emotion was significant [$F(2,50) = 5.76, p < .01$]. Negative and Positive words showed larger EPN amplitudes ($-0.96$ and $-0.94 μV$) than Neutral words ($-0.47 μV$). The Emotion × Frequency interaction was also significant [$F(2,50) = 10.75, p < .001$]. Follow-up contrasts revealed a significant Frequency effect for Neutral words, with LF Neutral words eliciting a larger EPN than HF Neutral words [$F(1,25) = 12.11, p < .01$]. As can be seen in Table 2 and Fig. 3C, the Frequency effect was in the opposite direction for Negative words, with HF Negative words eliciting a larger EPN [$F(1,25) = 7.04, p < .05$], and Positive words showed no effect [$F(1,25) = 1.31, p > .25$]. Within LF words, Emotion did not reliably influence EPN amplitude [Positive vs. Negative: $F(1,25) = 2.48, p = .128$; Positive vs. Neutral: $F(1,25) = 1.63, p > .20$; and Negative vs. Neutral: $F < 1$]. Within
HF words, Negative and Positive words (−1.27 and −0.81 μV) elicited a significantly larger EPN than Neutral words (−0.16 μV), replicating Kissler et al. (2007) whose stimuli, notably, were HF words; additionally, Negative words triggered a larger EPN than Positive words [Positive vs. Negative: F(1,25) = 9.00, p < .01; Positive vs. Neutral: F(1,25) = 9.14, p < .01; and Negative vs. Neutral: F(1,25) = 32.63, p < .001]. No other main effects or interactions were significant [all Fs < 1.41, ps > .20].

2.6. P300 window (300–450 ms)

To capture the P300’s centroparietal topography (see Fig. 5), we performed a 3 (Emotion: Positive, Negative, Neutral) × 2 (Frequency: LF, HF) × 3 (electrode: CPz, Pz, POz) ANOVA on the average voltage data. There was a main effect of electrode, with Pz (7.20 μV) having greater amplitude than CPz and POz (5.24 and 6.13 μV) [F(2,50) = 4.50, p < .05]. As can be seen in Table 2 and Fig. 3D, there was a main effect of Frequency, with LF words eliciting a smaller P300 than HF words (5.71 μV vs. 6.68 μV) [F(1,25) = 10.93, p < .01]. This replicates prior research (e.g., Polich and Donchin, 1988). No other effects were significant [all Fs < 1.58, ps > .20].

2.7. P300 peak latency

The P300 peak latency from electrode Pz was analyzed by a two-way ANOVA. Similar to the P300 pattern of results, there was only a main effect of Frequency, indicating an earlier peak for HF vs. LF words (534 ms vs. 566 ms) [F(1,25) = 9.00, p < .01]. This effect also replicates Polich and Donchin’s (1988) findings. No other effects were significant [all Fs < 2.13, ps > .14].

3. Discussion

The purpose of the current experiment was to investigate the early time course of emotion word processing. Positive, negative, and neutral words were presented randomly in an LDT while brain electrophysiological responses were recorded. Unlike most prior studies, we did not use masking, priming, mood induction, lateralized presentation, blocking, or repetition of stimuli. Such manipulations make results difficult to generalize as they may produce second order effects or induce strategic processing. Critically, we manipulated word frequency in order to better determine the onset of lexical–semantic processing, and employed a 3 (Emotion: Positive, Negative, Neutral) × 2 (Frequency: LF, HF) design.

Behaviorally, we found significant Emotion and Frequency effects as well as an interaction. For LF words, both Positive and Negative words were responded to faster than Neutral words; for HF words, Positive words were responded to faster than Negative and Neutral words. It is somewhat difficult to evaluate these findings with respect to the prior literature. While past studies often match their stimuli (positive, negative, and/or neutral words) on word frequency, with the exception of Nakic et al. (2006), none to our knowledge has directly manipulated word frequency. Nakic et al. did not find an interaction, but they only used negative and neutral words. It seems possible that the mixed nature of results across studies may arise from the frequency profile of the stimuli used. Although the pattern of our behavioral findings seems unambiguous, RTs from an LDT encompass a range of processes, from stimulus registration and lexical evaluation to motor planning and execution. A precise time course of lexical processing is difficult to infer from such data; one cannot simply align cognitive components of the LDT with corresponding components of the ERP. Nevertheless, the presence of an interaction in RT indicates that Frequency and Emotion influence at least one common processing stage. By examining the electrophysiological record, the temporal dynamics of the component processes of word recognition can be more effectively established.

We tracked the time course of processing by examining the pattern of effects across consecutive temporal windows. Taken together, these results reveal a transitory account of emotion word processing. We were initially interested in the N1 (135–180 ms) because this is when lexical effects (e.g., word frequency, contextual predictability) have been reliably demonstrated (e.g., Hauk and Pulvermüller, 2004; Sereno et al., 1998; Polich and Donchin, 1988). The P1 (80–120 ms) window allowed us to determine whether there was prior evidence of such effects, in particular, those related to stimulus arousal and valence. We then examined the EPN (200–300 ms), a window in which Kissler et al. (2007) reported an initial differentiation between high arousal (positive and negative) and neutral words. Finally, we examined the P300 (300–450 ms) time window, because previous electrophysiological studies of word recognition have reported word frequency effects in this late time range (e.g., Hauk and Pulvermüller, 2004; King and Kutas, 1998; Polich and Donchin, 1988; Rugg, 1990).

We had expected to find an N1 (135–180 ms) effect of word frequency. The N1, however, only showed a significant Emotion × Frequency interaction. For LF words, Neutral words generated higher amplitudes; for HF words, Negative words generated higher amplitudes. Neutral words exhibited the established frequency effect, with LF words eliciting a larger N1 than HF words. This replicates the findings of past studies which, notably, have used LF and HF emotionally neutral words (e.g., Sereno et al., 1998, 2003). Positive words, however, showed no frequency effect, and Negative words showed a frequency effect in the opposite direction, with HF words eliciting a larger N1 than LF words. Nevertheless, the presence of an interaction suggests that frequency is modulated by arousal and valence.

Our analysis of the earlier P1 (80–120 ms) revealed that the only experimental condition affecting P1 amplitude was the HF Negative word condition which elicited a smaller P1 than the other conditions. Hauk and Pulvermüller (2004) demonstrated P1 sensitivity to word length. Although LF Negative words were one character longer on average than HF Negative words in our study, this LF-HF length disparity was identical for Positive and Neutral words (see Table 1) where no such effect occurred. Thus, the P1 amplitude seemed to be selectively modulated by the combined features of high frequency, high arousal, and negative valence (i.e., HF Negative words).

Finally, we examined post-N1 time windows. In the EPN (200–300 ms), the N1 pattern of frequency effects for Neutral, Positive, and Negative words was maintained. In addition, while no significant differences emerged among LF words, for HF words, both Negative and Positive words generated a larger EPN than Neutral words. This last finding replicates Kissler et al. (2007) whose stimuli comprised HF words. The final P300 (300–450 ms) window only exhibited significant effects of frequency, with LF words eliciting a smaller P300 than HF words. Although this replicates the frequency effects of Polich and Donchin (1988), other ERP studies have reported N400 word frequency effects in sentence and word list paradigms, with LF words eliciting larger amplitudes than HF words (see Kutlas et al., 2008). These apparently opposite effects both accurately describe the same waveform pattern (i.e., LF words elicit a smaller positive-going P300 or a larger negative-going N400 than HF words). On the basis of our results, it is not possible to characterize these late word frequency effects as either P300 or N400 effects. Given that the N400, rather than P300, is sensitive to variations in language materials, it seems more plausible to assume that LF words elicited a larger N400 rather
than a smaller P300. An N400 which overlaps a more substantial P300 component could also account for the P300 latency shift, with longer latencies to LF than HF words. Regardless of the precise nomenclature of these later ERP components, it is clear that later stages of lexical processing appear to behave differently than earlier ones in that effects of emotion have become attenuated.

In the following, we describe a framework that allows us to interpret the current findings. Our interpretations rely on two assumptions. First, we suggest that words that are highly salient are easier to process. It is not disputed, for example, that HF words are easier to process than LF words because they are more familiar. We extend this notion of salience to arousal. High arousal words have stronger lexical representations and are more salient than low arousal (neutral) words because of their emotionality. This should speed recognition. However, unlike word frequency, arousal can have environmental consequences. Arousal that is positive or negative in valence will lead to vastly different outcomes. In addition, arousal that is HF vs. LF may lead to consequences which have more or less environmental significance, respectively.

Our second assumption is that some version of a “perceptual defense” mechanism operates on incoming stimuli. The idea of perceptual defense is not new; McGinnies (1949) developed it from Freud and Rogers’ notion of unconscious denial. McGinnies presented taboo and control words tachistoscopically and found that taboo words required longer exposures for correct identification. He suggested that perceptual defense insulated the observer from (negative) emotion-provoking properties of stimuli. Although there have been several criticisms of this study, including accounts of why the results were artifactual (e.g., taboo words had lower word frequencies; participants consciously withheld taboo word responses because of social convention), the idea itself remains viable and has been resurrected in various forms. For example, Pratto and John’s (1991) Automatic Negligence Function proposes that negative words require more cognitive resources and are processed longer than positive ones. Similarly, Taylor’s (1991) Mobilization-Minimization hypothesis states that if a stimulus is negative, there are strong, rapid physiological and cognitive responses in the initial processing of that stimulus – the mobilization stage. In the subsequent minimization stage, additional physiological and cognitive responses are employed to diminish the impact of the negative stimulus.

Our rendering of perceptual defense is that high arousal stimuli, in particular negatively valenced ones, are recognized more quickly and initiate an internal response because of their environmental significance. This internal response is manifest in the neural substrate as increased processing and can be interpreted either as enhancement or disruption. When an emotional stimulus is encountered, levels of high arousal are associated with that stimulus which is internally registered (consciously or not). In extreme cases, this awareness may occur preattentively. This internal registration will occur more quickly for high arousal stimuli that are more frequent. The valence of the arousal also plays a role, with a bias to process negative stimuli more rapidly than positive stimuli because they engender unpleasant consequences.

The overall pattern of results supports the proposal that frequency, arousal, and valence all contribute to the immediate processing of words. It remains less clear, however, precisely how these factors interact over different stages of processing. For example, HF Negative words are the most salient because of their frequency, arousal, and valence profile. The combination of these features seems to result in a processing head start: HF Negative words produced lower amplitudes than any other condition in the P1. According to our suppositions, early activation of high arousal that is both negative in valence and highly frequent in occurrence, however, will trigger an internal response which shows up as enhancement or disruption in the N1 window. With Positive words, the advantage that a moderate level of salience confers is seemingly offset by an equally moderate level of enhancement/disruption caused by the automatic internal response to high arousal stimuli. These opposing effects serve to mask the early frequency effect. With Neutral words, unaccompanied by any effects of emotion, N1 frequency effects clearly emerge. The subsequent EPN shows increased amplitude for HF Negative and Positive words vs. HF Neutral words which could be interpreted either as continued disruption from high levels of arousal or, as suggested by Kissler et al. (2007), enhancement of processing emotion vs. neutral words (their stimuli were HF words). By the P300/N400, emotion effects have become attenuated and all that remains is the behaviorally more robust frequency effect. The P300 peak latency shows the same pattern.

An alternative explanation of the early P1–N1 pattern of effects is one that relies instead on attentional mechanisms (see, e.g., Mangun and Hillyard, 1991, 1995) which are selectively responsive to HF arousal. Such an effect could be expressed electrophysiologically as a negative-going wave having an earlier onset and larger amplitude for HF Negative compared to HF Positive words. As a result, for HF Negative words, the amplitude of the P1 is reduced and the N1 greatly enhanced. For HF Positive words, because the attentional effect occurs later and to a lesser degree, only the amplitude of the N1 is enhanced, thereby counteracting the standard frequency effect. Whatever the explanation, the results clearly demonstrate an early effect of arousal that is modulated by word frequency. This suggests that the differential activation to at least a subset of high arousal words must engage brain mechanisms that are operative during early visual processing. Accumulating evidence in visual object processing has demonstrated that semantic analysis is more rapid than has been traditionally assumed (e.g., Thorpe et al., 1996) and that top-down feedback can begin to affect processing in sensory areas after 80 ms post-stimulus (e.g., Foxe and Simpson, 2002).

In sum, this experiment shows that the emotional tone of a word modulates its early lexical processing. Past N1 effects of lexical processing, as indexed by the presence of word frequency effects, were replicated. These effects were extended by demonstrating that such effects were modulated by the emotional characteristics of the word stimuli. Effects of emotion specifically for HF Negative words occurred as early as the P1. While emotion modulated early processing, in general its effect was more transient than word frequency. HF emotion and neutral words were differentiated in the post-N1, EPN. However, by the P300/N400, only effects of frequency were evident.

We recognize that the experiment has certain limitations. While the ERP methodology provides a rich temporal record of events, the precise neural mechanisms involved are less accessible. For example, it has often been suggested that the amygdala plays a role, having reciprocal connections to visual cortical areas. However, the timing of such activation is estimated to occur well after lexical access. There is a need to explore temporally more plausible determinants of emotional effects on word recognition. A second concern is that the presentation of words in isolation using a specialized task involves the recruitment and application of strategies not found in normal reading. Visual word recognition typically occurs during normal reading, where individual word meanings are activated and integrated on-line into a developing discourse context. To this end, we have already begun investigation of processing emotion words in normal reading while participants’ eye movements are monitored (Sereno et al., 2008). Finally, although our contributions to theoretical notions...
of affective word processing may be preliminary and speculative, we believe that our use of well-controlled stimuli and temporally precise measures has produced results which will inform such endeavors.

Acknowledgments

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Appendix A

Low- and high-frequency (LF, HF) positive, negative, and neutral words

<table>
<thead>
<tr>
<th>LF</th>
<th>HF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>Negative</td>
</tr>
<tr>
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<td>demon</td>
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<tr>
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<td>shark</td>
</tr>
<tr>
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<td>rude</td>
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<tr>
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<td>rage</td>
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<td>toxic</td>
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<td>poison</td>
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<td>hatred</td>
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<td>wicked</td>
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<td>intruder</td>
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<td>hurricane</td>
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References


