Oscillatory brain dynamics associated with the automatic processing of emotion in words

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Abstract

This study examines the automaticity of processing the emotional aspects of words, and characterizes the oscillatory brain dynamics that accompany this automatic processing. Participants read emotionally negative, neutral and positive nouns while performing a color detection task in which only perceptual-level analysis was required. Event-related potentials and time frequency representations were computed from the concurrently measured EEG. Negative words elicited a larger P2 and a larger late positivity than positive and neutral words, indicating deeper semantic/evaluative processing of negative words. In addition, sustained alpha power suppressions were found for the emotional compared to neutral words, in the time range from 500 to 1000 ms post-stimulus. These results suggest that sustained attention was allocated to the emotional words, whereas the attention allocated to the neutral words was released after an initial analysis. This seems to hold even when the emotional content of the words is task-irrelevant.

1. Introduction

It has been well established that emotional stimuli rapidly attract attention at early stages of sensory analysis, and obtain prioritized processing due to their potential relevance for survival (Lang, Bradley, & Cuthbert, 1997). LeDoux and Phelps (1993) proposed that a dual pathway theory which assumes that emotions are processed rapidly through a sub-cortical route to optimize chances for survival. However, this theory was primarily based on studies of non-linguistic stimuli (such as faces, sounds and pictures). Written words, as symbolic stimuli, are acquired rather late in evolutionary history. Also, the visual features of words are not as complex as those of pictures. Given the substantial differences between linguistic and non-linguistic stimuli, it remains unclear whether the lexical-semantics of words should be accessed prior to the identification of the emotional aspects of words. At the same time, traditional models of word recognition (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Grainger & Holcomb, 2009; Plaut, McClelland, Seidenberg, & Patterson, 1996) rarely include emotional variables. These models are used to describe the role of orthographic and phonological information in accessing semantic information of the words. Various factors have been shown to influence this process, such as word length, word frequency, concreteness and imageability. Surprisingly, no existing model is equipped to accommodate the emotional effect. Therefore, the examination of emotional processing of words has implications for both emotional processing and word recognition.

The automaticity of emotional processing can be manifested in two ways. First, one issue is whether the lexical-semantics of words have to be accessed before the emotional aspects of words are identified. The fast and dynamic neural processing of emotional stimuli can be measured with EEG, which has a high temporal resolution. Indeed, a large number of EEG studies have studied the event-related potentials (ERPs) elicited during the online processing of emotional words. Several ERP components have been associated with the processing of emotional words (for a review, see Citron, 2012). For instance, P1/N1, P2 and early posterior negativity (EPN) have been taken as evidence for the rapid processing (before 300 ms) of the emotional aspects of words. P1/N1 have been associated with early perceptual analysis of stimuli, probably resulting from top-down control of amygdala on sensory cortex (Vuilleumier, 2005). P2 and EPN have similar temporal characteristics with recognition potential (RP) that is sensitive to meaningfulness and task-relevance of visual words. Thus, the P2 and EPN have been taken as a reflection of attentional capture during early stages of meaning encoding. A late positive potential (LPP), peaking between 500 and 800 ms, has been associated with evaluation of emotional valence. Since lexical access is supposed to occur after
200 ms (Dien, 2009), the early ERP effects (such as N1/P1, P2 and EPN) seem to suggest that the emotional aspects of words can be recognized even before the words’ meaning is available. However, a large number of studies failed to find such early ERP effects (for a review see Citron, 2012). Therefore, it remains an open question whether the emotional aspects of words can be automatically activated. A second issue is whether the emotional aspects of words are activated even when the task is emotion-irrelevant. A few studies systematically examined the emotional effects of words in different tasks. Whereas Schacht and Sommer (2009b), Rellecke, Palazova, Sommer, and Schacht (2011) and Trauer, Andersen, Kotz, and Müller (2012) found that emotional words produced different ERPs from neutral words even when the emotional connotation of words was task-irrelevant, Hinojosa, Méndez-Bértolo, and Pozo (2010) failed to find an emotional effect when the participants were asked to identify meaningful words embedded in a stream of non-recognizable stimuli. The variability of the ERP effects can be accounted for by various factors (for reviews see Citron, 2012; Okon-Singer, Lichtenstein-Vidne, & Cohen, 2013), such as the ways of presenting words (subliminal vs. supraliminal; short vs. long duration; lateralized vs. central presentation), experimental control of word properties (word length, frequency and concreteness), task demands (color naming, lexical decision, grammatical judgment, semantic priming, silent reading, emotional evaluation) and subjects’ characteristics (health vs. high anxiety, female vs. male). This study aims to further examine the automaticity of emotional processing.

A typical way of analyzing the EEG data is to average multiple segments that are time-locked to a certain event, which results in ERPs (Luck, 2005). However, the ERPs largely cancel out event-related changes in non-phase-locked EEG oscillations (Bastiaansen, Mazerahi, & Jensen, 2012). Therefore, another way to analyze EEG data is to decompose the EEG signals into different frequency bands using time–frequency (TF) analysis, which results in time–frequency representations (TFRs) of power changes within the different frequency bands. Using both ERPs and TFRs, the present study investigates the brain dynamics underlying the automatic processing of emotional aspects of words.

A number of studies have addressed the TF power changes that result from processing emotionally valenced stimuli. Most of these studies used non-psychological stimuli, such as pictures (Cui et al., 2013; De Cesarei & Codispoti, 2011; Keil et al., 2001; Martini et al., 2012; Müller, Keil, Gruber, & Elbert, 1999), faces (Balconi, Brambilla, & Falbo, 2009; Balconi & Pozzoli, 2009), Knyazev, Barchard, Razumnikova, & Mitrofanova, 2012, musical pieces (Lin, Duann, Chen, & Jung, 2010; Schmidt & Trainor, 2001), films (Simons, Detenber, Cuthbert, Schwartz, & Reiss, 2003), and vocalization of nonsense syllables (Bekkedal, Rossi lii, & Panksepp, 2011). These studies were conducted in the framework of Davidson, Schwartz, Saron, Bennett, and Goleman (1979), which focused on an approach-withdraw model of emotion and hemispheric asymmetry (i.e., whether the left or right hemisphere is more important for emotional processing). However, the hemispheric asymmetry might be difficult to be inferred from EEG measures due to the non-linear relation of scalp EEG with its underlying neuronal generators.

They have reported different emotional effects to (non-linguistic) stimuli in different frequency bands. For instance, larger theta power (4–7 Hz) was found in response to emotional compared to neutral stimuli in the time window of 150–300 ms over the right anterior scalp for pictures (Balconi & Pozzoli, 2009) and in the time window of 300–500 ms over the central region for faces (Knyazev et al., 2012). Larger theta power was also found for negative compared to positive prosody in the time interval of 0–500 ms over right anterior areas (Bekkedal et al., 2011). However, using independent spectral component analysis, Lin et al. (2010) reported larger theta power for low arousing (and positive) musical pieces compared to highly arousing (and negative) musical pieces over frontal-central areas. Altogether, the theta frequency band has been proposed to be a sensitive marker for the arousing quality of emotional stimuli (Bekkedal et al., 2011).

For the alpha frequency band (around 10 Hz), it has generally been found that emotional stimuli yield more reduced alpha power compared to neutral stimuli over parietal and/or occipital areas after 300 ms for pictures, faces, films and musical pieces (Balconi et al., 2009; Cui et al., 2013; De Cesarei & Codispoti, 2011; Schmidt & Trainor, 2001; Simons et al., 2003). However, Keil et al. (2001) reported larger alpha power decreases in an early time window (280–340 ms) for negative and positive pictures when they were presented in right and left hemifield respectively, suggesting that the negative and positive stimuli were processed in different brain hemispheres. The alpha frequency band has been related to either enhanced perceptual analysis (De Cesarei & Codispoti, 2011) or to motivated attention (Cui et al., 2013; Keil et al., 2001; Simons et al., 2003).

Finally, regarding the gamma frequency band (>30 Hz), Keil et al. (2001) found low gamma power (30–45 Hz) increases around 80 ms for negative pictures as well as high gamma power (46–65 Hz) increases around 500 ms for both negative and positive pictures over temporal and occipital regions. However, Balconi and Pozzoli (2009) reported enhanced gamma power for emotional faces between 150 and 250 ms in the right hemisphere, and Müller et al. (1999) found a similar pattern over a longer time window (up to 6 s). The gamma band frequency has been proposed to reflect either amplified processing of stimuli (Keil et al., 2001; Müller et al., 1999) or enhanced motivation in elaborating significant stimuli (Balconi & Pozzoli, 2009).

More generally, outside of the domain of emotional processing, the different EEG frequency components have been linked to a range of cognitive processes. For instance, the theta frequency band has been related to working memory and memory retrieval (Bastiaansen, Linden, Keurs, Dijkstra, & Hagoort, 2005; Bastiaansen, Oostenveld, Jensen, & Hagoort, 2008). The alpha frequency band has been associated with attention (Hanslmayr, Gross, Klimesch, & Shapiro, 2011; Jensen, Bonnefond, & VanRullen, 2012; Wang et al., 2012) and working memory (Jensen, Gelfand, Kounios, & Lisman, 2002). In particular, the event related power changes in posterior alpha were proposed to play an important role in prioritizing and ordering visual input according to their intrinsic or task relevance (Jensen et al., 2012). Moreover, the gamma frequency band has been related to visual binding in object representation (Tallon-Baudry & Bertrand, 1999) and semantic unification operation in language comprehension (Hagoort, Hald, Bastiaansen, & Petersson, 2004; Wang, Zhu, & Bastiaansen, 2012). Therefore, given the domain-general cognitive correlates of the different EEG frequency-band-specific responses, it seems reasonable to assume that the observed oscillatory responses to emotionally valenced stimuli are not uniquely related to the processing of the emotional aspects of stimuli, but rather reflect domain-general cognitive processes involved in emotional processing, such as enhanced attention, or increased working memory engagement.

Although previous studies have attempted to examine the brain oscillations during emotion processing, only a small number of studies used emotional words as stimuli. The processing of emotional words was shown to activate partly different brain regions as compared to the processing of emotional pictures (Kensinger & Schacter, 2006), and different ERP responses were found between the processing of emotional words and faces (Frühholz, Jellinghaus, & Herrmann, 2011; Rellecke et al., 2011; Schacht & Sommer, 2009a). So far, only three studies have compared the oscillatory responses during the processing of emotionally neutral
vs. valenced words. Hirata et al. (2007) found decreased beta and gamma power during the reading of emotional words over anterior cingulate cortex and left inferior and middle frontal gyri, while Putman, Arias-Garcia, Pantazi, and van Schie (2012) reported an increased delta-beta power coupling (i.e., an increased correlation between power in the beta and delta frequency bands) for participants who showed less interference of the emotionality of the words when naming the color of negative words. Therefore, the latter authors took the beta frequency band as a specific index of emotion processing. In addition, using generalized additive modeling, Kryuchkova, Tucker, Wurm, and Baayen (2012) found that oscillations in delta, theta and low-alpha frequency bands related to the degree of rated danger and usefulness, in the time window of 150 ms and 350 ms after words onset, when participants passively listened to these words.

The current study aims to further investigate how emotional words are processed in the brain, by quantifying both ERPs and time–frequency responses (TFRs) at the same time. EEG signals were recorded while participants read negative, positive and neutral nouns. In order to assess the automaticity of emotional processing, we used a perceptual task (i.e., a color detection task), in which participants only needed to press a button upon detecting a word printed in red. In this way, we induced a shallow processing strategy. The observed ERP effects in the current study will provide further evidence on the automaticity of emotional information processing. For the TF analysis, we argue that if the emotional words automatically capture more attention than the neutral words in the passive task, this should be reflected by stronger alpha power decreases for the emotional words compared to the neutral words. Also, following the results of Hirata et al. (2007) and Putman et al. (2012), if the beta band frequency is related to automatic emotional processing we expect decreased beta power for emotional compared to neutral words. In sum, our study will provide further information on two questions related to emotional word processing: Is there automaticity in the processing of emotional words, and what are the oscillatory brain dynamics that accompany the (automatic) processing of emotional aspects of words.

2. Material and methods

2.1. Participants

Twenty-four university students (mean age 23 years, 18–30 years old; 10 males) served as paid volunteers. They were all right-handed native speakers of Chinese with normal or corrected to normal vision. None of them had dyslexia or any neurological impairment. They signed a written consent form before the experiment.

2.2. Stimuli

We collected 249 nouns from Chinese web pages. All of the nouns are two-character Chinese words. We then asked 24 raters (different from the EEG participants) to rate the concreteness, valence and arousal of the nouns on 7-point Likert scales (7 indicates the most concrete, the most positive, and the most arousing). We first selected the nouns whose concreteness scores were larger than 3.1. Then we categorized the nouns into three groups based on their valence scores: negative (valence rating < 3.5), neutral (valence rating between 3.5 and 4.5) and positive (valence rating > 4.5). Next we selected 42 negative, 42 neutral and 42 positive nouns that matched on concreteness, log-frequency of the whole word and each character of the word (which was obtained from a Chinese corpus developed by Cai and Brysbaert (2010)) and number of strokes. The arousal level between the negative and positive nouns was also matched. See Table 1 for rating scores of the selected nouns. Statistical analysis showed significant valence difference between positive, neutral and negative nouns (F(2,125) = 733.144, p < .001; negative vs. neutral: F(1,83) = 657.07, p < .001; neutral vs. positive: F(1,83) = 258.57, p < .001; negative vs. positive: F(1,83) = 1101.07, p < .001). The arousal of the emotional and neutral nouns also differed (F(2,125) = 123.291, p < .001; negative vs. neutral: F(1,83) = 227.64, p < .001; positive vs. neutral: F(1,83) = 151.35, p < .001), with no difference between the positive and the negative nouns (F(1,83) = 1.66, p = .20). In addition, the nouns showed no significant difference among the negative, positive and neutral conditions in either concreteness (F(2,125) = 1.429, p = .243), frequency (whole word: F(2,125) = 2.470, p = .089; word's first character: F(2,125) = .491, p = .613; word's second character: F(2,125) = .524, p = .593) or number of strokes (F(2,125) = 1.381, p = .255). Moreover, no correlation between word frequency and valence rating was found (r = -.001, p = .990). It should be noted that although Chinese is an ideographic language, no obvious correspondence between the words’ visual properties and their emotionality has been identified.

We also selected an additional 14 negative, 14 neutral and 14 positive nouns as target words. These words were presented in red color and participants were asked to press a button whenever these words appeared. In this way, participants were engaged in a shallow word processing condition, and no motor response was needed for the experimental words. In addition, there were 168 verbs (with 1/3 of them being negative, positive and neutral), in which 42 verbs were shown in red color. Since the focus of this paper is on the emotional processing of highly concrete nouns, we do not report the properties of the verbs in detail here. Overall, the experimental materials contained 336 words, with 126 experimental nouns (defined as CWs, 42 CWs in each of the emotional conditions), 42 target nouns (shown in red color), as well as 168 verbs (42 of which were shown in red color).

2.3. Procedure

Participants were seated in a comfortable chair in front of a computer screen. The words were presented in either white or red color on a black background, with a font size of 36. A trial started with a fixation cross (duration 2000 ms) in the center of the screen followed by a 500 ms blank screen. Then the word was presented for 1000 ms. After a 500 ms blank screen interval, the next trial began. The participants were instructed to press the ‘ENTER’ key on the keyboard upon detecting a word with red color. In order to avoid motor-related ERP/TFR responses, the emotional/neutral target words were presented in red color, so no response was needed for the experimental words. Because the ratio between the white and red words was 3:1, the participants only need to press the button for 1/4 of the trials. The participants were told not to move or blink during the presentation of words, but to blink during the presentation of the fixation cross.

The experimental nouns, target nouns and verbs were mixed in one list. The stimuli were divided into 6 blocks in total (56 words per block), with each block lasting about four minutes. The words were presented in a pseudo-random order, with no more than three nouns of the same condition being presented in succession. In between blocks there was a small break, after which subjects could start the next block by pressing a button. The whole experiment took about one hour, including subject preparation, instructions and a short practice consisting of 12 words.

2.4. Electroencephalogram (EEG) recording and analysis

The EEG data were recorded with a 64-channel NeuroScan system. The electrodes were placed according to the extended 10–20
system. The left mastoid electrode served as the reference, and an electrode placed between Fz and FPz electrodes served as the ground. The vertical (VEOG) and horizontal (HEOG) eye movements were monitored through four electrodes placed around the orbital region (bipolar montage). All electrode impedances were kept below 5 kΩ during the experiment. Recording was done with a band pass filter of 0.05–100 Hz and a sampling rate of 500 Hz.

The EEG data were re-referenced off-line to the average of both mastoids. The EEG artifacts were automatically corrected by NeuroScan software (Semlitsch, Anderer, Schuster, & Presslich, 1986). Then, the data were segmented from −0.6 s to 1.5 s relative to the onset of the experimental nouns (the critical words; CWs). EEG responses to the target nouns were not analyzed due to contamination of motor responses. An automatic artifact rejection procedure was taken to exclude trials exceeding ±100 μV. Additionally, the trials containing wrong responses were excluded. In the end, 38 trials resulted on average in each condition, with no significant difference in trial numbers between conditions (f(2,46) = .11).

2.4.1. ERP analysis
For the computation of the ERP, we applied an additional band-pass filter of 0.1–30 Hz (24 dB/oct slope). Then, epochs between −0.1 s and 1 s relative to CW onset were defined, followed by a baseline correction from −0.1 s to 0 s preceding CW onset. After that, we computed an average across all items for each condition and each participant.

2.4.2. Time–frequency (TF) analysis of single-trial data
Time–frequency (TF) analysis was performed with an open-source Matlab toolbox, the Fieldtrip software package (Oostenveld, Fries, Maris, & Schoffelen, 2011). TFRs of the single trial data (epochs from −0.6 s to 1.5 s relative to the CWs) were computed in two different, partially overlapping frequency ranges. In the low-frequency range (2–30 Hz), a 400 ms Hanning window was applied in frequency steps of 1 Hz and time steps of 10 ms. In the high-frequency range (25–80 Hz), a multitaper approach, as described by Mitra and Pesaran (1999), was used. Power estimates were computed with a 400 ms time-smoothing and a 5 Hz frequency-smoothing window, in 2.5 Hz frequency steps and 10 ms time steps. Then we averaged the single trial TFRs of the three conditions separately, for each participant. The power changes in the post-stimulus interval were expressed as a relative change from the baseline interval (from −0.4 s to −0.15 s).

2.4.3. Time–frequency (TF) analysis of the ERP data
The evoked ERPs mainly reveal phase-locked EEG responses to the eliciting event, while the induced TFRs contained both phase-locked and non-phase-locked EEG power changes. In this sense, the standard TF analysis based on single-trial data may partially contain the TFRs of the ERP waveforms. Since a TF analysis of the subject-averaged ERPs contains only the evoked responses, we can qualitatively compare the TFRs based on ERPs with those based on single-trial data in order to determine to which extent the standard TF analysis can be accounted for by the (TFR of the) ERP data. In this way, we can test whether the TFR is merely a time–frequency transform of the frequency contents of the ERP.

First, the average ERP in each condition was computed by averaging the epochs from −0.6 s to 1.5 s relative to the CWs. Then the TFRs of the ERP data were obtained in a similar way as described in the time–frequency (TF) analysis section. After that, the TFRs were averaged across all the 24 participants for each condition.

2.5. Statistical analysis
For a statistical evaluation of the ERP and TFR responses, we used a cluster-based random permutation test (Maris & Oostenveld, 2007). It identifies clusters of significant differences between conditions in the time, space and frequency dimensions.

For every data point (electrode by time by frequency for the ERP data, electrode by time by frequency for the TFR data) of two conditions, a simple dependent-samples t test is performed (giving uncorrected p values). All adjacent data points exceeding a preset significance level (5%) are grouped into clusters. For each cluster the sum of the t statistics is used in the cluster-level test statistic. Next, a null distribution that assumes no difference between conditions is created. To create this distribution, the data points of the conditions were randomly assigned within participants for 1000 times and the largest cluster-level statistic for each randomization was chosen. Finally, the actually observed cluster-level test statistics are compared against the null distribution, and clusters falling in the highest or lowest 2.5th percentile are considered significant.

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>Valence</th>
<th>Arousal</th>
<th>Concreteness</th>
<th>Freq_word</th>
<th>Freq_1st</th>
<th>Freq_2nd</th>
<th>Nr_stroke</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral</td>
<td>5.01 (.84)</td>
<td>4.42 (.32)</td>
<td>5.24 (.88)</td>
<td>2.78 (.53)</td>
<td>3.14 (.89)</td>
<td>3.25 (.90)</td>
<td>3.02 (.77)</td>
</tr>
<tr>
<td>Positive</td>
<td>4.95 (.75)</td>
<td>5.18 (.40)</td>
<td>5.22 (.88)</td>
<td>2.55 (.60)</td>
<td>3.07 (.77)</td>
<td>3.13 (.96)</td>
<td>3.02 (.96)</td>
</tr>
<tr>
<td>Negative</td>
<td>4.32 (.40)</td>
<td>3.30 (.36)</td>
<td>4.95 (.84)</td>
<td>2.54 (.53)</td>
<td>3.07 (.89)</td>
<td>3.02 (.96)</td>
<td>3.02 (.96)</td>
</tr>
</tbody>
</table>

Note: Each cell displays the mean value (and the standard deviation) of the rating. Freq_word: logfrequency of the whole word; Freq_1st: logfrequency of the first character of the word; Freq_2nd: logfrequency of the second character of the word; Nr_stroke: number of strokes.

### 3. Results

#### 3.1. Behavioral results

The average reaction times (mean ± SD = 434 ms ± 90, 426 ms ± 85 and 429 ms ± 91) and accuracies (mean ± SD = 99.7 ± 1.5%, 99.7 ± 1.5% and 99.7 ± 1.5%) were obtained for the negative, positive and neutral fillers respectively. We found no significant difference among conditions in either RT (f(2,46) = 1.03, p = .36) or accuracy (f(2,46) < 1).

#### 3.2. ERP results

Fig. 1A presents the grand average ERP waveforms evoked by the nouns in different emotional valence conditions.

The contrast of negative vs. neutral revealed two (marginally) significant clusters, indicating that the negative nouns elicited a larger P2 in the time window of 180–270 ms over anterior-central region (p = .092) and a larger late positivity in the time window of 500–700 ms over left anterior-central region (p = .007) than the neutral nouns. In addition, the contrast of negative vs. positive revealed three significant clusters, showing a larger P2 in the time window of 180–320 ms over central region (p = .023), a larger late positivity in the time window of 460–780 ms (p < .001) and 840–980 ms (p = .011) over anterior-central region for the negative compared to the positive nouns. No significant cluster was found...
for the contrast of positive vs. neutral. The distributions of the observed ERP effects are shown in Fig. 1B.

### 3.3. TF results

Fig. 2A presents the TFRs induced by the three emotional conditions of nouns at one representative electrode (Pz). For the low frequency band (2–30 Hz), the contrasts of negative vs. neutral nouns, and positive vs. neutral nouns both revealed one significant cluster ($p = .03$ and $p = .049$, respectively) in the frequency range of 9–14 Hz in the time interval of 0.5–1.0 s over posterior region, while no difference was found for the contrast of negative vs. positive nouns ($p = .649$). Although visual inspection showed theta power difference among the three conditions, no statistically significant difference was found for the theta frequency band in any of the contrasts. In addition, no significant cluster was found in the statistical analysis of the data in the higher frequency bands. Fig. 2B presents the TFR contrasts for each pair of conditions as well as the scalp
distributions of the TFR effects. Fig. 3 shows the time course of the evolution of alpha power (9–14 Hz) after word onset at electrode Pz.

Fig. 4 presents the TFRs obtained after the TF analysis of ERPs in the three conditions at electrode Pz. The negative nouns elicited both a larger P2 and a larger LPP than the positive and neutral words. Moreover, statistical analysis showed no significant difference for any comparison.

4. Discussion

This study aimed to investigate the brain dynamics underlying emotional processing of nouns in an implicit task. The ERP and TFR effects in response to emotional valence were assessed in a shallow processing condition (i.e., color detection task). The negative words elicited both a larger P2 and a larger LPP than the positive and neutral words. Moreover, both the negative and positive words
induced strong alpha power suppressions relative to the neutral words in the time window of 500–1000 ms.

4.1. Negative words elicited different ERPs compared to positive and neutral words

During the color detection task, the negative words produced both an early P2 and a late LPP effect relative to the neutral and positive words. Note that although the statistical analysis of the difference between the negative and the positive words revealed two late positive effects, we took them as one LPP effect given their similar scalp topographies and almost-adjacent time intervals. The P2 effect in response to emotional valence of words has been repeatedly found in previous studies (Bernat, Bunce, & Shevrin, 2001; Herbert, Kissler, Junghöfer, Peyk, & Rockstroh, 2006; Kanske & Kotz, 2007; Ortigue et al., 2004; Schapkin, Gusev, & Kuhl, 2000; Trauer et al., 2012). Although the direction of the effect varied across studies (larger P2 for all emotional words, only for the negative or only for the positive words compared to neutral words), the P2 effect is assumed to reflect post-perceptual selective attention in the service of enhanced lexico-semantic analysis of task-irrelevant emotional words (Bernat et al., 2001; Herbert et al., 2006; Trauer et al., 2012). Such an early ERP effect supports the notion that the emotional aspects of words are processed automatically. In addition, the LPP effect has been related to deeper emotional evaluation due to the motivational relevance of the stimuli (Citron, 2012). Therefore, the larger LPP, together with the previous P2 effect, indicates that people are more aware of the negative than the neutral and positive information because negative information is more relevant for biological survival. The phenomenon that people preferentially process negative compared to positive and neutral stimuli is referred to as “negative bias” (Ito, Larsen, Smith, & Cacioppo, 1998).

The color detection task could be successfully performed on the basis of perceptual analysis of the words, and therefore the emotional valence of the words should be irrelevant for the task. One might argue that color itself contains emotional information. For instance, red can be positive (e.g., happiness) or negative (e.g., danger). Likewise, white can be negative (e.g., death) or positive (e.g., pure). However, the color-emotion association has mostly been found during explicit association tasks. Because we only asked the participants to press a button when they detected words printed in red font, we feel that it is unlikely that it induced a color-emotion association in the “implicit” color detection task. Moreover, since the critical words were all printed in white font, any emotional processing caused by the white color would be the same for both the emotional and neutral words. Therefore, we do not think the color detection task has had any systematic influence on the emotional processing of the critical words in our stimulus materials. Our findings are in line with several recent ERP studies in which the emotional meaning of words was irrelevant to the task (Rellecke et al., 2011; Schacht & Sommer, 2009b; Trauer et al., 2012). Schacht and Sommer (2009b) instructed participants to indicate whether all the letters of the words were written in the same font or not. Rellecke et al. (2011) asked participants to discriminate words and faces, while Trauer et al. (2012) required participants to pay attention to the movements of squares that were superimposed on emotional or neutral words. Although the exact ERP effects were different between the current study (P2 and LPP effects) and the above-mentioned three studies (EPN and LPP effects in the Schacht and Sommer (2009b) study, P1 effect in the Rellecke et al. (2011) study, P2 and N400 effects in the Trauer et al. (2012) study), the presence of ERP effects indicates that the emotional meaning of words can be automatically activated. Nevertheless, another study found no ERP effect when shallow processing was made (Hinojosa et al., 2010). Hinojosa et al. (2010) asked participants to identify meaningful words embedded in a stream of non-recognizable stimuli or pseudo words. They only found EPN and LPP effects when the emotional words were embedded in pseudo words, suggesting that some degree of linguistic processing is needed to activate the emotional aspects of words. The discrepancy might be attributed to the fact that the duration of the presentation of the words in this study was much shorter (300 ms) than in the current study, and that the motor responses immediately following the presentation of the words might have masked possible ERP effects.

Overall, our data provide additional evidence that people automatically devote attention to negative words and engage in enhanced lexico-semantic analysis as well as deeper evaluative processing of negative words compared to neutral and positive words, even when the emotional valence of words is not task-relevant.

4.2. A sustained alpha decrease was found for emotional words

The TFRs of emotional and neutral words displayed different patterns of alpha activity. For both the negative and the positive
words, alpha power suppressions were found starting around 200 ms and lasting till 1000 ms. However, for the neutral words the alpha power was first suppressed and then recovered, and even increased relative to baseline at around 500 ms. Since the alpha frequency band suppression relates to the engagement of attention (Hanslmayr et al., 2011; Jensen et al., 2012), the initial alpha power suppression (around 200–500 ms) for both the emotional and the neutral words suggests that the words received attentional resources irrespective of their emotional valence, which was probably guided by the color detection task. However, the alpha power increase in the later time window (around 500–1000 ms) for the neutral words might indicate a disengagement of attention after the initial processing of the neutral words (Jensen et al., 2012).

The observation of alpha power decrease is consistent with a number of previous studies on emotional processing (Balconi et al., 2009; Cui et al., 2013; De Cesarei & Codispoti, 2011; Schmidt & Trainor, 2001; Simons et al., 2003). For instance, alpha power differences between emotional and neutral stimuli were found over parietal and/or occipital regions in different time windows [280–340 ms: Keil et al. (2001); 400–800 ms: Cui et al. (2013); 300–700 ms: De Cesarei and Codispoti (2011)], indicating enhanced perceptual analysis of the input (De Cesarei & Codispoti, 2011; Keil et al., 2001) or motivated attention (Cui et al., 2013; Simons et al., 2003). Some other studies observed similar emotional modulation of alpha power in larger time windows (up to 6 s) over frontal regions, presumably reflecting the activation of an emotion-related network (Balconi et al., 2009; Schmidt & Trainor, 2001). These studies required participants to either explicitly evaluate the emotional valence/arousal of stimuli (Balconi et al., 2009; Schmidt & Trainor, 2001) or to passively view the stimuli (Cui et al., 2013; De Cesarei & Codispoti, 2011; Keil et al., 2001; Simons et al., 2003). In the current study, only a perceptual analysis of the words was necessary, so the alpha response seems to be independent of the task at hand.

In addition, the alpha power reduction has been systematically linked to enhanced attention outside of the emotional processing domain (Hanslmayr et al., 2011; Jensen et al., 2012; Klimesch, Doppelmayr, Russegger, Pachinger, & Schweiger, 1998), so the alpha response is better explained in terms of general attentional differences to the emotional and neutral words, and thus should not be taken as emotion-specific. For example, during sentence comprehension the processing of semantically incongruent (but emotionally neutral) words relative to previous discourses also induced neutral words, supporting the notion of “negative bias” and of automaticity of processing of emotionally valenced words. In addition, both the negative and positive words induced long-lasting alpha power suppressions whereas an alpha power rebound was induced by the neutral words, indicating at a more basic cognitive level that more sustained attentional resources were allocated towards the processing of emotional words, even though emotionality was task-irrelevant.

5. Conclusions

This study examined both ERP and TFR responses to emotional and neutral words in a shallow processing task. The negative words elicited a larger P2 and a larger late positivity than the positive and neutral words, supporting the notion of “negative bias” and of automaticity of processing of emotionally valenced words. In addition, both the negative and positive words induced long-lasting alpha power suppressions whereas an alpha power rebound was induced by the neutral words, indicating at a more basic cognitive level that more sustained attentional resources were allocated towards the processing of emotional words, even though emotionality was task-irrelevant.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.bandl.2014.07.011.
References


