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Event related potentials to emotional adjectives during reading

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Abstract

We investigated to what extent emotional connotation influences cortical potentials during reading. To this end, event-related potentials (ERPs) were recorded during reading of high arousal pleasant and unpleasant and low arousal neutral adjectives that were presented at rates of 1 Hz and 3 Hz. Enhanced processing of both pleasant and unpleasant emotional compared to neutral adjectives was first reflected in an amplified early posterior negativity (EPN) starting from 200 ms after word onset. Later potentials (>300 ms), as analyzed in the slower 1 Hz condition, revealed facilitated processing selectively for pleasant adjectives that were associated with a reduced N400 and an enhanced late positive potential (LPP). Pleasant adjectives were also better remembered in an incidental memory test. Thus, emotionally relevant adjectives are processed spontaneously and selectively. Initially, emotional arousal drives attention capture (EPN). Healthy subjects may have a natural bias toward pleasant information facilitating late ERPs (N400, LPP) to pleasant adjectives as well as their superior recall.

Descriptors: Emotion, Word processing, Early posterior negativity, Recognition potential, N400, Late positive potential

Human perception is tuned to preferentially detect and discriminate emotionally relevant stimuli from neutral ones (Lang, Bradley, & Cuthbert, 1997). Emotionally unpleasant and pleasant stimuli spontaneously arouse and capture the viewer's attention and are processed in a facilitated manner. This "stimulus-driven," "natural," or "motivated" attention helps to increase the likelihood with which relevant (i.e., potentially threatening or rewarding) information can be perceived and further evaluated (Bradley & Lang, 2000; Lang et al., 1997). Growing evidence in support of this thesis comes from electroencephalographic event-related brain potential (ERP) studies that investigate the time course of emotional picture processing. These ERP studies demonstrate that pleasant and unpleasant pictures spontaneously capture and guide selective attention at early (<300 ms) and late (>300 ms) processing stages. An enhanced early posterior negativity (EPN) from around 200 ms after stimulus onset and an increased late positive potential around 500 ms have by now been repeatedly reported to differentiate emotional from neutral pictures (for an overview, see Schupp, Flaisch, Stockburger, & Junghofer, 2006).

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However, it is still controversial if processing differences between stimuli varying in emotional significance also occur for perceptually simple and highly symbolic visual inputs such as words and whether emotional significance will be extracted as automatically from words as from pictures. The meaning of words is entirely acquired by learning, whereas for other affective stimuli, such as faces or fear-relevant material such as spiders or snakes, emotional significance is, at least to some extent, supposed to be based on evolutionary preparedness (Öhman, Flykt, & Esteves, 2001; Öhman & Mineka, 2001). Moreover, words provide a much more abstract description of emotional contents than pictures and can be assumed to be much less perceptually engaging than visually complex color slides. Indeed, two recent ERP studies attribute at least the early emotion effect during picture viewing (EPN) mostly to differences in stimulus complexity, rather than emotional content (Bradley, Hamby, Löw, & Lang, 2007; Codispoti, Ferrari, & Bradley, 2007). Because of their lesser visual complexity, words may be less prone to confounds from large perceptual differences and therefore particularly well suited for investigating the effect of emotional content on cortical processing. Q2

So far, the literature regarding the impact of emotional content on early (<300 ms) ERP indices of word processing provides mixed results. Several studies failed to find affective differentiation in early time windows, suggesting that the emotional connotation of written words may either be irrelevant or analyzed relatively later in the processing stream, only after their meaning has been subjected to higher-level semantic processing and conscious recollection as typically reflected in variations of later brain potentials such as the P3 or late positive potential (LPP; e.g., Cacioppo, Crites, Bernston, & Coles, 1993; Fischler & Bradley, 2006). Such findings may also reflect the possibility that early emotion effects (< 300 ms) are particularly sensitive to stimulus complexity (Bradley et al., 2007; Codispoti et al., 2007) and therefore may not arise with perceptually simple stimuli such as words. On the other hand, a few studies report surprisingly early ERP differentiation between emotional and neutral words, particularly when active tasks, such as evaluative or lexical decision, were used. Occasionally ERP modulations driven by emotional content have been observed as early as the P1–N1 time window at about 100–200 ms, extending to the P2–N2 time window at about 200–260 ms after word onset (Begleiter & Platz, 1969; Chapman, McCrary, Chapman, & Bragdon, 1978; Ortigue et al., 2004). But although a number of ERP studies found early brain potentials (< 300 ms) to distinguish between affective and neutral words across several different experimental designs, tasks, and subject groups (for a review, see Kissler, Assadollahi, & Herbert, 2006), the validity of these findings is still debated (Bradley et al., 2007; Fischler & Bradley, 2006). The earliest reported effects (P1, N1) are particularly controversial, as many researchers would not expect access to word meaning to occur earlier than 200 to 300 ms after word onset. Traditional theories of word processing assume sequential analysis, with the assembly of visual word form at around 180–200 ms after stimulus onset preceding semantic analysis (Cohen et al., 2000), although differences in conditioned responses to simple geometric figures have been observed as early as the C1 component (Stolarova, Keil, & Moratti, 2006). If the cortical response to emotionally significant words were mainly based on conditioned responses, extremely rapid discrimination between emotional and neutral stimuli could be expected to occur before semantic access.

Somewhat later than the N1, namely, 250 ms after stimulus onset, an increased ERP response to emotionally arousing words has recently been reported, when subjects read, without further instructions, a large number of nouns presented in rapid serial visual presentation at 3 or 1 Hz frequencies (Kissler, Herbert, Peyk, & Junghofer, 2007). The enhanced occipito-temporal negativity differentiated both pleasant and unpleasant from neutral nouns. The potential developed between 200 and 300 ms after word onset and had its maximum around 250 ms. With regard to timing and topography, this effect is largely consistent with affective modulation of the aforementioned EPN potential found for affective pictures (e.g., Junghofer, Bradley, Elbert, & Lang, 2001; Schupp, Junghofer, Weike, & Hamm, 2003a, 2003b, 2004). During passive picture viewing, emotional pictures, pleasant and unpleasant alike, lead to larger EPN responses than neutral pictures. This effect is further increased when attention is explicitly directed to emotional pictures (Schupp, Stockburger, Codispoti, et al., 2007), whereas performing a highly demanding feature-based attention task on emotional pictures interferes with the emotion-driven EPN enhancement (Schupp, Stockburger, Bublatzky, et al., 2007). The EPN to emotional pictures also resembles an early negativity occurring in response to targets during instructed classification of complex pictures (Codispoti, Ferrari, Junghofer, & Schupp, 2006). Together, the picture studies suggest that the emotional-content-driven EPN effect reflects differential initial stimulus categorization and allocation of "motivated" attention, although the extent to which this effect is susceptible to differential stimulus complexity has been debated (Bradley et al., 2007; Codispoti et al., 2007).

The EPN effect for emotional words is also reminiscent of an early negativity repeatedly related to early semantic processing in reading research, namely, the recognition potential (RP), which peaks around 250 ms after word onset (Dien, Frishkoff, Cerbone, & Tucker, 2003; Rudell, 1992; for a review, see also Martin-Loeches, 2007). The RP arises when words are presented rapidly in continuous streams. It is larger for meaningful words relative to meaningless stimuli (e.g., pseudowords, nonwords, and letter strings) and further amplified in response to attended compared to unattended words (Rudell & Hua, 1996). Although the RP has been most frequently studied using verbal material, it has also been found with picture and face stimuli (Rudell, 1992; Hinojosa, Martin-Loeches, Gomez-Jarabo, & Rubia, 2000). The RP has been interpreted as a signature of early semantic processing (e.g., Hinojosa et al., 2001; Hinojosa, Martin-Loeches, Munoz, Casado, & Pozo, 2004; Martin-Loeches, Hinojosa, Gomez-Jarabo, & Rubia, 2001; Rudell, 1992).

Although it remains to be conclusively determined to what extent the RP and the EPN effect reflect the same or different mechanisms, there are clear similarities, and both cortical effects seem to reflect rudimentary semantic stimulus classification and are sensitive to attention modulations. At the very least, the effects occur in a time window where the analysis of formal stimulus attributes is completed and effects are theoretically consistent with early conceptual analysis. Thus, along with picture studies, our previous ERP study of emotional word processing suggests that the emotional connotation of a word enhances its early conceptual processing via mechanisms of "motivated attention" (Kissler et al., 2007). However, this previous study with nouns presented rapidly in continuous streams (RSVP) did not explicitly assess whether and to what extent either very early (P1, N1) or later stages of word processing (N400, LPP) are modified by a word's emotional connotation.

A later component extensively studied in semantic word processing is the N400 component (Kutas & Hillyard, 1980, 1984). Modulation of the N400 by emotional word content has hardly been investigated, although some studies have found amplitude variations of N400 or N400-like ERPs to emotional words in normal controls and a lack thereof in psychopaths (Kiehl, Hare, McDonald, & Brink, 1999; Williamson, Harpur, & Hare, 1991). The N400 potential reflects semantic integration within a larger context, either created by subjects' expectations on sentence content (Kutas & Federmeier, 2000) or other contextual factors such as participants' emotional state (Chung et al., 1996; Federmeier, Kirson, Moreno, & Kutas, 2001; Kiefer, Schuch, Schenk, & Fiedler, 2007). Usually, larger N400 amplitudes reflect a violation of semantic expectations and difficulties with context integration. However, mood can modulate N400 amplitude, as unexpected and distantly related words elicit smaller N400 amplitudes in sentences spoken in mildly positive mood, reflecting facilitated semantic integration in positive mood (Federmeier et al., 2001). In line with this finding Kiefer and colleagues, investigating the effect of mood on the cortical processing of pleasant and unpleasant adjectives, reported facilitated semantic integration of pleasant adjectives when subjects were in a positive mood as indicated by attenuated N400 amplitudes for pleasant in contrast to unpleasant adjectives. Thus, a number of studies suggest that both a word's emotional content and the participants' emotional state may affect the N400 ERP response.

As in ERP studies of affective picture processing (e.g., Bradley et al., 2007; Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp et al., 2000), studies on the impact of emotional content on visual word processing often focused on late positive potentials (LPP). LPP are thought to mirror cognitive processing load required for sustained attention, stimulus evaluation, or memory encoding (Kok, 1997). So far, enhanced LPPs with a centro-parietal maximum occurring around 500 ms after stimulus onset are the most consistently, although not invariably (see Kissler et al., 2006; Vanderploeg, Brown, & Marsh, 1987), reported effects of emotional word content on the ERP. Fischler and Bradley (2006) review a series of studies where cognitive processing demands were systematically varied. A robust arousal-driven LPP (larger for both pleasant and unpleasant compared to neutral words) was found whenever the task required semantic evaluation, but emotional-neutral differences were attenuated or even absent when orthographic or low-level lexical aspects of the words had to be evaluated. However, these authors report no early effects (<300 ms) of emotional content on the visually evoked ERP in any of their studies.

Corroborating a major impact of emotional arousal on the LPP, Williamson et al. (1991) found larger LPPs to positively and negatively valenced words in contrast to neutral words when normal subjects performed a lexical decision task. Herbert, Kissler, Junghofer, Peyk, and Rockstroh (2006) had subjects covertly evaluate pleasant, unpleasant, and neutral adjectives. Although earlier positivities (P2, P3a) responded to the arousal dimension of the words, the LPP was selectively enhanced only during processing of pleasant adjectives. A similar processing advantage for pleasant contents has been reported by Schapkin, Gusev, and Kuhl (2000), who found enhanced LPP responses to pleasant compared to both neutral and unpleasant words during an emotional evaluation task.

With picture stimuli, larger LPPs in response to emotionally arousing contents have been reported under conditions where subjects were asked to attend to the pictures or evaluate their emotional content for later memory testing as well as during passive picture viewing (e.g., Bradley et al., 2007; Cuthbert et al., 2000; Keil et al., 2002; Palomba, Angrilli, & Mini, 1997; Schupp et al., 2000, 2003b, 2004). LPP responses to emotional words during uninstructed silent reading, the analogy to free picture viewing, have not yet been investigated.

A demonstration of facilitated processing of stimuli with emotional content in the absence of a specific experimenter-induced task would considerably strengthen the argument that all kinds of emotional stimuli, even highly abstract and symbolic ones such as words, spontaneously and preferentially draw on processing resources as part of our evolutionary heritage. To further investigate this issue, the present study evaluates affective modulations of early (P1, N1, EPN) and late (N400, LPP) event-related potentials as subjects silently and repeatedly read random sequences of pleasant, unpleasant, and neutral adjectives, presented either at a fast (three words per second) or slow (one word per second) rate. Adding the slower stimulation rates allows us to disambiguate the timing of the effects: If early ERP effects, as measured in the faster stimulation rate, were due to overlap from late components from the previous stimulus, the timing of the effect would shift at a different presentation rate. Furthermore, at slower presentation rates the modulation of later potentials by emotional contents can be studied.

We repeatedly presented series of words at both the 3-Hz and the 1-Hz stimulation rates. Stimulus repetition allows assessment of the stability and processing nature of potential emotion effects. In passive attention, stimuli may capture attentional resources simply because they are novel. Widely studied in the context of the orienting response, the repeated presentation of sensory stimuli usually prompts habituation, that is, response decrement (for a review, see Öhman, Flykt, & Lundqvist, 2000). Previous picture viewing studies suggest little habituation of the EPN enhancement to emotional pictures across 90 repetitions (Codispoti et al., 2007; Schupp, Stockburger, et al., 2006), and a similar observation has been made across 10 repetitions for emotional words (Kissler et al., 2007), but there are no data on repetition effects on later components during emotional word processing. Data from picture viewing studies suggest reduction of emotion effects on the LPP only after a very large number of repetitions: Olofsson and Polich (2007) found no reduction of the emotion effect after 5 repetitions, but Codispoti et al. (2007) suggested a decrement of the effect after 90 repetitions.

In view of the so far very heterogeneous findings regarding the timing and direction of processing differences between pleasant, unpleasant, and neutral words in visual word processing and the recent debate about the influence of low-level visual features on ERP effects in emotional picture viewing, the present study aimed at replicating and extending our previous results (Kissler et al., 2007) with a completely independent set of stimuli, namely, adjectives with emotional connotations. Adjectives have often been used in studies of implicit attitudes (e.g., Cacioppo et al., 1993) as well as in ERP studies of emotional word processing (Bernat, Bunce, & Shevrin, 2001) and, particularly when they have emotional connotations, often describe personality traits. Moreover, adjectives, as a word class, occur much less frequently than the previously used nouns, as their inherent function is to further characterize an object or a person (Dixon, 1999), thus extending our previous results to a pool of stimuli with high personal relevance, but much lower frequency counts than we have previously used. Interactions of various neurolinguistic effects with word frequency have previously been reported (Assadollahi & Pulvermuller, 2001, 2003). We use a stimulus set where the emotion categories were matched for a wide range of stimulus attributes of no interest, namely, word length, orthographic neighborhood density, bigram frequency, word frequency, and concreteness.

In line with previous studies of both emotional nouns (Kissler et al., 2007) and pictures (e.g., Junghofer et al., 2001; Schupp et al., 2004; Schupp, Stockburger, et al., 2006), we expected an early negativity to respond to the emotional arousal dimension of the presented adjectives, being larger for both pleasant and unpleasant than for neutral words. Furthermore, we expected this component to be essentially unaffected across multiple repetitions (Codispoti et al., 2007; Kissler et al., 2007; Schupp, Stockburger, et al., 2006). Concerning earlier time windows as indexed by the P1 and N1, we expected no emotional modulation, because the literature suggests that affective modulation of P1–N1 amplitudes seems to be restricted to specific designs, word contents, or certain patient groups (for a review, see Kissler et al., 2006).

For the N400 component our analysis was exploratory, because, as yet, very few studies have investigated the impact of emotional content on this component. However, effects of facilitated semantic integration in pleasant mood, reflected by smaller N400 amplitudes for pleasant as opposed to unpleasant adjectives, have been reported (e.g., Kiefer et al., 2007). The amplitude of N400 responses is known to diminish across multiple stimulus repetitions, although additional factors, such as word frequency, can modify this repetition effect (e.g., Rugg, 1990; Young & Rugg, 1992). Whether possible emotion effects on the N400 are reduced across several repetitions remains to be empirically tested.

In picture studies the LPP has been found to respond primarily to the emotional arousal dimension of the stimuli (e.g., Cuthbert et al., 2000), indicating that both pleasant and unpleasant pictures are selected for sustained processing irrespective of the processing task. The question is open whether, during uninstructed silent reading, the LPP will respond to the words' emotional connotation and, if so, whether a possible difference will be driven by emotional arousal (Fischler & Bradley, 2006) or valence (Herbert et al., 2006; Schapkin et al., 2000). It is also unclear to what extent a possible emotion modulation is altered across several word repetitions (Codispoti et al., 2007; Olofsson & Polich, 2007). As in our previous study (Kissler et al., 2007), we also report postexperimental incidental memory data from the subjects to assess whether reading of emotional content has a lasting impact on memory.

Methods

Participants

A total of 16 native German students (8 female, 8 male, mean age: 27 years) from the University of Konstanz participated for either course credit or a financial bonus of 10 Euros. All participants were right-handed as determined by handedness scores on the Edinburgh Handedness Inventory (Oldfield, 1971). Upon interview, participants reported normal or corrected-to-normal vision and no drug abuse, neurological, mental, or chronic bodily diseases, or medication for any of these. All participants read and signed a consent form approved by the University of Konstanz Institutional Review Board.

Stimulus Material

Experimental stimuli consisted of 180 adjectives from three different emotional categories, including 60 highly arousing pleasant, 60 highly arousing unpleasant, and 60 low arousing neutral adjectives. Words were selected according to previous independent ratings of 45 student subjects on a total of about 500 adjectives. The ratings were obtained on the dimensions of perceived emotional arousal and hedonic valence using a standardized version of the Self-Assessment Manikin (SAM; Bradley & Lang, 1994; Lang, 1980). Pleasant, unpleasant, and neutral word categories differed significantly with respect to valence ratings. Pleasant and unpleasant adjectives did not differ significantly from each other in arousal, but both were significantly more arousing than neutral adjectives. The pleasant and unpleasant adjectives described a broad range of affective traits and states (e.g., successful, happy, brutal, anxious, nervous, sick, etc.) whereas neutral adjectives referred to less arousing and salient traits and states (e.g., neutral, normal, civilian, formal, etc.). In addition, adjectives were rated for concreteness by 31 student subjects using a 9-point Lykert scale, and word categories were controlled for a number of additional variables such as word frequency, word length, and orthographic neighborhood density and bigram frequency. Word frequency, orthographic neighborhood density, and bigram frequency were controlled using frequency counts for written language from the standardized word database CELEX (Baayen, Piepenbrock, & Gulikers, 1995) and neighborhood density and bigram frequeny were analyzed with WordGen software (Duyck, Desmet, Verbeke, & Brysbaert, 2004). Emotional word categories did not differ in concreteness ratings, word frequency, or word length, orthographic neighborhood density or bigram frequency. Data are presented in Table 1.

Experimental Design

All words were presented in black letters (Times font, 40 point) on a white background, centered on a 15-in. computer monitor positioned 80 cm from the participants' eyes. The order of words was randomized with the restriction that transition between pleasant, unpleasant, and neutral words was held equiprobable and no more than three words of the same valence could appear in sequence. Adjectives were presented randomly, in 10 blocks of rapid serial visual stream presentation (RSVP). Each block presented all 180 adjectives (60 pleasant, 60 unpleasant, and 60 neutral) in different random orders. Stimuli were presented at two different stimulation rates with either 1 Hz (1000 ms per word) or 3 Hz (333 ms per word) and no perceivable interstimulus interval. In 5 of the 10 blocks, words were presented at a presentation rate of 1 Hz and the other 5 blocks at a rate of 3 Hz. Block order was counterbalanced across subjects. Experimental runs were generated and controlled by Presentation software (Neurobehavioral Systems Inc.). An illustration of the stimulation is given in Figure 1.

Procedure

Upon their arrival, participants were familiarized with the laboratory setting and the experiment was explained to them in general terms. They were questioned with regard to their medical status, their handedness was determined, and they signed an informed consent form. Participants sat in a recliner chair in a dimly lit, sound-attenuated room and EEG as well as EOG electrodes were attached. Participants were then familiarized with the experimental instruction. They were told that words would be presented that they should read attentively. No other explicit instruction was given. At the beginning of the experiment subjects were asked to avoid eye movements, blinks, and body movements during stimulation as far as possible. In the breaks between the blocks, subjects were allowed to relax.

Thirty minutes after the experiment, participants were asked to remember as many of the presented words as they could in an unexpected free recall task.

Physiological Data Collection and Reduction

Electrophysiological data were recorded from 64 channels, using an EasyCap system and Neuroscan SynAmps amplifier and software. Vertical and horizontal electrooculograms (EOG) were recorded above and below the left and right eye (VEOG) and lateral to the outer canthus of each eye (HEOG). Raw EEG data were continuously recorded at a sampling rate of 250 Hz and referenced to the Vertex electrode (Cz). The Vertex reference was converted off-line to an average reference. During recording, impedance was held beneath 5 kΩ. Filtering, artifact rejection, and analyses of the ERP–EEG responses followed off-line: Early ERP components (P1, N1, EPN) were digitally filtered from 0.53 to 40 Hz. The N400 and LPP component were filtered with a low cutoff of 0.1 Hz. Filtered data were corrected for blinks and vertical and horizontal eye movements using the ocular correction algorithm of Brain Electrical Source Analysis (BESA) software (Ille, Berg, & Scherg, 2002). Semiautomatic artifact rejection excluded epochs if signal amplitudes at any point in

Table 1. *Stimulus Material Characteristics*

	Adjectives		
	Pleasant	Unpleasant	Neutral
Valence	6.6 (0.11)	2.7 (0.06)	5.0 (0.07)
Arousal	5.5 (0.09)	5.7 (0.09)	3.4 (0.07)
Concreteness	4.5 (0.15)	4.2 (0.14)	4.6 (0.23)
Word length	8.7 (0.33)	8.5 (0.27)	7.9 (0.29)
Word frequency	14.98 (2.49)	14.52 (3.05)	22.53 (3.61)
Orthographic neighborhood density	0.55 (0.15)	0.42 (0.11)	0.63 (0.17)
Bigram frequency	28,691 (2100)	32,053 (2299)	26,248 (2090)

Note: Mean valence, arousal, and concreteness ratings as well as word length (number of letters) and word frequency, orthographic neighborhood density, and bigram frequency for pleasant, unpleasant, and neutral adjectives. For valence, arousal, and concreteness, ratings ranged from 1 (*extremely negative valence*, *extremely low arousal or concreteness*) to 9 (*extremely positive valence*, *extremely high arousal or concreteness*). Word frequency, orthographic neighborhood density, and bigram frequency are based on counts (words per million) for written German from the CELEX database. Standard errors are in parentheses.

time were above 150 μV at any sensor or below 0.0032 μV at all sensors or if voltage differences were greater than 50 μV between two consecutive sampling points in any sensor. Artifact-free EEG data were segmented separately for each emotional word category, block, and viewing condition. In the 3-Hz stimulation conditions EEG data were segmented from 333 ms before word onset until word offset. In the 1-Hz stimulation conditions data were segmented from 1000 ms before word onset until word offset. In both viewing conditions, the prestimulus segment was used for baseline correction before averaging (333 ms in the 3-Hz condition and 1000 ms in the 1-Hz condition). Because the stimulus sequence was completely randomized, content-related differences in baseline activity cancel out.

Methodological Considerations in RSVP Designs

In RSVP designs late visual brain potentials of one stimulus may overlap into the processing of subsequent stimuli and might thus impede the unambiguous temporal assignment of ERP effects. Using an additional slower presentation rate of 1 Hz where component overlap is unlikely allows unambiguous temporal assignment of early brain potentials (Junghofer et al., 2001, Kissler et al. 2007). Moreover, at the slower presentation rate late brain potentials can be analyzed. When stimulus order is carefully counterbalanced across different word categories as in the present study, content-related differences in baseline activity are canceled out and no differences in baseline measures are to be expected.

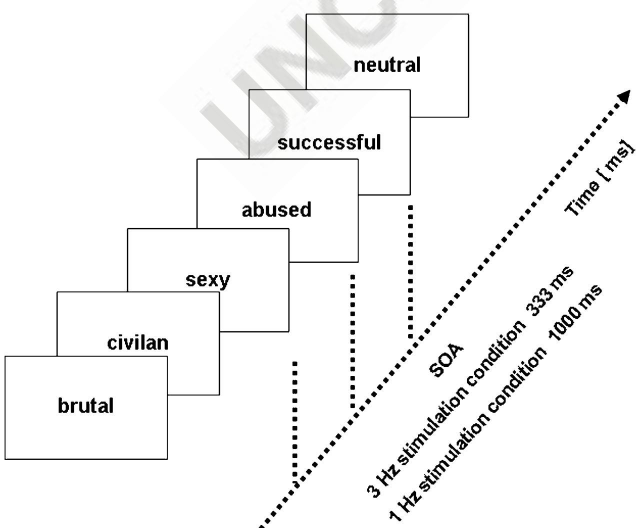

Figure 1. Experimental design. Rapid serial visual presentation (RSVP) of emotional and neutral adjectives.

Early Visual ERP Potentials (3-Hz Condition and 1-Hz Condition)

Early brain potentials (P1, N1, EPN) were analyzed as averaged activity within three discrete time windows, namely, from 80 ms to 130 ms for the P1 potential, from 130 ms to 190 ms for the N1 potential, and from 200 ms to 280 ms after word onset for the EPN. The P1 was analyzed at six left parieto-occipital (P5, P7, P9, PO3, O1, and O9) and six corresponding parieto-occipital electrodes over the right hemisphere (P6, P8, P10, PO4, O2, and O10) for which the P1 was maximally pronounced. The N1 as well as the EPN amplitudes were maximal at eight left hemisphere (TP7, TP9, P5, P7, P9, PO3, O1, and O9) and eight right hemisphere (TP8, TP10, P6, P8, P10, PO4, O2, and O10) posterior electrodes. The reported electrode groups were selected on the basis of ERP grand average waveforms reflecting the topography and temporal dynamics of each of the three brain potentials. To determine hemisphere differences in affective modulation patterns, effects involving hemispheric lateralization are reported for normalized data according to the procedure suggested by McCarthy and Wood (1985):

$$X_{i\text{new}} = (X_{i\text{meas}} - \text{min})/(\text{max} - \text{min}),$$

where $X_{i\text{new}}$ is the normalized value at sensor i, $X_{i\text{meas}}$ is the measured value at sensor i, and max and min are the maximum and minimum potentials across all sensors within each subject.

Late Visual ERP Potentials (1-Hz Condition Only)

N400 potential. Visual inspection of individual waveforms revealed the N400 component as most prominent in an interval between 360 and 470 ms after word onset and at medial and medio-lateral centro-parietal electrodes with a right dominant focus. Across subjects the N400 potential could be reliably detected at electrodes Cz, C4, CPz, CP2, and CP4. For statistical analysis these five centro-parietal electrodes were grouped together and the N400 potential was scored by determining the mean voltage activity within a time window from 360 ms to 470 ms after word onset.

Late positive potential. The LPP was most pronounced between 470 ms and 600 ms after word onset. In contrast to the N400 potential, the LPP revealed no hemisphere dominance and was more pronounced over centro-parietal leads. Effects are reported for single subjects' averaged activities from 470 to 600 ms from a group of 10 electrodes (CPz, CP3, CP4, Pz, P1, P2, P5, P6, PO3, PO4) where the LPP could be reliably detected.

For the N400 and the LPP no hemisphere laterality effects were analyzed. Instead, brain activation elicited at single electrodes was collapsed across the respective electrode groups in order to get a topographically stable estimate of the underlying brain activity.

Statistical Data Analysis

Early Visual ERP Potentials (3-Hz Condition and 1-Hz Condition)

Effects of early selective processing of emotional adjectives on the P1, N1, and EPN were statistically examined by separate repeated measurements of variance (ANOVA). ANOVAs included the factors valence (pleasant, unpleasant, and neutral), repetition (five blocks per stimulation rate), presentation rate (3 Hz vs. 1 Hz), and hemisphere (left posterior sensors vs. right posterior sensors) as repeated measures for each potential. Interaction effects including the factor hemisphere are reported for normalized data that were used to follow up significant effects apparent in the raw data. Follow-up planned comparison tests were performed to test affective modulation patterns across all three emotion categories, all stimulus repetitions, both presentation rates, and both hemispheres.

Late Visual ERP Potentials (1-Hz Condition Only)

N400 and LPP. Effects of selective processing of emotional adjectives were analyzed for the N400 and the LPP, separately. Statistical analysis was conducted with ANOVAs including the factors valence (unpleasant, pleasant, and neutral) and repetition (five blocks of repeated word presentations) as repeated measures.

Significant effects containing more than one degree of freedom in the numerator are reported after adjustment for violations of the sphericity assumption using the Greenhouse–Geisser procedure and Greenhouse–Geisser epsilons (G–G ε) smaller than 1.0.

Memory performance. Whether subjects' incidental memory performance differed depending on the emotional content of the adjectives was statistically tested by repeated measurement ANOVA with the factor valence containing the levels pleasant, unpleasant, and neutral. Two participants did not take part in the free recall test, so the behavioral analysis contained data from 14 out of 16 participants.

Results

Early Visual ERP Potentials

P1 and N1. Emotional and neutral adjectives elicited a prominent P1 and N1 potential with peak amplitudes at left and right parieto-occipital electrode sensors. However, no statistically significant main effects of valence, P1: $F(2,30) = 0.39$, $p > .65$, $\varepsilon = .83$; N1: $F(2,30) = 0.58$, $p > .56$, $\varepsilon = .97$, or any interactions with the factor valence were observed either for the P1 or the N1, Presentation Rate × Valence, P1: $F(2,30) = 0.61$, $p > .52$, $\varepsilon = .85$; N1: $F(2,30) = 0.01$, $p > .99$, $\varepsilon = .99$; Repetition × Valence, P1: $F(8,120) = 1.2$, $p > .34$, $\varepsilon = .49$; N1: $F(8,120) = 0.86$, $p > .5$, $\varepsilon = .56$, and Presentation Rate × Repetition × Valence, P1: $F(8,120) = 1.9$, $p > .11$, $\varepsilon = .55$; N1: $F(8,120) = 1.1$, $p > .4$, $\varepsilon = .56$; Hemisphere × Valence, P1: $F(2,30) = 0.71$, $p > .5$, $\varepsilon = .89$; N1: $F(2,30) = 0.86$, $p > .4$, $\varepsilon = .82$. In addition, besides a significant main effect of presentation rate, P1: $F(1,15) = 30.2$, $p < .001$; N1: $F(1,15) = 34.4$, $p < .001$, indicating larger P1 and N1 amplitudes during the faster 3-Hz than during the slower 1-Hz word presentations, no other statistically significant main effects or interaction effects were found (all $p > .2$).

Early posterior negativity. Selective processing of emotional adjectives first occurred in a time window of the early posterior negativity at 200–280 ms after word presentation and was indicated by a significant main effect of valence, $F(2,30) = 16.0$, $p < .001$, $\varepsilon = .97$. Post hoc tests revealed significantly increased EPN amplitudes for pleasant and unpleasant compared to neutral adjectives, $F(1,15) = 23.9$, $p < .001$ for pleasant > neutral and $F(1,15) = 23.5$, $p < .001$ for unpleasant > neutral.

Across the 10 repetitions (5 per stimulation rate), the amplitude of the early posterior negative potential did not diminish significantly: repetition, $F(4,60) = 1.76$, $p > .15$, $\varepsilon = .81$, and there was also no evidence for habituation of the emotion effect: Repetition × Valence, $F(8,120) = 1.3$, $p > .26$, $\varepsilon = .56$. Thus, the amplitude of the early negative potential reliably distinguished repeatedly presented pleasant and unpleasant adjectives from repeatedly presented neutral adjectives irrespective of stimulus repetition and presentation rate: Repetition × Presentation Rate × Valence: $F(8,120) = 0.8$, $p > .51$, $\varepsilon = .7$.

No significant overall amplitude differences were found between adjectives presented at rates of 333 ms and 1000 ms: presentation rate: $F(1,15) = 0.23$, $p > .64$. In both viewing conditions pleasant and unpleasant adjectives increased the amplitudes of the EPN significantly compared to neutral adjectives: 3-Hz rate: $F(1,15) = 29.3$, $p < .001$ for pleasant > neutral; $F(1,15) = 21.1$, $p < .001$ for unpleasant > neutral; 1-Hz rate: $F(1,15) = 10.2$, $p < .005$ for pleasant > neutral; $F(1,15) = 10.6$, $p < .005$ for unpleasant > neutral. However, emotion effects tended to be more pronounced during the faster (3 Hz) than during the slower (1 Hz) word presentations: Presentation Rate × Valence: $F(2,30) = 3.2$, $p = .06$, $\varepsilon = .9$.

Analysis of the topographic distribution of the early posterior negativity did not yield any significant effects for the main factor, hemisphere: $F(1,15) = 1.16$, $p > .29$, but the laterality differed depending on emotional content and presentation speed in analyses of both raw and normalized data: Hemisphere × Duration × Valence: $F(2,30) = 4.6$, $p < .05$, $\varepsilon = .94$. Post hoc tests revealed that the interaction effect was due to a left hemispheric processing advantage for unpleasant compared to neutral adjectives at the faster 3-Hz presentation rate: 3 Hz > 1 Hz: $F(1,15) = 5.9$, $p < .05$, for unpleasant > neutral adjectives. In contrast, no hemispheric difference in affective processing across the presentation rates was obtained for pleasant compared to neutral adjectives: 3 Hz > 1 Hz: $F(1,15) = .55$, $p > .47$, for pleasant > neutral adjectives. Grand average waveforms as well as topographic difference potential maps of the early posterior negative potential are shown in Figure 2a (3-Hz presentation rate) and Figure 2b (1-Hz presentation rate).

Late Brain Potentials (1 Hz Condition Only)

N400. When adjectives were presented at a rate of 1 Hz, they elicited a negative N400 brain potential between 360 and 470 ms

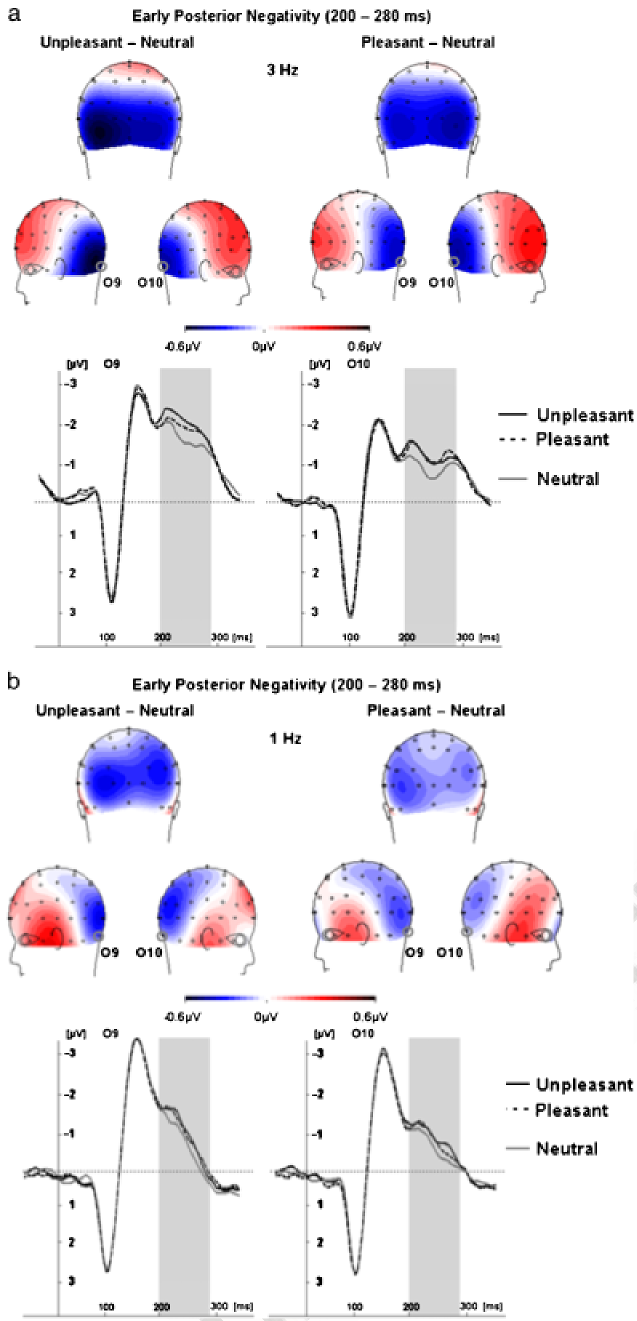

Figure 2. a: Three-hertz condition. Top: Topographic maps of the difference potentials of the early posterior negativity, subtracting neutral from pleasant and neutral from unpleasant word categories. Bottom: Grand-averaged ERP waveforms during viewing of pleasant, unpleasant, and neutral adjectives. Effects are shown for left and right occipital electrodes (O9 and O10). b: One-hertz condition. Top: Topographic maps of the difference potentials of the early posterior negativity, subtracting neutral from pleasant and neutral from unpleasant word categories. Bottom: Grand-averaged ERP waveforms during viewing of pleasant, unpleasant, and neutral adjectives. Effects are shown for left and right occipital electrodes (O9 and O10).

after word onset with a regional focus over centro-parietal leads (see Figure 3). Word content had a significant impact on the N400 amplitudes: valence, $F(2,30) = 3.2$, $p = .05$, $\varepsilon = .94$. Post hoc tests revealed smaller N400 amplitudes for pleasant compared to unpleasant adjectives: pleasant > unpleasant,

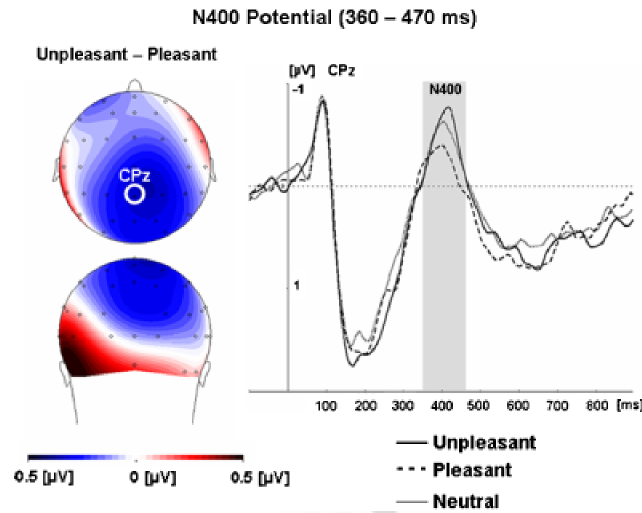

Figure 3. N400 emotion effects (1-Hz condition only). Left: Topographic maps of the difference potential of the N400 potential, subtracting unpleasant from pleasant adjectives. Right: Grand-averaged ERP waveforms of the N400 potential during viewing of pleasant, unpleasant, and neutral adjectives. Effects are shown for a representative centro-parietal electrode (CPz).

$F(1,15) = 8.3$, $p < .01$. Pleasant and neutral as well as unpleasant and neutral adjectives did not differ.

Across repeated word presentations the amplitudes of the N400 potential decreased significantly but the interaction between word repetition and emotional word category (pleasant, unpleasant, and neutral) remained unaffected: Repetition × Valence, $F(8,120) = 0.85$, $p > .5$, $\varepsilon = .71$. Figure 3 depicts effects of emotional content on the N400 component.

Late positive potential. An LPP was identified from 470 to 600 ms after word onset. The LPP varied depending on the valence of the stimulus shown: valence, $F(2,30) = 5.5$, $p < .01$, $\varepsilon = .98$. Post hoc tests revealed larger LPP amplitudes for pleasant adjectives as compared to unpleasant and neutral adjectives: pleasant > neutral, $F(1,15) = 7.04$, $p < .01$; pleasant > unpleasant, $F(1,15) = 8.4$, $p < .01$, but there was no difference between unpleasant and neutral adjectives. Word repetition did not attenuate the amplitudes of the LPP significantly: repetition, $F(4,60) = 0.71$, $p > .56$, $\varepsilon = .79$, and there was no attenuation of the valence effect by repeated presentation: Repetition × Valence, $F(8,120) = 0.41$, $p > .84$, $\varepsilon = .62$. Across 10 word repetitions, valence effects were strongest for pleasant adjectives. Affective modulation of the LPP is shown in Figure 4.

Memory performance. Memory performance of correctly remembered pleasant, unpleasant, and neutral adjectives is shown in Figure 5. In spite of modest overall incidental memory performance, pleasant adjectives were remembered better than neutral ones as indicated by a main effect of the factor valence, $F(2,26) = 5.6$, $p < .01$. Post hoc tests revealed significantly better recall for pleasant compared to neutral words, $F(1,13) = 11.08$, $p < .01$ for pleasant > neutral. Recall of unpleasant and neutral words did not differ ($p > .1$).

Discussion

The current study examined the impact of emotional word content on ERPs elicited during silent reading of adjectives presented in an RSVP design. Two different presentation rates (1 Hz and 3

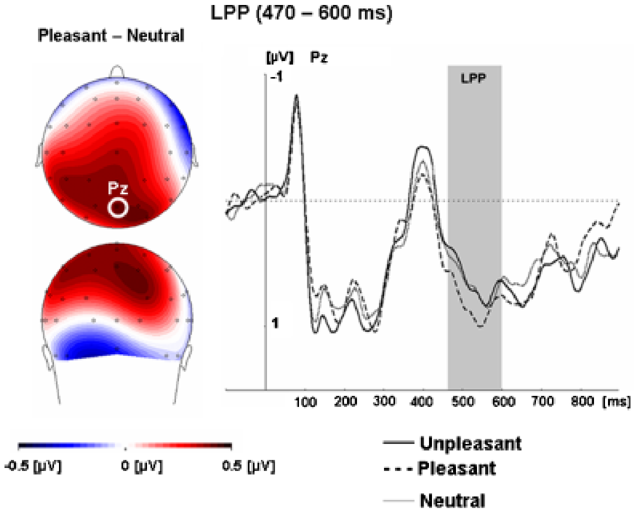

Figure 4. LPP emotion effects (1-Hz condition only). Left: Topographic maps of the difference potential of the LPP, subtracting pleasant from neutral adjectives. Right: Grand-averaged ERP waveforms of the LPP during viewing of pleasant, unpleasant, and neutral adjectives. Effects are shown for a representative centro-parietal electrode (Pz).

Hz) were used to allow an unambiguous temporal assignment of ERP differences and to address possible early (P1, N1, EPN) as well as late selection effects (N400, LPP) of emotional word content. Stimulus repetition afforded assessment of the stability of the effects. Both emotional arousal and valence influenced ERPs from the EPN onward. In the present passive viewing design where emotional and neutral words were carefully matched for additional linguistic variables, no effects of emotional content on cortical processing occurred on the P1 and N1 components. Effects in the P1/N1 time range in previous studies may thus have arisen as artifacts if experimental stimuli were not controlled for other confounding physical and linguistic dimensions. Alternatively, the extant literature suggests that ERP differentiation between emotional, particularly unpleasant, and neutral words in the P1/N1 time range is more likely to occur in studies using very brief stimulus presentation, near or even below the perceptual threshold (Begleiter & Platz, 1969; Bernat et al., 2001: Chapman et al., 1978; Chapman, McCrary, Chapman, &

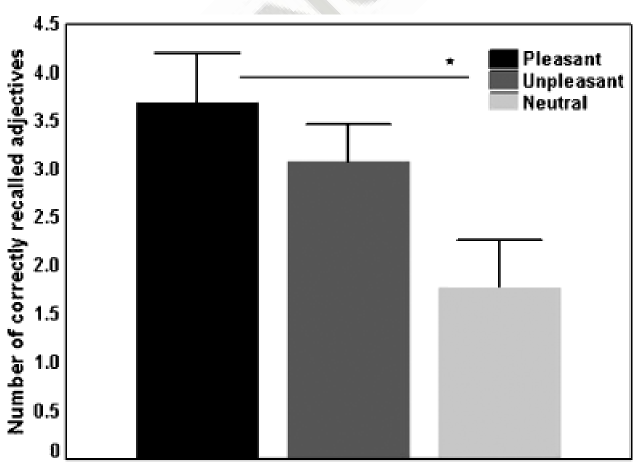

Figure 5. Memory performance of correctly remembered pleasant, unpleasant, and neutral adjectives during a surprise free recall test at about 30 min after the end of the EEG experiment.

Martin, 1980; Kostandov & Arzumanov, 1977; Ortigue et al., 2004), when disorder-relevant words are presented to patients populations (Flor, Knost, & Birbaumer, 1997; Knost, Flor, Braun, & Birbaumer, 1997; Pauli, Amrhein, Muhlberger, Dengler, & Wiedemann, 2005), or sometimes both (Knost et al., 1997; Pauli et al., 2005). A possible mechanism for effects occurring in the P1/N1 range is a subcortical feed-forward mechanism, as extensively described by LeDoux and colleagues (for reviews, see LeDoux, 2000, 2003), which appears to be responsible both for the acquisition of conditioned responses and the detection of emotional stimuli when perceptual resources are severely limited, like in subliminal or near-threshold presentation. This subcortical route may be particularly sensitized in patient populations.

Emotional arousal influenced word perception between 200 and 280 ms after word presentation as reflected by an enhanced EPN to pleasant and unpleasant versus neutral words. Similar early facilitation effects of emotional content were observed for both presentation rates. Because previous studies showed attentional modulations of the EPN with attended stimuli being associated with larger EPNs (Codispoti et al., 2006; Schupp, Stockburger, Codispoti, et al., 2007; Schupp, Stockburger, Bublatzky, et al., 2007), the present results are in line with the view that pleasant and unpleasant adjectives were selectively attended to. The results are also consistent with the view that, in visual word processing, emotion effects normally first appear in a time window where initial conceptual and semantic analysis is possible (see, e.g., Martin-Loeches, 2007). The arousal-driven pronounced early occipito-temporal negativity replicates a previous ERP study that found an enhanced early negativity to emotional nouns, both pleasant and unpleasant, during uninstructed silent reading (Kissler et al., 2007). The results of our previous and the present study show that words with emotional content are preferentially processed and support the thesis of "motivated attention" predicting enhanced visual processing of emotionally significant stimuli due to a rapid capture of attention (Lang et al., 1997). Moreover, as previously demonstrated for emotional pictures (Schupp, Stockburger, et al., 2006) and emotional nouns (Kissler et al., 2007), this early facilitated processing of emotional adjectives was not affected by stimulus repetition. Instead, its magnitude was similar across several repetitions and not due to a larger novelty response to emotional contents. The present results strengthen the case for an enhanced early posterior negativity in response to emotionally salient stimuli by showing that this effect occurs even with perceptually simple and well-controlled stimuli such as words differing on the dimension of emotional content but, on average, equal in word length, frequency, and concreteness or orthographic neighborhood density or bigram frequency.

The early cortical amplification tended to be more pronounced during the faster presentations blocks (3 Hz conditions), suggesting attention capture by emotional content increases with perceptual processing load. At processing speeds of three words per second, attention is temporally more limited and stimuli have to compete for processing resources to be correctly identified (for an overview, see Potter, 2005). From an evolutionary point of view, enhanced visual processing of emotionally significant stimuli in the context of limited attentional resources is particularly beneficial, because it ensures that potentially survival-promoting or challenging stimuli will not be missed. Written words themselves do not promote or threaten survival, but in certain situations their message may, and this phylogenetically old mechanism may have generalized across various emotional stimulus categories (faces, pictures, words).

Later ERPs (N400, LPP) were analyzed in order to explore whether the emotional content of single words is processed beyond initial attention capture and may affect semantic integration and cortical stimulus encoding. Memory performance in a surprise free recall test was also assessed to this end. The N400, a component so far rarely analyzed in emotional word processing studies, was attenuated by pleasant as compared to unpleasant words. Its amplitudes were reduced in response to pleasant adjectives, possibly indicating facilitated semantic integration of pleasant compared to unpleasant adjectives. This emotional valence effect was stable across repeated blocks of word repetition, that is, word repetition had no significant effect on the affective N400 modulation pattern, although, in line with previous findings (Smith & Halgren, 1987), the overall amplitudes of the N400 were significantly attenuated by word repetition, indicating better semantic integration of pleasant, unpleasant, and neutral adjectives over blocks of repeated word exposures. The N400 modulation pattern suggests that, in spite of an overall repetition effect facilitating semantic integration of adjectives regardless of their emotional valence, pleasant as opposed to unpleasant words benefited the most from this facilitation effect, which is consistent with findings of better semantic integration of pleasant as opposed to unpleasant words reported in recent ERP studies.

For instance, Schirmer, Kotz, and Friederici (2005) found smaller N400 amplitudes to pleasant target words as opposed to unpleasant target words when words were primed by sentences spoken in emotionally congruent intonations (happy or sad). That is, priming effects were larger for pleasant than for unpleasant pairs. Modulation of the N400 amplitude by pleasant valence has also been found when single words were presented randomly without an affective prime–target or sentence context: Kiefer and colleagues (2007), for instance, found that pleasant as opposed to unpleasant adjectives significantly attenuate N400 amplitudes in states of positive mood. In both studies congruency effects for pleasant valence extended into the time window of late positive potentials with larger amplitudes for positively primed target words (Schirmer et al., 2005) and mood-congruent pleasant words (Kiefer et al., 2007). In the above-mentioned studies, mood was induced experimentally either by presenting emotional sentences (Schirmer et al., 2005) or by showing emotional movies prior to word exposure (Kiefer et al., 2007). Given that mildly positive mood characterizes the modal human experience in healthy subjects (cf. Diener & Diener, 1996), our results may imply a "default" positive mood bias in situations where no explicit mood context is experimentally established. In the present study, better semantic integration of pleasant than unpleasant adjectives cannot be explained by other contextual factors or variables that are known to modulate the N400 potential such as word repetition or differences in word length, word frequency, or concreteness (see Smith & Halgren, 1987). Although there is a possibility that the statistical difference in N400 responses between pleasant and unpleasant words indicates enhanced processing of unpleasant instead of pleasant words, we think this is less likely in view of the LPP and behavioral data.

Pleasant adjectives were associated with augmented LPP. This indicates that pleasant information attracts attention more efficiently and leads to deeper stimulus encoding than unpleasant and neutral information (Ferré, 2003). More efficient memory encoding of pleasant information is further supported by our incidental memory data which show better free recall performance for pleasant in contrast to neutral or unpleasant adjectives. Two other published studies find a pattern similar to that of the present study during covert evaluation of emotional words, namely, arousal-sensitive earlier ERP responses (P2, P3a) and a LPP potential that was selectively enhanced for pleasant words (Herbert et al., 2006; Schapkin et al., 2000). However, Fischler and Bradley (2006) reviewed a series of experiments where the LPP was enhanced to both pleasantly and unpleasantly arousing words, and yet other studies yielded a very complex pattern of results (e.g., Naumann, Bartussek, Diedrich, & Laufer, 1992; Naumann, Meier, Diedrich, Becker, & Bartussek, 1997). This suggests that sustained cortical processing of emotional content as indexed by LPPs may depend on task demands or may be specific to certain types of words (e.g. adjectives vs. nouns).

The factors driving effects of emotional content on early versus late ERP components during word processing await further specification. One possibility is, indeed, that, during covert evaluation or uninstructed silent reading, the subjects' mood state or the self-relevance of the material biases the processing of emotional content in a mood-congruent manner after an initial, arousal-driven attention capture as reflected by an enhanced EPN. This proposal is encouraged by investigations of processing biases in healthy subjects versus mood-disordered, depressive subjects (see Deldin, Keller, Gergen & Miller, 2001; Matt, Vasquez, & Campell, 1992). This literature suggests that, unlike depressives, healthy subjects hold profound biases toward pleasant information resulting in deeper evaluation, encoding, and memory for pleasant in contrast to unpleasant and neutral stimuli. On a cortical level, these positive biases often manifest in modulations of late positive potentials (Deldin et al., 2001) and may already begin at the level of contextual integration of emotional content as indexed by the N400 potential (Kiefer et al., 2007).

The stimulus type may also play a role: For words, the most robust demonstrations of valence-driven processing effects on later ERPs have been found in studies in which adjectives instead of nouns were used (Herbert et al., 2006; Kiefer et al., 2007; Naumann et al., 1992; Schirmer et al., 2005). Perhaps because they often describe personality traits or mood states, adjectives have been shown to induce self-referential processing more easily than nouns, resulting in facilitated responses to the pleasant in normal subjects (Fossati et al., 2003; Lewis, Critchley, Rotshtein, & Dolan, 2007; Tagami, 2002). To follow up on this possibility we obtained additional rating data from 22 student subjects (11 males, 11 females) with biographic background and age comparable to those of the participants in the present ERP study. Subjects rated on 9-points scales, analogous to the SAM, the degree to which the words we had used in this study were descriptive of personality traits or states and to what extent subjects thought the meaning of these words was relevant for themselves: Pleasant and unpleasant adjectives were both rated as more descriptive of personal traits and states than neutral adjectives: pleasant > neutral, $F(1,177) = 33.2$, $p < .001$ and unpleasant > neutral, $F(1,177) = 35.9$, $p < .001$. However on the dimension of self-relevance, pleasant adjectives were judged as significantly more self-relevant than unpleasant, $F(1,777) = 145.1$, $p < .001$,, or neutral adjectives, $F(1,177) = 34.5$, $p < .001$. This is consistent with the behavioral results reported by Tagami and Lewis et al. Moreover Ferré (2003) assumes that pleasant information, which is thought to be mostly mood congruent in normal people, attracts attention more efficiently and leads to deeper semantic integration and stimulus encoding than mood-incongruent unpleasant information. This "positivity bias" is more likely to occur in implicit processing tasks (i.e., tasks that do not promote deep encoding strategies) and has also been observed without inducing mood experimentally (Ferré, 2003).

In healthy subjects processing advantages in favor of pleasant stimuli have also been reported for pleasant pictures (not exclusively erotic contents) provoking larger P3–LPP potentials than unpleasant and neutral pictures, especially when studied in tasks where subjects are not explicitly asked to evaluate the emotional meaning of the stimuli (e.g., Delplanque, Lavoie, Hot, Silvert, & Sequeira, 2004). The effects of positive affect on cognitive processing have been reviewed in recent papers (e.g., Isen, 2001; Fredrickson & Branigan, 2005), indicating that pleasant emotion induced by viewing pleasant stimuli broadens the scope of attention and enhances memory encoding for pleasant material.

Several variables such as the hedonic nature of the stimulus, its emotional intensity, task instructions, attentional demands and mood-congruent stimulus processing effects may influence the mobilization of processing resources devoted to affective stimuli at later processing stages. Our suggestion that, during uninstructed reading, late ERP results may be driven by a positive mood bias and greater self-reference of the pleasant words, although tentative, conforms to theoretical suggestions and previous empirical findings, but clearly awaits and warrants future investigation.

In sum, the current study demonstrated effects of emotional word content on a sequence of relatively early (EPN) and late (N400, LPP) cortical indices during uninstructed reading of words: Initially, the brain responds to the emotional significance of a word, regardless of its valence. However, cortical responses at later stages seem to be flexibly modulated and at present showed selective preferential processing of pleasant contents that was also reflected in better memory for pleasant adjectives.

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