Research Report

Buzzwords

Early Cortical Responses to Emotional Words During Reading

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ABSTRACT—***Electroencephalographic event-related brain potentials were recorded as subjects read, without further instruction, consecutively presented sequences of words. We varied the speed at which the sequences were presented (3 Hz and 1 Hz) and the words' emotional significance. Early event-related cortical responses during reading differentiated pleasant and unpleasant words from neutral words. Emotional words were associated with enhanced brain responses arising in predominantly left occipito-temporal areas 200 to 300 ms after presentation. Emotional words were also spontaneously better remembered than neutral words. The early cortical amplification was stable across 10 repetitions, providing evidence for robust enhancement of early visual processing of stimuli with learned emotional significance and underscoring the salience of emotional connotations during reading. During early processing stages, emotion-related enhancement of cortical activity along the dominant processing pathway is due to arousal, rather than valence of the stimuli. This enhancement may be driven by cortico-amygdaloid connections.***

Reading a good book can make one laugh or cry, and guidebooks to literary writing emphasize that a writer's appropriate use of emotional connotation is crucial for literary success (Weaver, 1974). Whether such recommendations have a biological underpinning is unknown, but when people explicitly evaluate the connotations of perceptual objects, two main determining factors emerge: valence (pleasant vs. unpleasant) and arousal (arousing vs. calm). Stimuli that are perceived as being very pleasant or unpleasant are usually also rated as being highly arousing (Bradley & Lang, 1994).

Although the idea that emotional concepts have a dimensional structure was first suggested on the basis of linguistic analysis (Osgood, Suci, & Tannenbaum, 1975), emotion research has since focused mainly on the processing of nonlinguistic stimuli, advancing understanding of how emotional facial expressions (Schupp, Öhman, et al., 2004; Vuilleumier, Richardson, Armony, Driver, & Dolan, 2004) and pictures (Junghöfer, Bradley, Elbert, & Lang, 2001; Schupp, Junghöfer, Weike, & Hamm, 2003; Schupp, Öhman, et al., 2004; Schupp et al., 2006) are processed. Responses to such stimuli are at least partly based on biological predisposition (Öhman & Mineka, 2001). Words, by contrast, are entirely symbolic; their meaning is acquired by learning.

Some initial event-related potential (ERP) studies used words with different emotional connotations as stimuli (Begleiter & Platz, 1969; Lifshitz, 1966), albeit with mixed results. Visually inspecting the data, Lifshitz did not find marked ERP differences between words varying in emotional content; however, Begleiter and Platz, examining results from a single electrode, reported that words with different emotional content elicited statistically different ERP responses. Later, Vanderploeg, Brown, and Marsh (1987) used an evaluation task and found no reliable ERP differences between emotional and neutral words. More recently, Skrandies (1998), using a memorizing task, and Ortigue et al. (2004), using a lexical decision task, both reported differences in ERP responses to emotional words versus neutral words. Studies differ vastly in the tasks and recording techniques used, and the results obtained, but together they suggest that, at least when subjects are explicitly instructed to perform a task on the presented words (e.g., evaluation of emotional content, lexical decision, memorization), ERPs elicited by emotional words may differ from those elicited by neutral words.

In everyday life, people implicitly evaluate a continuous stream of visual information as exciting or dull without having

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been told to do so. Detection and preferential processing of emotional words may therefore not depend on explicit instructions. ERP brain responses can be used to examine ongoing semantic (Kutas & Hillyard, 1980) and affective (Junghöfer et al., 2001; Schupp et al., 2006) stimulus processing without requiring overt instructions or responses. Indeed, during reading, the brain automatically differentiates various nonemotional semantic properties of presented words (Dehaene, 1995; Hinojosa, Martin-Loeches, Munoz, Casado, & Pozo, 2004; Kutas & Hillyard, 1980).

Potentials appearing within the first 150 ms after word onset usually index structural differences between words, nonwords, and letter strings, rather than differences in meaning (Cohen et al., 2000; Schendan, Ganis, & Kutas, 1998). Surface negative brain potentials arising around 250 ms after word presentation and originating in occipito-temporal extrastriate regions of the left hemisphere are probably the earliest consistently reported electrophysiological indicators of semantic processing (Dehaene, 1995; Hinojosa et al., 2004; Rudell, 1992). For instance, using a category-decision task, Dehaene (1995) found that ERPs to members of various target categories (animal names, proper names, and verbs) differ from one another at around 250 ms after stimulus onset. Similarly, the amplitude of the "recognition potential" (Rudell, 1992), which peaks around 260 ms after word onset, responds to semantics: It is enhanced for target relative to nontarget words, considerably reduced for orthographically legal pseudowords, and absent for letter strings (Hinojosa et al., 2004; Rudell, 1992).

Content-sensitive early negativities can be elicited using rapid serial visual presentation (RSVP) paradigms, in which participants are shown quickly alternating, continuous sequences of stimuli (Hinojosa et al., 2004; Junghöfer et al., 2001; Rudell, 1992). For instance, an RSVP study of picture viewing showed that a posterior negative ERP deflection peaking around 250 ms after stimulus onset is sensitive to emotional content: This deflection is larger in response to emotionally arousing pictures, pleasant and unpleasant alike, than in response to neutral ones (Junghöfer et al., 2001). The enhanced early negativity in response to emotional pictures is not restricted to RSVP designs (Junghöfer et al., 2001; Schupp et al., 2006), in which it has been observed for fast (5 Hz, 3 Hz) and slow (1 Hz) stimulation rates, but also occurs in designs containing interstimulus intervals (Schupp, Öhman, et al., 2004).

In this article, we report an investigation of whether early stages of word processing, as reflected by posterior negativities, are enhanced in response to emotional content during uninstructed reading (i.e., reading without a primary, attention-guiding task) of rapidly presented sequences of words varying in emotional significance. If so, is such a differentiation specific to words of unpleasant valence, as some studies reporting preferential detection of negative stimuli suggest might be the case (see Öhman & Mineka, 2001, for a review), or is it a general response to arousing material, irrespective of valence, as previous picture studies imply? We used an RSVP paradigm, which allows for the presentation of a large number of stimuli within a reasonable acquisition time and results in an excellent signal-to-noise ratio. Two different stimulation rates, 3 Hz and 1 Hz, were used so we could ascertain the stability of effects and demonstrate that the timing of ERP differences is not due to overlap of components.

METHOD

Subjects

Sixteen native German students (8 women; mean age = 23.7 years) from the University of Konstanz participated for course credit or for a financial bonus. All subjects were right-handed and had normal or corrected-to-normal vision.

Stimuli

We selected 180 German nouns (60 high-arousal unpleasant words, 60 high-arousal pleasant words, and 60 low-arousal neutral words) from a pool of 300 nouns that 45 student subjects had previously rated for arousal and valence using the Self-Assessment Manikin (Bradley & Lang, 1994). An analysis of variance (ANOVA) and planned comparisons showed that all three emotion categories differed with respect to valence ratings. Arousal levels for pleasant and unpleasant words did not differ and were significantly higher than arousal levels for neutral words. The three emotion categories were matched for concreteness, word length, and word frequency (the latter based on the CELEX database; Baayen, Piepenbrock, & Gulikers, 1995). Table 1 presents the three categories' means and standard errors for these characteristics.

Procedure

Subjects were familiarized with the laboratory, were provided an explanation of the experiment (in general terms), and signed an

TABLE 1
Characteristics of the Word Stimuli Used in the Experiment

	Word category					
	Pleasant		Neutral		Unpleasant	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
Valence	7.40	0.12	5.10	0.05	1.90	0.09
Arousal	5.70	0.12	2.20	0.10	5.80	0.11
Concreteness	4.51	0.17	4.02	0.26	4.09	0.18
Word length (letters)	7.70	0.37	7.40	0.35	7.30	0.32
Word frequency (per million)	97.48	17.91	108.78	15.83	60.01	22.67

Note. 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 is based on counts for written German from the CELEX database.

informed-consent form. Then, they were seated in an electrically shielded room. Electroencephalogram (EEG) electrodes were attached, and subjects were instructed that they should carefully read the 10 runs of words that would be presented.

The words were presented in two blocks (*fast* and *slow*). Each block contained five differently randomized RSVP sequences, and each sequence contained all 180 words. Thus, each of the 180 words was repeated 10 times in total (5 times in the fast block and 5 times in the slow block). Exposure duration was 333 ms per word (3 Hz) in the fast block and 1,000 ms per word (1 Hz) in the slow block. Block order was counterbalanced across subjects. The words were presented in black letters (40-point font) centered on a 15-in. computer monitor positioned 60 cm from the subjects. Experimental runs were generated using Presentation software (Neurobehavioral Systems, Albany, CA). At the end of the experiment (after the electrodes had been removed), a surprise free-recall task was given to the subjects: They were asked to write down as many of the presented words as they could remember.

EEG Recording

Recordings were made from 64 EEG channels using NEUROSCAN SynAmps amplifiers and software (Compumedics, El Paso, TX). Recording impedances were held beneath 5 kΩ. The sampling rate was 250 Hz, and the recording reference was Cz. Off-line, an average reference was computed, and data were band-pass filtered from 0.5 to 30 Hz. Horizontal and vertical electrooculograms were recorded for artifact control. Eye movement artifacts were corrected using a topographic correction algorithm (Ille, Berg, & Scherg, 2002). Subsequently, epochs still containing amplitudes exceeding 100 μV were rejected. ERPs were averaged for each word type (pleasant, unpleasant, and neutral) and each presentation rate (3 Hz and 1 Hz) separately. The segmented epochs were from 333 ms before to 333 ms after word onset (3-Hz condition) or from 1,000 ms before to 1,000 ms after word onset (1-Hz condition). For each word, the mean activity evoked by the immediately preceding stimulus (beginning 333 ms or 1,000 ms before the onset of the target word, respectively) was used as a baseline. Because the stimulus sequence was completely randomized, content-related differences in baseline activity were expected to cancel out. Indeed, no content-dependent differences in baseline activity were observed.

Data Analysis

ERPs

Modulation of ERP amplitudes and their spatial distribution were assessed from 200 to 300 ms after word onset using the averaged activity of two groups of eight occipito-temporal electrodes, one in the left hemisphere and one in the right hemisphere (see Fig. 1c). Statistical effects were tested using repeated measures ANOVAs with emotion category (unpleasant, pleasant, neutral), presentation rate (3 Hz, 1 Hz), hemisphere, and repetition (first, second, third, fourth, or fifth presentation) as repeated measurements. Significant interactions were followed up by individual ANOVAs and planned comparisons. The reported effects of emotional content on the topographic distribution of the scalp potential (Hemisphere × Emotion Category interaction and follow-ups) are based on normalized data, with the overall main effect of emotion category removed (McCarthy & Wood, 1985). Effect sizes are reported using partial eta-squared as calculated by SPSS. We estimated the sources of differential cortical activations by using the topography of the difference between ERP responses to emotional words and ERP responses to neutral words from all 64 channels from 200 to 300 ms after word onset. A linear inverse-source-modeling approach (the minimum-norm least square solution, MNLS; Hamalainen & Ilmoniemi, 1994) was used.

Recall Performance

Recall performance was analyzed with repeated measures ANOVAs using emotion category as a factor. Separate ANOVAs were conducted for correctly recalled words and erroneous intrusions.

RESULTS

ERPs

Across all blocks and for both presentation rates, emotionally significant words led to a prominent enhanced negativity peaking around 250 ms after stimulus onset, $F(2, 30) = 29.1$, $p < .001$, $\eta_p^2 = .5$ (main effect of emotion category; see Fig. 1). This was true for both pleasant words, $F(1, 15) = 43.25$, $p < .001$, $\eta_p^2 = .74$ (pleasant vs. neutral words), and unpleasant words, $F(1, 15) = 32.33$, $p < .001$, $\eta_p^2 = .68$ (unpleasant vs. neutral words). ERPs to pleasant and unpleasant words did not differ, $F(1, 15) = 1.02$.

After correcting for the overall main effect of emotion category across regions (McCarthy & Wood, 1985), we found that the impact of emotion category still differed between the hemispheres, $F(2, 30) = 6.4$, $p < .01$, $\eta_p^2 = .49$ (interaction of emotion category and hemisphere). Follow-up analyses showed a large effect of emotion category in the left hemisphere, $F(2, 30) = 9.75$, $p < .001$, $\eta_p^2 = .30$; the corresponding effect in the right hemisphere was not substantial, $F(2, 30) = 3.13$, $p > .05$, $\eta_p^2 = .17$.

Furthermore, there was no evidence for habituation or sensitization across 10 repetitions (5 per presentation rate), $F(8, 120) < 1$ (Repetition × Emotion Category), and the effect of emotion category was more pronounced for the faster presentation speed, $F(2, 30) = 5.46$, $p < .01$, $\eta_p^2 = 0.5$ (Emotion Category × Presentation Rate; see Table 2).

These overall effects were followed up in separate analyses for the fast and slow presentation rates. The results of these analyses are summarized in Table 2.

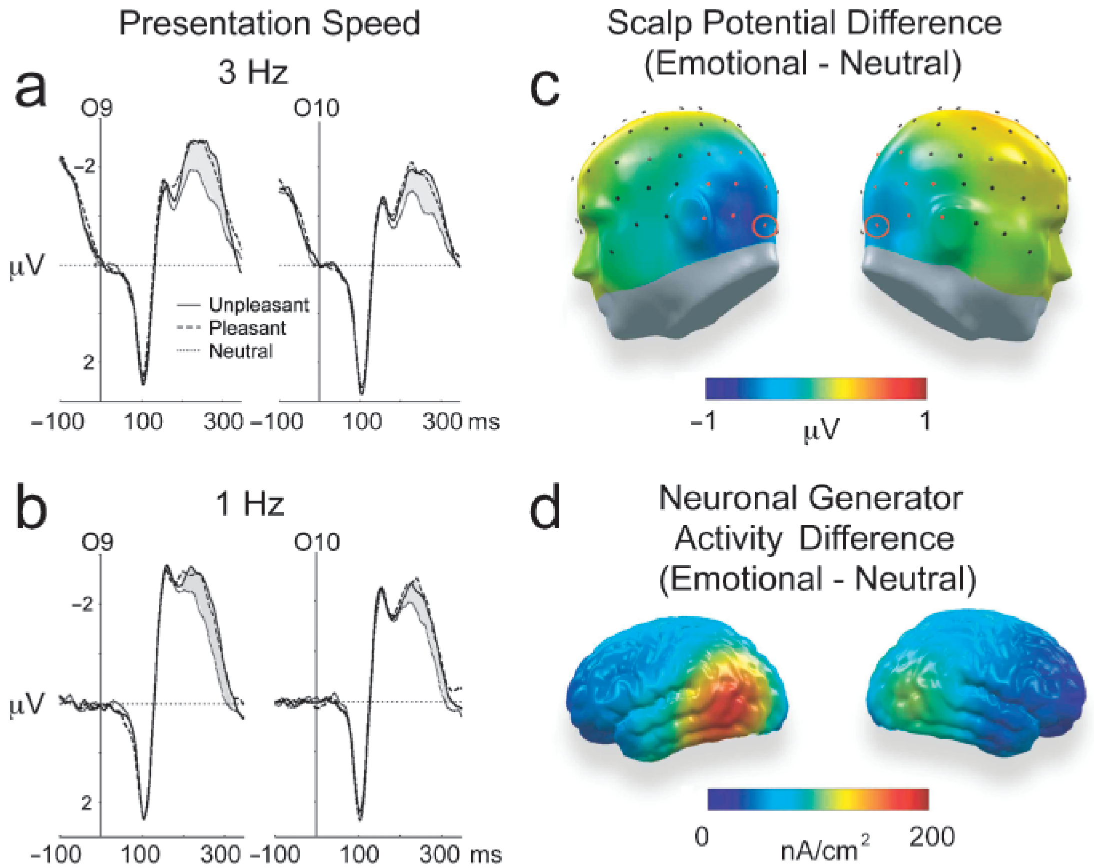

Fig. 1. Evoked potentials during reading of words from three emotion categories. The graphs in (a) and (b) show the time course of cortical activation for the 3-Hz and 1-Hz presentation rates, respectively, at two occipital sensors (O9 and O10). The gray shading highlights the difference between word types. Because activations were very similar regardless of valence and presentation rate, the maps in (c) and (d) collapse across these variables. The map in (c) illustrates the scalp distribution of the difference potential between emotional and neutral words (emotional words – neutral words) between 200 and 300 ms after word onset. The red dots indicate the electrodes grouped for this statistical analysis (one group per hemisphere); the dots corresponding to O9 and O10 are circled in red. Cooler colors indicate more negative-going potentials. The map in (d) displays the distribution of cortical generators of the enhanced negativity in response to emotional words (minimum-norm least square electrocortical source analysis) 200 to 300 ms after word onset. Warm colors indicate more neural activity during reading of emotional words relative to neutral words.

Electrocortical source analysis (MNLS) confirmed that the stronger responses to emotionally arousing than to neutral words originated mainly in left-hemisphere extrastriate areas (see Fig. 1d).

Recall Performance

Figure 2 shows that incidental recall was superior for emotional relative to neutral words, $F(2, 30) = 8.80, p < .001, \eta_p^2 = .37$. This was true for both pleasant words, $F(1, 15) = 9.53, p < .01, \eta_p^2 = .30$, and unpleasant words, $F(1, 15) = 12.79, p < .01, \eta_p^2 = .46$. Correct recall did not differ between pleasant and unpleasant words, $F(1, 15) = 1.64, p > .1$. Also, compared with neutral words, pleasant and unpleasant words were recalled with fewer intrusions of words that had not actually been presented, $F(2, 30) = 12.67, p < .001, \eta_p^2 = .46$ (main effect of emotion category). Again, this was true for both pleasant words, $F(1, 15) = 13.33, p < .01$, and unpleasant words, $F(1, 15) = 15.51, p < .001$.

DISCUSSION

Words with emotional connotations spontaneously catch the reader's attention. During uninstructed reading, early cortical responses are enhanced in response to both pleasant and unpleasant words, compared with neutral words. The time course and the spatial distribution of the ERP effect indicate reliable enhancement of an early, predominantly left occipito-temporal negativity in response to emotionally arousing words, implying that a word's emotional significance amplifies early stages of semantic analysis. Enhanced processing of emotional words is also reflected in better incidental memory. Thus, spontaneous preferential processing of emotional stimuli is not restricted to material with evolutionary significance (e.g., emotional faces—Öhman & Mineka, 2001; Schupp, Öhman, et al., 2004; Vuilleumier et al., 2004; pleasantly and unpleasantly arousing pictures—Junghöfer et al., 2001), but instead extends to material with learned emotional significance and results in

TABLE 2

Statistical Effects of Emotion Category on the Early Negative Component (200–300 ms)

Effect	*F*	*p*	η_p^2
Fast presentation rate (3 Hz)			
Emotion category	$F(2, 30) = 27.34$	< .001	.65
Pleasant vs. neutral words (pleasant > neutral)	$F(1, 15) = 38.07$	< .001	.71
Unpleasant vs. neutral words (unpleasant > neutral)	$F(1, 15) = 30.09$	< .001	.67
Pleasant vs. unpleasant words (pleasant > unpleasant)	$F(1, 15) = 5.27$	< .05	.26
Emotion Category × Hemisphere	$F(2, 30) = 4.67$	< .05	.24
Emotion category: left hemisphere	$F(2, 30) = 8.27$	< .01	.37
Emotion category: right hemisphere	$F(2, 30) = 2.93$	n.s.	.11
Emotion Category × Repetition	$F(8, 120) = 1.59$	n.s.	.11
Slow presentation rate (1 Hz)			
Emotion category	$F(2, 30) = 18.87$	< .001	.56
Pleasant vs. neutral words (pleasant > neutral)	$F(1, 15) = 28.73$	< .001	.66
Unpleasant vs. neutral words (unpleasant > neutral)	$F(1, 15) = 20.23$	< .001	.57
Pleasant vs. unpleasant words (pleasant = unpleasant)	$F(1, 15) = 1.49$	n.s.	.09
Emotion Category × Hemisphere	$F(2, 30) = 5.18$	< .01	.26
Emotion category: left hemisphere	$F(2, 30) = 4.61$	< .05	.24
Emotion category: right hemisphere	$F(2, 30) = 2.08$	n.s.	.12
Emotion Category × Repetition	$F(8, 120) = 1.31$	n.s.	.08

automatically amplified early cerebral processing of such material. Our study demonstrates that this amplification occurs robustly across several repetitions, a result in line with recent findings of little habituation of cortical responses to emotional content during picture viewing (Schupp et al., 2006). Thus, across a variety of stimulus types, emotional significance is reflected in robustly amplified extrastriate negativities.

The present results imply that during reading, a word's emotional connotation is spontaneously activated immediately after assembly of its visual-word-form representation, which occurs within about 150 ms after word presentation (Cohen et al., 2000; Schendan et al., 1998). Semantic access usually follows this structural "word/nonword" decision (Schendan et al., 1998). Indeed, exploratory analyses of our data showed no evidence for an emotion effect before 200 ms, suggesting that the ERP enhancement to emotional stimuli occurs on the level of semantic analysis, not at a prelexical stage. Just after lexical access, bidirectional connections between the extrastriate ventral stream and the amygdala may amplify the ERP response to emotional words. Such connections in monkeys have been extensively described (Amaral, Behniea, & Kelly, 2003). In humans, an interaction between extrastriate areas and the amygdala has recently been demonstrated in emotional face processing (Vuilleumier et al., 2004). Moreover, left amygdala lesions selectively impair detection of emotional words in an RSVP paradigm (Anderson & Phelps, 2001).

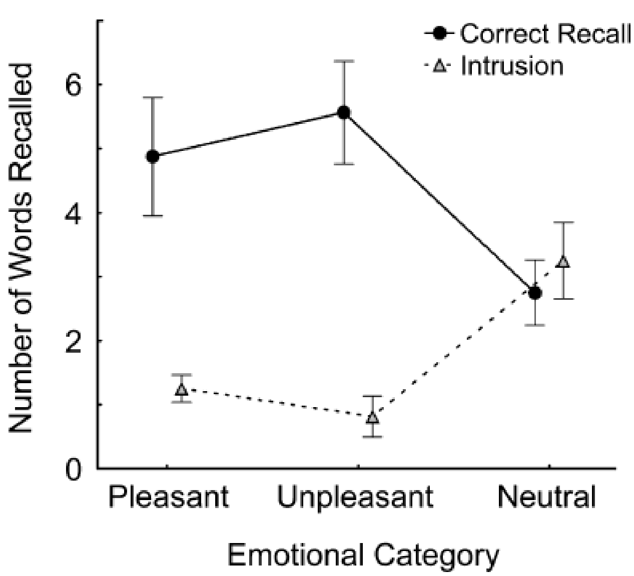

Fig. 2. Number of accurately and falsely remembered pleasant, unpleasant, and neutral words in the postexperimental incidental-memory test. Error bars represent standard errors.

Free recall in RSVP designs, particularly with unexpected and delayed testing, is generally modest. Because of continuous interference from new stimuli, only information that can be immediately bound to a structure can be retained (Potter, 1993). Even under such adverse circumstances, emotional words enjoy a memory advantage in terms of both the total amount of recalled material and recall accuracy. Again, enhanced amygdala activation at encoding may be responsible for this effect (Cahill et al., 1996).

The present results might bear on theories of the laterality of emotion in the brain. Borod et al. (1998) suggested that the right cerebral hemisphere is the "emotional brain"; other researchers view the left hemisphere as mediating pleasant affect, and the right hemisphere as mediating unpleasant affect (Davidson, 1984). However, our data suggest that during early stages of stimulus processing, emotion acts as a non-valence-specific alerting system that enhances initial semantic analysis along its dominant pathway.

Thus, we have shown that enhanced processing of emotional stimuli extends to stimuli with symbolic, ontogenetically learned emotional significance; it occurs at early stages of semantic analysis and without specific instructions to the observer. These findings suggest that the impact of emotional content during reading has a physiological basis that may contribute to the emotions one experiences when reading an absorbing novel.

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