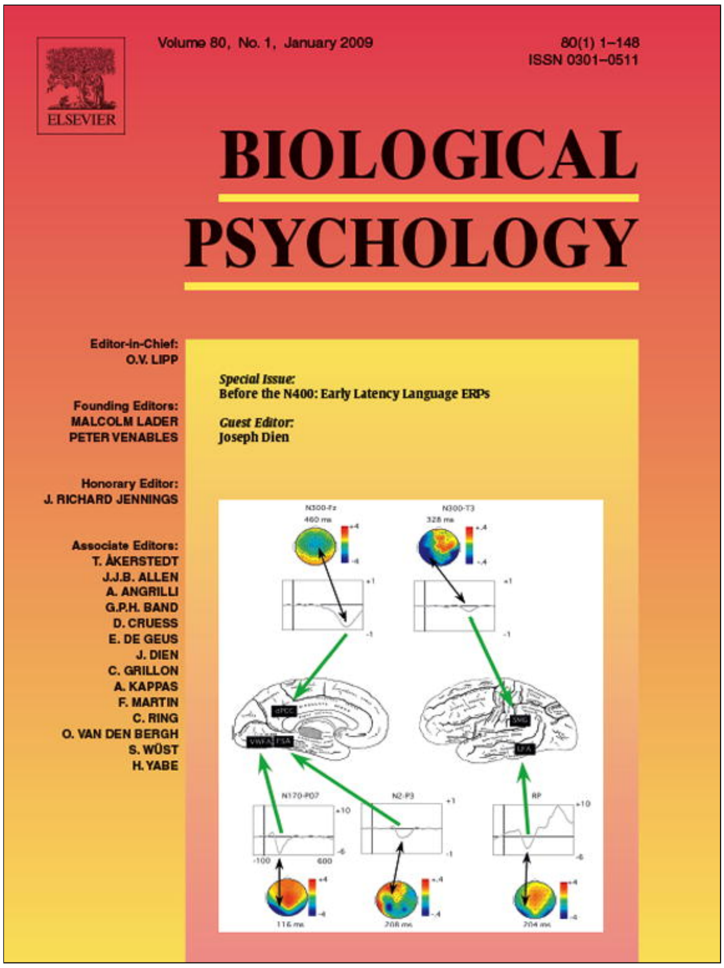
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Emotion and attention in visual word processing—An ERP study

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A B S T R A C T

Emotional words are preferentially processed during silent reading. Here, we investigate to what extent different components of the visual evoked potential, namely the P1, N1, the early posterior negativity (EPN, around 250 ms after word onset) as well as the late positive complex (LPC, around 500 ms) respond differentially to emotional words and whether this response depends on the availability of attentional resources. Subjects viewed random sequences of pleasant, neutral and unpleasant adjectives and nouns. They were first instructed to simply read the words and then to count either adjectives or nouns. No consistent effects emerged for the P1 and N1. However, during both reading and counting the EPN was enhanced for emotionally arousing words (pleasant and unpleasant), regardless of whether the word belonged to a target or a non-target category. A task effect on the EPN was restricted to adjectives, but the effect did not interact with emotional content. The later centro-parietal LPC (450–650 ms) showed a large enhancement for the attended word class. A small and topographically distinct emotion-LPC effect was found specifically in response to pleasant words, both during silent reading and the active task. Thus, emotional word content is processed effortlessly and automatically and is not subject to interference from a primary grammatical decision task. The results are in line with other reports of early automatic semantic processing as reflected by posterior negativities in the ERP around 250 ms after word onset. Implications for models of emotion–attention interactions in the brain are discussed.

1. Introduction

Stimuli that people regard as emotionally arousing obtain prioritized processing. This fact has by now been well established for potentially fear-relevant material, such as snakes or spiders, pictures of human or animal attack but also erotic pictures and emotional facial expressions (see for reviews e.g. Öhman and Mineka, 2001; Schupp et al., 2006; Vuilleumier and Pourtois, 2007). Rapid and preferential responses to these stimuli are thought to be biologically adaptive as emotionally intense stimuli usually represent things that, if encountered in reality, would either threaten or promote one's well being.

Particularly when subjects are free to allocate their attentional resources in any way they wish as is the case in 'passive' viewing tasks, large physiological responses to emotionally arousing compared to neutral stimuli have been reported. In the cortical event-related potential (ERP) two types of effects of emotional content arise during free viewing of emotional and neutral pictures: First, an early negativity over extra-striate visual cortex which peaks between 200 and 300 ms, is larger for emotionally arousing than for neutral pictures when subjects view them in random sequence without any explicit instruction. This 'early posterior negativity' (EPN, Junghofer et al., 2001; Schupp et al., 2004, 2007a,b) is topographically and regarding timing similar to the 'selection negativity' obtained in response to target stimuli in studies of directed attention (Luck and Ford, 1998, see also Schupp et al., 2006).

Later in the processing stream, after about 500 ms, a broad positive potential in response to emotionally arousing pictures peaks over parietal brain areas. This potential seems to be part of the P3 family and has been variously termed P3, P3b, LPP or LPC. In the following, we will use the term LPC, late positive complex, for this positivity or family of positivities. Late positivities have generally been associated with task demands such as attentional capture, evaluation, or memory encoding (see e.g. Dien et al., 2004). They are likely to share a proportion of neural generators and differ on others, reflecting the extent to which the tasks that elicit them draw on similar or different neural systems.

So far, research has mostly used photographical renderings of emotionally evocative objects, which immediately resemble the object they depict. However, humans, as a highly 'symbolic species'

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can use much more abstract signalling systems to efficiently communicate facts about themselves and their environment, namely spoken and written language. Although not as much physiological research has been devoted to the role of emotional content in language processing as in the processing of other visual stimuli, a number of studies exists and several findings are similar from the picture processing literature: for instance when subjects read streams of words that vary in their emotional significance the evoked potential shows a negative deflection from around 200 to 300 ms which is enhanced for pleasant and unpleasant compared neutral words (Herbert et al., 2008; Kissler et al., 2007). This effect has been demonstrated for nouns and adjectives that were matched for a number of other potentially relevant dimensions such as word length, word frequency or concreteness (Kissler et al., 2007), and recently also orthographic neighbourhood and bi-gram frequency (Herbert et al., 2008). The larger early negativity to emotional words is found although the subjects receive no explicit instruction to attend to any specific words more than to others. As with the EPN effect found for emotional pictures, this enhanced posterior negativity has been suggested to reflect seemingly effortless and spontaneous, if not completely automatic, selective processing of emotionally significant words. Moreover such results indicate that at least a rudimentary semantic classification of the words occurs within the first 250 ms after word onset.

The EPN effect for emotional words is reminiscent of an early negativity repeatedly related to early semantic processing in reading research, namely the 'recognition potential' (RP), which also peaks around 250 ms after word onset (RP, Rudell, 1992; see also Martin-Loeches, 2007 for a review). The 'RP' arises when words are presented in rapid sequence, embedded in continuous streams of meaningless background stimuli. It is larger for words relative to pseudowords and non-words, and disappears for letter strings. The 'RP' is further amplified in response to attended target words compared to unattended non-target words (Martin-Loeches et al., 2001; Rudell and Hua, 1996). While the 'RP' potential has been most frequently studied using verbal material, it has also been found with picture and face stimuli (Hinojosa et al., 2000; Rudell, 1992). It remains to be conclusively determined to what extent the RP and the EPN effect reflect the same or different mechanisms, but there are clear similarities and both cortical effects seem to reflect at least rudimentary semantic stimulus classification. Dehaene (1995) also found the earliest ERP differences between words of different categories (verbs, proper names, animals) 250–280 ms after word onset. The semantic category differences were reflected in the scalp distribution of a left occipito-temporal negativity. Although posterior negativities between 200 and 300 ms have also been found to be sensitive to formal visuo-perceptual properties of the presented material which may occur either in close temporal sequence or even in parallel with semantic effects (for reviews see Dien et al., 2003; Martin-Loeches, 2007), EPN emotion effects to words occur in a time window where effects are theoretically consistent with early semantic analysis (Posner et al., 1999; Sereno et al., 1998). Several studies have even shown effects of lexical status, particularly of word frequency, before the EPN/RP time window, most frequently on the N1 (Dien et al., 2003; Hauk and Pulvermüller, 2004; Pulvermüller et al., 2001; Sereno et al., 2003; Sereno and Rayner, 2003).

Emotional-content-dependent ERP modulations have even been observed as early as the P1–N1 time window (about 100–200 ms), extending into the P2–N2 time window at about 200–260 ms after word onset (Bernat et al., 2001; Chapman et al., 1978; Ortigue et al., 2004; Skrandies, 1998). These effects are remarkable in that they may suggest pre- or even extra-lexical processing of emotion words. Although our own previous studies have not reliably revealed emotion effects in the P1–N1 time range, neither in visual inspection (see Kissler et al., 2007) nor when assessed statistically (Herbert et al., 2008), such effects may emerge under particular experimental conditions. P1–N1 effects of emotion words have been repeatedly found in patient populations (Flor et al., 1997; Knost et al., 1997), perhaps reflecting conditioned responses (Montoya et al., 1996). Finally, emotion effects may interact with other lexical variables such as word frequency, for instance resulting in differential timing of emotion effects for frequent versus infrequent words (see Scott et al., 2009).

Several hundred milliseconds later, namely in the LPC window, emotion effects have also been reported: larger LPC responses during silent reading have been found for both pleasant and unpleasant words (Fischler and Bradley, 2006) or only to pleasant but not unpleasant compared to neutral words (Herbert et al., 2008). During silent reading the emotion-induced LPC is comparatively less pronounced than during picture viewing where it has been consistently found (Schupp et al., 2000, 2004, 2007b). In neurolinguistics late positivities have often been suggested to index syntactic re-analysis following morpho-syntactic violations (e.g. Friederici et al., 1996; Hagoort and Brown, 2000; Osterhout et al., 1994), but some studies cast doubt on such syntax specificity and report modulations of late positivities by semantic attributes (e.g. Molfese, 1985; Munte et al., 1998).

While it is by now relatively well established that the organism, when left to its own devices, as during free viewing or silent reading, preferentially processes all kinds of emotionally intense stimuli, be they pictures, faces or words, it is hotly debated to what extent this preferential processing holds when subjects are given explicit tasks which may compete for available resources (Pessoa, 2005; Schupp et al., 2006; Vuilleumier and Pourtois, 2007). A crucial question is, to what extent emotional stimuli, like other perceptual objects, have to compete for resources in a capacity limited system or whether they draw on separate resources, allowing them to by-pass attentional bottlenecks.

In the picture processing literature, empirical effort has been made to determine the degree to which enhanced ERP responses to emotionally arousing pictures are modulated by directed attention. Several different patterns have been reported so far: amplification of the emotional EPN effect and even more of the LPC potential has been found when emotional pictures were targets in an explicit task (Schupp et al., 2007b). Conversely, when explicit attention was devoted to a highly demanding primary feature-based attention task, the EPN was considerably reduced (Schupp et al., 2007a). However, when subjects counted stimuli interspersed in a stream of emotional and neutral pictures, the task did not interfere with the emotion-driven EPN effect, in spite of subjects' adequate task involvement (Schupp et al., 2003). This indicates a complex interaction between emotional stimulus content- and feature-based attention. On the one hand, results suggest some attention-dependence of the EPN effect and argue against the view that the processing of emotional stimuli occurs completely automatically and does not consume attentional resources at all. On the other hand, emotional stimuli are intrinsically 'attention-grabbing', and this in some cases even holds when primary volitional tasks direct resources away from emotional stimuli. Nevertheless, under certain circumstances volitional tasks can override the endogenous 'attention-grabbing' power of emotional stimuli. Specifying the experimental conditions under which emotion and attention compete, collaborate or act in parallel during stimulus processing will further our understanding of the functional architecture of the underlying processing systems.

So far, ERP research on emotion–attention interactions in visual word processing has focused on the LPC. Fischler and Bradley (2006) review a series of studies where task demands were manipulated as subjects processed words or simple phrases that varied in emotional content: they report an enhanced fronto-central positivity between 300 and 600 ms after stimulus onset in response to both pleasant and unpleasant compared to neutral material, when subjects explicitly evaluate emotional content or perform other semantic tasks on the presented material. In Fischler and Bradley's studies (2006), LPC emotion effects emerged when attention was directed to stimulus content. However, in tasks involving orthographic judgements or lexical decisions, the emotion-dependent LPC enhancement was diminished or eliminated, suggesting a competitive interference between emotional processes and experimental tasks. Naumann et al. (1992) on the other hand, comparing an evaluative decision on the affective content of pleasant, neutral and unpleasant words with a structural processing task, report a larger LPC for emotional (pleasant and unpleasant) than for neutral words, in both the structural and the evaluative decision task, suggesting a relative independence of a LPC emotion effect from the particular task demands. Notably, the task and the emotion effect peaked at different electrodes. However, in a subsequent study, where unpleasant and neutral words were presented in a letter-search, a concrete-abstract and unpleasant–neutral decision, a larger LPC to unpleasant words was found only when participants attended to the emotion dimension (Naumann et al., 1997). Thus, during visual word processing, emotion-dependent LPC differences occur robustly when subjects pay attention to emotion. When subjects focus on other attributes of the words, LPC results are much more variable. The question, to what extent the enhanced early negative response (EPN) to emotional words is subject to interference from a primary volitional task, has not yet been addressed.

Here, we study the interaction of emotion and attention during visual word processing at an early selection stage, as indexed by the EPN, and a late stage, as reflected by the LPC, during a grammatical decision task. This task presumably requires perceptual stimulus encoding, but not necessarily explicit semantic stimulus evaluation, as subjects have to access the visual word form but then go on to evaluate a grammatical, not a semantic property of the presented words. Subjects are presented with continuous random sequences of adjectives and nouns that vary in emotional content (highly arousing pleasant and unpleasant and un-arousing neutral). For both word classes an emotion-driven EPN effect (Herbert et al., 2008; Kissler et al., 2007) has previously been reported during silent reading. A small but significant LPC enhancement in response to pleasant adjectives has also been found both during reading (Herbert et al., 2008) and during covert evaluation (Herbert et al., 2006).

To replicate previous results, we first investigate 'spontaneous' processing of emotional word content in a run where subjects were instructed to silently read the presented material. Here, we expect an enhanced EPN to emotionally arousing pleasant and unpleasant words, both adjectives and nouns, and possibly also an increased LPC to emotional words, either to both pleasantly and unpleasantly arousing ones (Fischler and Bradley, 2006), or to pleasant words only (Herbert et al., 2008). Second, attention will be selectively directed to one word class, namely either the adjectives or the nouns, by instructing subjects to count their respective occurrences. This task should tap into the resources reflected by the LPC. Whether it will affect the EPN is open, although effects of grammatical class on the ERP have been reported around 200 ms after word onset (Federmeier et al., 2000). The emotion–attention interaction will be measured by assessing the relative impact of task and emotional content on EPN and LPC amplitudes. Thus, we assess the extent, to which emotional content and instructed word processing will compete for the same resources, act in parallel, or act cooperatively at an early (EPN) and late (LPC) processing stage. Because pre-EPN emotion effects in word processing have also been reported, we are including an analysis of emotion and task effects on the P1 and N1 components to investigate the onset emotion effects in word processing. As in previous studies (Herbert et al., 2008; Kissler et al., 2007) we also assess incidental memory performance via a free recall test to assess whether emotional word content has at least some lasting impact on cognitive systems.

2. Methods

2.1. Participants

Twenty healthy student volunteers (10 women, 10 men) participated in return for course credit or a financial bonus of 12 Euros. All were native speakers of German and right-handed as determined by the Edinburgh Handedness Inventory (Oldfield, 1971). Their mean age was 23.9 years (range 20–31). Upon interview, subjects reported no drug abuse, neurological, mental or chronic bodily diseases or medication for any of these. All volunteers read and signed a detailed consent form approved by the University of Konstanz Institutional Review Board.

2.2. Stimulus materials and design

198 German words, 99 adjectives and 99 nouns, served as stimuli. For both word classes the words varied in emotional content. 33 were highly arousing unpleasant, 33 neutral and 33 highly arousing pleasant. The words were selected from a pool of 500 adjectives and 310 nouns rated by 45 student subjects on the dimensions of arousal and valence. Ratings were obtained using a computerized version of the Self-Assessment Manikin (SAM; Bradley and Lang, 1994). Nouns and adjectives were matched across emotion categories for word length and for word frequency (CELEX database, Baayen et al., 1995). All pleasant and unpleasant words were matched for perceived arousal but differed from neutral words. Furthermore, pleasant, neutral and unpleasant words differed significantly in valence ratings. Details on the word parameters are summarized in Table 1.

2.2.1. Stimulus presentation

Words were presented in black 40 pt capital letters on a white 17 in. PC-monitor background. The 198 words were shown consecutively as a 'movie' consisting of a randomized sequence of words with a stimulus-duration of 680 ms each and without inter-stimulus interval. The experiment consisted of three different tasks each involving two differently randomized repetitions of the 'movie'. The repetitions were implemented to assess the stability of effects. The tasks were (i) silent reading without specific instructions, (ii) counting of adjectives and (iii) counting of nouns. The uninstructed reading task was always first so as not to bias the subjects' attention. The order of the two counting tasks (adjectives versus nouns) was counterbalanced across subjects. Experimental runs were generated and controlled by 'Presentation' software (Neurobehavioral Systems Inc.).

2.3. Procedure

Subjects were familiarized with the laboratory setting, they were questioned about their medical status, their handedness was determined and they signed an informed consent form. Hereafter, EEG electrodes were attached. Participants were given experimental instructions for each block separately. Between tasks, subjects were given 2–3 min breaks. Thirty minutes after the experiment, participants were asked to remember as many of the presented words as they could in an unexpected free recall test.

Table 1
Mean valence, arousal, word frequency and word length values of adjectives and nouns used in the experiment

	Valence		Arousal		Word frequency		Word length	
	Adjectives	Nouns	Adjectives	Nouns	Adjectives	Nouns	Adjectives	Nouns
Pleasant	7.03 (.86)	7.17 (.62)	5.42 (.86)	5.28 (.72)	53.7 (72.7)	64.42 (64.9)	8.52 (2.9)	7.73 (2.6)
Neutral	5.12 (.45)	5.17 (.43)	3.11 (.43)	2.85 (.64)	68.7 (107.8)	76.1 (98.1)	7.85 (2.5)	8.15 (2.64)
Unpleasant	2.66 (.32)	2.55 (.56)	5.59 (.58)	5.35 (.53)	44.21 (46.4)	65.94 (129.3)	8.57 (1.75)	7.55 (1.94)

Standard errors are in brackets.

2.3.1. Electroencephalographic recording

The EEG was recorded from 64 channels, using an EasyCap system and NEUROSCAN SynAmps amplifiers and software. Raw EEG data were sampled at 250 Hz and recorded with an on-line band-pass from 0.1 to 100 Hz. During recording, all EEG-channels were referenced to Cz. They were re-referenced off-line to an average reference. Recording impedance for all electrodes was held beneath 5 kΩ. Filtering, artifact rejection, and analyses of the ERP responses followed off line: data were filtered from 0.5 to 30 Hz. Filtered data were corrected for eye movement artifacts using the ocular correction algorithm of Ille et al. (2002). In addition, a semi-automatic artifact rejection as implemented in BESA (MEGIS Software GmbH) was run to eliminate remaining artifacts. Artifact free EEG data were segmented from 680 ms before until 680 ms after word onset and baseline corrected using the entire 680 ms before word onset as a baseline. When stimulus order is carefully counterbalanced across different word categories as in the present study, content-related differences in baseline activity are cancelled out and no differences in baseline measures are to be expected.

2.3.2. Event-related potentials (ERPs)

ERP components were analysed in four time windows previously suggested to be sensitive to emotional and attentional aspects of visual word processing, namely the P1, the N1, the EPN and the LPC. The respective time windows of interest were determined based on visual inspection of the grand averages at typical sensors (see Figs. 2 and 3) and were similar to the ones reported in previous studies. The P1 was measured between 80 and 130 ms after word onset, the N1 from 135 to 190 ms after word onset and the EPN from 240 to 300 ms. P1 and N1 windows are the same as in Herbert et al. (2008). In the present study the EPN consistently peaked a little later than previously reported and was measured between 240 and 300 ms (see Figs. 2 and 3).[1] LPC activity was assessed from 470 to 570 ms after word onset in the silent reading condition which is largely consistent to the analysis window used in Herbert et al. (2008), where the emotion LPC during reading was assessed in a window from 470 to 600 ms after word onset. In the active task, a window from 450 to 650 ms was used which is similar to the analysis-window for the Emotion $\times$ Attention interaction presented by Schupp et al. (2007b), who had used an interval from 400 to 600 ms. Visual inspection of the grand-average waveforms indicated that these time windows best captured the respective cortical activities in the two conditions (see Figs. 2 and 3).

P1 was quantified at a left (O1, O9, PO3, P9, P7, P5) and right (O2, O10, PO4, P10, P8, P6) occipital group of electrodes. The N1 and EPN were assessed at a left (O1, O9, PO3, P9, P7, P5, TP9, TP7) and a right (O2, O10, PO4, P10, P8, P6, TP10, TP6), posterior sensor group, and the LPP at two groups of centro-parietal sensors (one best capturing the emotion effect, the other best capturing the task effect, see below). In line with results by Schupp et al. (2006), the LPC emotion effect during passive viewing appeared at a group of 11 posterior electrodes (Oz, O1, O2, PO3, PO4, P5, P6, P1, Pz, P2, CPz). The task effect was initially also assessed at this group, where it turned out to be highly significant. But since the task effect proper in the present experiment had a more frontal distribution, we added an analysis of the task and emotion effects over a more frontal region of interest also comprising 11 electrodes (CPz, CP3, CP4, C3, Cz, C4, FC1, FC2, FCz, FC3, FC4). The averaged activities from these groups of electrodes were, for each component individually, entered into the statistical analysis in order to get a topographically stable estimate of the underlying brain activity without inflating the likelihood of type I errors.

2.4. Statistical data analysis

To examine the effect of emotional content during silent reading of a random sequence of pleasant, unpleasant and neutral adjectives and nouns, repeated measures analyses of variance (ANOVA), were conducted for each ERP component separately. The ANOVAs involved the within factors Word Class (adjective, noun), Emotional Content (unpleasant, neutral, pleasant) and Repetition (first, second). For the P1, N1 and EPN components Hemisphere (left–right) was included as an additional factor, whereas the LPC was assessed at a single channel group.

Furthermore, the effect of attentional engagement on the processing of emotional words was assessed with repeated measures analyses of variance (ANOVAs), separately for the P1, N1, EPN and LPC components. These ANOVAs involved the within factors Task (target word, non-target word), Word Class (adjective, noun), Emotional Content (unpleasant, neutral, pleasant) and Repetition (first, second). Again, for the P1, N1 and EPN components Hemisphere (left–right) was included as an additional factor, whereas the LPC was assessed at a single channel group.

[1] We also assessed the EPN in the larger analysis window that we have previously reported on, namely 200–300 ms after word onset. Like in the 240–300 ms analysis, main effects of Emotional Content emerged (Emotional Content in the Reading condition: $F_{(2,38)} = 6.8$, $p < .01$ and Emotional Content in the Word Counting condition: $F_{(2,38)} = 8.8$, $p < .01$). The only difference was that with this analysis window in the Reading condition the unpleasant–neutral comparison failed to reach significance. For the counting task, there was no qualitative (or major quantitative) difference between the analysis windows. Overall, the effect peaked a little later than in previous studies.

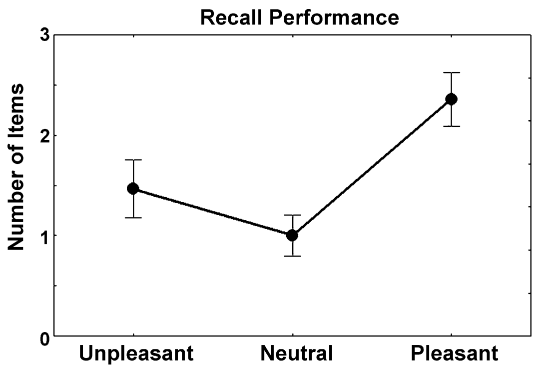

Fig. 1. Mean incidental free recall of unpleasant, neutral and pleasant words 30 min after the experiment.

Where appropriate, significance levels are reported after adjustment for violations of the sphericity assumption using the Huynh–Feldt procedure.

3. Results

3.1. Behavioral data

3.1.1. Incidental memory

Fig. 1 shows incidental memory performance for words with different emotional content. Although, due to experimenter error, recall data were available only for 14 participants and even though performance was relatively poor, differences depending on emotional content emerged (Emotional Content: $F_{(2,26)} = 9.8$, $p < .01$): specifically pleasant words were recalled more often than neutral and unpleasant ones (pleasant–unpleasant: $F_{(1,13)} = 11.52$, $p < .005$; pleasant–neutral: $F_{(1,13)} = 16.58$, $p < .005$; unpleasant–neutral: n.s.).

3.1.2. Word counting task

On average, subjects identified 86.1 (S.D. = 15.85) of the 99 target adjectives and 92.3 (S.D. = 14.8) of the 99 target nouns. The difference between the word classes was not significant.

3.1.3. P1

3.1.3.1.Silent reading. In the silent reading condition there was no effect of Word Class, Emotional Content, or Repetition on the P1 component (all $ps > .1$).

3.1.3.2.Word counting task. Likewise, during word counting no clearly significant effects of any of the factors emerged. There were some marginal trends indicating a possible hemispheric difference in P1 amplitude (Hemisphere: $F_{(1,19)} = 3.03$, $p = .1$), a possible difference between the task effect during the first and second repetition (Task $\times$ Repetition: $F_{(2,38)} = 3.18$, $p = .09$) and a possible complex three-way interaction between Emotional Content, Repetition and Hemisphere ($F_{(2,38)} = 2.35$, $p = .11$).

3.1.4. N1

3.1.4.1.Silent reading. There were no clearly significant effects, but two trend-level main effects: overall, the N1 tended to be larger over the right hemisphere ($F_{(1,19)} = 4.25$, $p = .05$). Moreover, in tendency, N1 amplitudes differed depending on their Emotional Content ($F_{(2,38)} = 3.11$, $p = .06$). Descriptively, the latter effect was due to the N1 to pleasant words being a little larger than the N1 to neutral or unpleasant words.

3.1.4.2.Word counting task. In the N1 window no main effects of Task or Emotional Content emerged during counting ($ps > .2$). There was, however, an effect of Hemisphere: the N1 was larger over right posterior electrodes ($F_{(1,19)} = 5.5$, $p < .05$). There was also a significant interaction between Hemisphere and Emotional Content ($F_{(2,38)} = 4.35$, $p < .05$). Over the right hemisphere the N1 was smaller for pleasant than for both unpleasant ($F_{(1,19)} = 5.23$, $p < .05$) and neutral ($F_{(1,19)} = 4.5$, $p = .05$) words, but no emotion-dependent difference was found over the left hemisphere (all $ps > .15$). In tendency, there was also a three-way interaction of Task × Emotional Content × Repetition on the N1 ($F_{(2,38)} = 2.94$, $p = .07$), whose significance was not apparent. No other trends or effects emerged.

3.1.5. Early posterior negativity

3.1.5.1.Silent reading. In the interval from 240 to 300 ms after word presentation, word valence affected the ERP in all three processing conditions (Emotional Content: $F_{(2,38)} = 6.32$, $p < .01$), see Fig. 2a. Planned comparisons showed that both unpleasant (unpleasant–neutral: $F_{(1,19)} = 4.30$, $p = .05$) and pleasant (pleasant–neutral: $F_{(1,19)} = 14.05$, $p = .001$) words differed from neutral ones. No other significant effects emerged.

3.1.5.2.Word counting task. Even when subjects had to attend to the word type (adjective or noun) and count the respective occurrences, the words' emotional content still had an impact on the EPN potential ($F_{(1,19)} = 11.22$, $p < .001$). Planned comparisons revealed that the EPN to unpleasant words differed from the one to neutral words ($F_{(1,19)} = 15.79$, $p < .001$). Likewise, the EPN to pleasant words differed from the one to neutral words ($F_{(1,19)} = 20.22$, $p < .001$). The effect of emotional content on the EPN during word counting is shown in Fig. 2b.

There was also an effect of the counting task on the EPN which interacted with word type (Word Type × Task: $F_{(1,19)} = 5.28$, $p < .05$). For adjectives, the EPN was more negative to targets than to non-targets (Task: $F_{(1,19)} = 7.43$, $p < .05$), but this task effect did not emerge for nouns. There was also a difference in the spatial distribution of the ERP to adjectives and nouns (Word Type - × Hemisphere: $F_{(1,19)} = 11.760$, $p < .01$). In the right hemisphere the EPN to adjectives was a little more pronounced than the EPN to nouns ($F_{(1,19)} = 5.5$, $p < .05$), whereas no such difference emerged in the left hemisphere. No other significant effects or interactions were found. In particular, there was no interaction between word valence and task ($F_{(2,38)} = .03$, $p = .97$).

3.1.6. Late positive complex

3.1.6.1.Silent reading. The interval from 470 to 570 ms after word presentation, word valence also affected the parietal positivity (valence: $F_{(2,38)} = 3.84$, $p < .05$). The LPC to pleasant words was larger than the one for unpleasant words (pleasant–unpleasant: $F_{(1,19)} = 11.71$, $p < .01$). This effect is illustrated in Fig. 3a. No other significant effects were found.

3.1.6.2.Word counting task. In the active task, a large parietal positivity developed between 450 and 650 ms after word onset (see Fig. 3b and c). We initially assessed the relative impact of emotional word content and task requirements on this potential

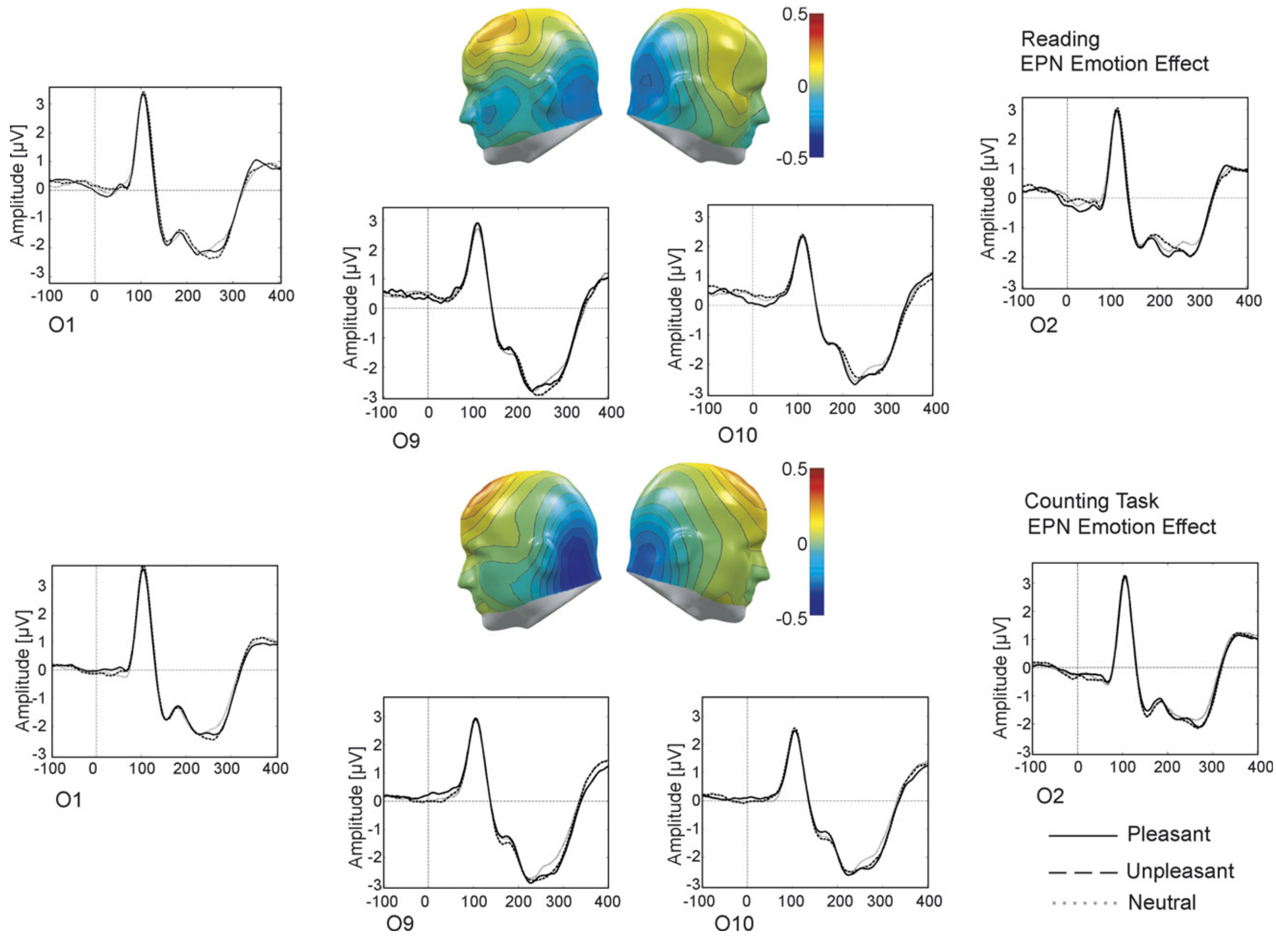

Fig. 2. The difference topography of cortical responses to emotional minus neutral words 240–300 ms after word onset is shown. The topographical view collapses across pleasant and unpleasant adjectives and nouns as there was no interaction involving pleasantness or word class. Additionally, ERP tracings from individual occipital channels during passive reading are shown collapsing across adjectives and nouns, but separately for pleasant and unpleasant stimuli. (a) (top) illustrates silent reading and (b) (bottom) illustrates the word type counting task.

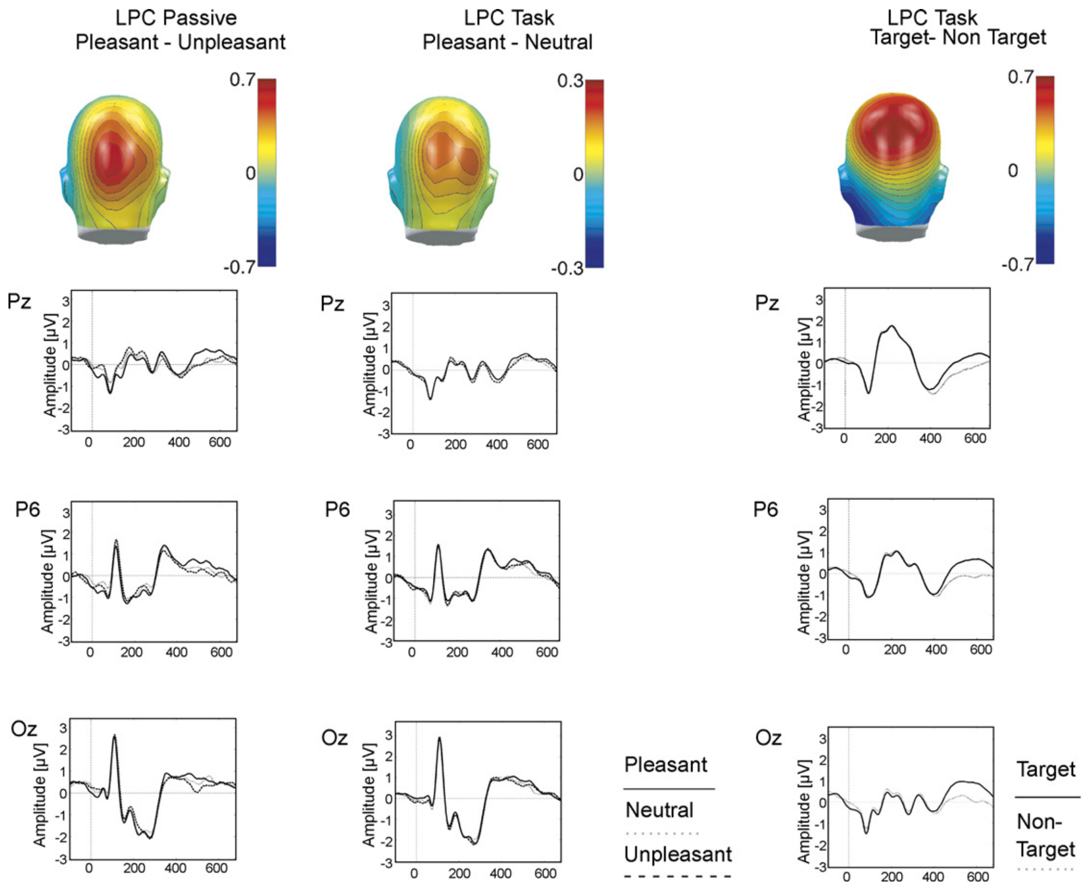

Fig. 3. The emotion (a—left panel and b—mid panel) and task effects (c—right panel) for the LPC are shown for the silent reading (a) and word counting (a and b) conditions. The top row shows the topographical distributions of the effects. Rows two to four depict the time courses of the ERPs in the different conditions at selected sensors.

using the same channel group as during silent reading. We found a sizeable effect of task, the potential being much larger for the attended than for the unattended word type (Task: $F_{(1,19)} = 36.7$, $p < .001$), but it also still exhibited a significant sensitivity to the word's emotional content (valence: $F_{(2,38)} = 5.36$, $p < .01$), with the LPC to pleasant words being more positive than the one to neutral ones (pleasant–neutral: $F_{(1,19)} = 12.46$, $p < .01$), while the comparison between unpleasant words and either the neutral or the pleasant ones did not reach significance. The LPC was in general larger during the first than during the second run (Repetition: $F_{(1,19)} = 19.35$, $p < .01$), and the task effect was somewhat diminished across repetitions (Task × Repetition: $F_{(1,19)} = 4.28$, $p = .053$). Also, repeating the words tended to affect nouns and adjectives differently (Repetition × Word Type: $F_{(1,19)} = 4.20$, $p = .054$). Brain responses to the nouns were initially somewhat more positive than to adjectives, but the difference disappeared upon repetition. No other significant interactions emerged for this brain region.

As inspection of the potential distribution indicated that the task effect proper had a more frontal distribution than captured by the current sensor group (see Fig. 3), we added an analysis of possible task and emotion effects over this more central brain region. Here, only the task had a major impact on the scalp potential ($F_{(1,19)} = 97.68$, $p < .001$), responses to target words being relatively more positive than responses to non-target words. Other than that no significant effects or interactions emerged.

4. Discussion

This study investigated the effect of emotional content on word processing and its interaction with volitional attention to a non-emotional attribute, namely grammatical class. Four visual ERP components were measured, namely P1 and N1, the EPN and the LPC. Particularly the EPN and LPC have previously been reported to be sensitive to emotional word content and task demands, although effects on P1 and N1 have occasionally also been reported.

We did not find any clearly significant effects on the P1 in the present study. The N1 was in tendency larger in response to pleasant words during silent reading. Moreover, in the counting task, the N1 to pleasant words over the right hemisphere was reduced compared to neutral or unpleasant words. Although in the present as in other previous studies (e.g. Skrandies, 1998), effects of emotion words on N1 amplitudes were found, these effects are often small and do not appear to lend themselves to a straightforward interpretation. It is possible that such effects are more likely to occur in 'active' tasks (e.g. Scott et al., 2009). In line with this assumption, there was more evidence of pre-EPN effects in the counting than in reading condition. However, a much clearer theoretical framework is needed before P1 or N1 emotion effects in word processing will be understood (see also Kissler et al., 2006 for a discussion).

Replicating previous research (Herbert et al., 2008; Kissler et al., 2007), we found the EPN to be consistently enhanced to emotionally arousing pleasant and unpleasant versus neutral words, both for adjectives and nouns. Also in line with previous research (Herbert et al., 2008), the LPC during silent reading was somewhat larger to pleasant words.

Deciding on the words' grammatical class and thus paying attention to a non-emotional attribute of the words did not interfere with the emotion effects on either the EPN or the LPC. In the EPN window, mainly emotional content affected the ERP amplitude.

There was also a smaller effect of task on the ERP which was restricted to the adjectives. Conceivably, subjects used a different strategy to decide on target adjectives than to decide on target nouns. Since many German adjectives can be identified by their affix ('-lich', 'ig'), a structural attribute of the words may have been used to identify a considerable proportion of target adjectives early in the processing stream. If so, this process did not interact with the impact of emotional content.

For the LPC, on the other hand, a sizeable task effect emerged for both adjectives and nouns: A centrally distributed positivity was considerably larger for words belonging to the target than to the non-target class. This effect did not interact with emotional content. Instead, although by far not as large as the task effect, a more posterior positivity was also enhanced in response to pleasant words.

Thus, the emotion EPN effect emerged as a very robust and replicable phenomenon in the processing of emotional words. It turned out not to be sensitive to interference from a non-emotional, grammatical word processing task. Because words with emotional connotation cannot be recognized on the basis of a restricted set of orthographic or morphemic features, the present results strengthen the argument for a very reliable early semantic classification which results in an enhanced EPN.

It might be argued that the ERP difference between emotional and non-emotional words could arise as the result of a conditioned response and may thus be different from semantic analysis proper. At present, we cannot exclude this possibility, but if this were the case, the conditioned response would appear in brain regions and in a time window that by others has been shown to be sensitive to a broader range of semantic properties (Dehaene, 1995; Hinojosa et al., 2004; Martin-Loeches, 2007). Moreover, such a conditioned response would allow for a temporally very stable differentiation among a vast amount of physically very similar word stimuli. In fact, short-term conditioning effects for words or simple geometric figure have been observed in even earlier time windows than our EPN effect (Montoya et al., 1996; Stolarova et al., 2006). Perhaps pre-EPN effects, which seem less consistent across studies, might result from such conditioned responses.

Although effects in the EPN time range (for example for the conspicuously similar RP) have been shown to be sensitive to visual expertise (Rudell and Hua, 1997), a strictly expertise-based explanation of the EPN emotion effect would likely result from differences in word frequency which we have controlled for in this as well as in previous studies. However, very recent results suggest that word frequency may affect the timing of ERP differences between emotional and neutral words. Scott et al. (2009) investigated ERPs to high-frequency (about 60 occurrences per million) versus low-frequency (about 8 occurrences per million) pleasant, unpleasant and neutral words. They replicated the EPN effect for emotional words only for the high-frequency, but not for low-frequency words. While another recent study (Herbert et al., 2008), indicates that emotion EPN effects can occur even with adjectives that have a frequency of about 15 per million, which is numerically closer to Scott et al.'s low- than their high-frequency words, there is still the possibility of a non-linear drop in the effect below a certain cut-off point.

In the present study the emotion EPN effect occurred somewhat later, but with the same topography as previously reported (see also footnote 1). Kissler et al. (2007), like Scott et al. (2009) measured the effect between 200 and 300 ms after word onset, Herbert et al. (2008) found it between 200 and 280 ms. Here, the effect was consistently seen across all conditions between 240 and 300 ms after word onset. While there is no apparent reason for this variance, it is possible that in an effort to equate word frequencies of adjectives and nouns we used less typical words than before, which may have taken longer to identify. Also, in order to exclude the possibility that adjectives and nouns could be differentiated on the basis of their first letter, which is usually the case in German, we capitalized all words which results in a less customary presentation format. This may have delayed word identification and thus the EPN emotion effect.

We have previously suggested a 'causal' interpretation of this EPN emotion effect (Kissler et al., 2006, 2007) as based on an interaction between extra-striate, possibly fusiform, visual regions and the amygdala. Possibly, immediately after conceptual identification of a visual word form, bi-directional interactions with the amygdala could enhance the processing of a word identified as having emotional significance. Similar proposals have been made for the processing of fearful faces (Vuilleumier and Pourtois, 2007; Vuilleumier et al., 2004). Within such a framework, the enhancement by emotion would be delayed, if stimulus identification was delayed. Indeed, emotion-driven processing enhancements in the face perception literature precede the effects in word processing (e.g. Righart and de Gelder, 2006). Clearly, the mechanism underlying the emotional-neutral EPN effect in word processing requires further specification. For instance, the 're-entrant processing' interpretation poses the problem of how the emotional significance of words is acquired in the first place, since unlike for faces, evolutionary preparedness cannot be called upon. However, accumulating evidence underscores that the effect is a robustly replicable phenomenon which is functionally distinct from the emotional LPC effect. The LPC shows a different pattern of modulation by emotion, although in the present study an interaction between emotional content and task requirements did not emerge in either time window.

Here, as in Naumann (1992) no interference between a primary task and the words' emotional content emerged, although both attributes had an independent impact on the LPC. The task effect on the LPC was large as the task was subjectively very demanding for the participants. In fact, we had behaviourally piloted several different stimulation frequencies and found faster ones than the one we used here too hard for the subjects to successfully complete.

The influence of emotional content on the LPC was much smaller than the task's, but pleasant words had still a significantly larger LPC than neutral ones and the topography of the effect resembled the one we found during silent reading. Like in a previous study (Herbert et al., 2008), the LPC pattern paralleled the subjects' memory performance, which was better for pleasant words. Another previous study using nouns (Kissler et al., 2007) focused on the EPN, but also reported incidental memory data. In that study, the memory data paralleled both the EPN enhancement and the LPC pattern (unpublished data), making it impossible to gauge the relative impact of either component on memory performance. However, previous findings suggest a relationship between memory encoding and late positivities during stimulus perception. Larger late positivities during picture viewing predicts subsequent superior recall of emotional pictures (e.g. Dolcos and Cabeza, 2002), but so far little is known about the specific contribution of the EPN to episodic memory processes.

Although it may appear puzzling that only pleasant words were associated with a larger LPC, this pattern also appeared in two previous studies, where we have extensively discussed it (Herbert et al., 2008, 2006) as well as in a study by a different group of authors (Schapkin et al., 2000). Regardless of their functional interpretation, such results underscore that the EPN and LPC represent functionally distinct stages of emotional stimulus processing and suggest that beyond facilitated identification as reflected by the EPN, the processing of emotional stimuli can be dynamically modulated.

Furthermore, the data suggest parallel processing of emotional content and task-relevant grammatical attributes. Although both

EPN and LPC exhibited at least some sensitivity to both task demands (small and restricted to adjectives for EPN, large for LPC) and emotional word content (large for EPN, small for LPC), there was no interaction at either processing stage. Superficially, these data, in line with other previous ones, may argue for an independence of emotional processing from cognitive processing and the availability of attentional resources (LeDoux, 1989; Naumann et al., 1992). However, in view of the variety of results that have already been reported in studies on the interaction of emotion and a primary task in general, and for the EPN and LPC components in particular, it seems reasonable to conceive of the task–emotion interaction in a situation-specific, dynamic manner, where interactive competition, additive cooperation as well as parallel independence may arise. The extent to which experimental data will reflect either of these possible patterns may be determined by both the global availability of processing resources and by the availability of task-specific resources at different stages of processing. For example, Lavie (2005) recently suggested that the type of processing load will determine the extent to which in directed attention tasks distractors will be processed. In this model, a high perceptual load is thought to interfere with distractor processing, whereas a high load on frontal cognitive control processes does not interfere with perceptual distractor processing. This idea may help to explain the present pattern of results as well as other similar ones: deciding on a word's grammatical class is likely to be a process which draws on frontal lobe resources. Still, it may leave unaffected the analysis of 'non-target' attributes of the presented stimuli, such as their emotional content. In a similar vein, Munte et al. (1998) have suggested topographically independent contributions from syntactic and semantic factors to the late positive complex. By analogy, it seems likely that emotional and cognitive processing will interfere only to the extent that both processes utilize the same neural circuitry at the same point in time. While such situations can arise (Pessoa et al., 2002), non-interference is possible to the extent that concurrent processes differ in their timing and the neural structures they use. This may have been the case in the present experiment. Thus, for instance the simultaneous, but topographically distinct, effects of task and emotion on the LPC may arise from separate contributions of distinct cortical and sub-cortical generator structures involved in generation of P3-like effects.

Taken together, two new findings arise from the present study: First, deciding on a word's grammatical class does not affect emotional modulation of early stages of word processing as reflected by an enhanced EPN to arousing words. Second, even where a large effect of task emerged, namely in the LPC window, no interference with the effect of pleasant emotional content was observed. These first two findings imply two additional important points, namely a functional independence between the EPN potential and the LPC in the processing of emotional stimuli and an independence of implicit processing of emotional word content and a grammatical decision. Futures studies will detail interactions between different types of tasks and the implicit processing of emotional content at various processing stages.

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