International Journal of Psychophysiology 78 (2010) 299–307

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Reading emotional words within sentences: The impact of arousal and valence on event-related potentials

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ARTICLE INFO

Article history:
Received 12 January 2010
Received in revised form 29 August 2010
Accepted 13 September 2010
Available online 18 September 2010

Keywords:
Emotion
Language
Word processing
Event-related potentials
Corrugator activity

ABSTRACT

Effects of emotional word meaning have been studied exclusively for words in isolation but not in the context of sentences. We addressed this question within the framework of two-dimensional models of affect, conceiving emotion as a function of valence and arousal. Negative and neutral target verbs, embedded within sentences, were presented while event-related brain potentials (ERPs) and the activity of the *Corrugator* muscle were recorded. Twenty-one participants performed a semantic decision task on the target verbs. In contrast to single word studies no early posterior negativity was present. However, emotion effects in ERPs were evident in a late positive complex (LPC) for negative, high-arousal words in comparison to neutral words. Interestingly, the LPC was unaffected by pure arousal variation when valence was controlled for, indicating the importance of valence for this emotion-related ERP effect.

1. Introduction

Reading can be a highly emotional experience, eliciting feelings of joy or distress, excitement or serenity. Although the study of emotion has made much progress in many domains, it is in its infancy when reading is concerned. This holds true, particularly, with respect to sentence processing where reports about the impact of emotion appear to be absent. It was the general aim of the present study to help filling this gap by investigating the impact of emotional words in the context of short sentences.

The processing of emotional stimuli has often been studied with event-related brain potentials (ERPs), where emotion effects have been shown to start as early as 100 ms post-stimulus (Junghöfer et al., 2001; Smith et al., 2006). Initially, ERP studies concentrated on processing of affective pictures, but recently, the focus has been widened to emotional words. It is often suggested that emotional stimuli are preferentially processed because they involuntarily draw attentional resources (Lang et al., 1997). This is reflected in at least two temporally and topographically distinguishable ERP components, reported to be more pronounced for high-arousal positive or negative as compared to low-arousal neutral, stimuli. The first ERP component consists in an early, negative-going difference wave at temporo-occipital electrode sites, termed early posterior negativity (EPN), starting around 200 to 400 ms after stimulus onset for both positive and negative relative to neutral pictures (e.g., Schupp et al., 2004a, 2007) and words (e.g., Herbert et al., 2008; Kissler et al., 2007, 2009; Schacht and Sommer, 2009a, 2009b). Regarding its scalp distribution and latency, the EPN is similar to ERP components elicited by voluntary attention to non-emotional stimuli. The EPN was therefore suggested to reflect attention allocation caused by the higher intrinsic relevance of emotional stimuli (Schupp et al., 2007).

A second ERP effect of emotion appears at later stages. Here, emotional stimuli increase the amplitudes of the late positive complex (LPC), which typically starts in the time range of the P300 component and lasts for several hundred milliseconds. Increased LPC amplitudes have been shown for affective pictures (e.g., Cuthbert et al., 2000; Schupp et al., 2000, 2004a, 2004b) as well as for emotional words (e.g., Fischler and Bradley, 2006; Herbert et al, 2006; Naumann et al., 1992, 1997; Schacht and Sommer, 2009b).

As for the EPN, several studies reported increased LPC amplitudes for high-arousal stimuli of both positive and negative valence relative to neutral, low-arousal stimuli (Cuthbert et al., 2000; Dillon et al., 2006; Fischler and Bradley, 2006; Rozenkrants et al., 2008; Schupp et al., 2000, 2004c). Therefore, it has been suggested that enhanced LPC amplitudes are due to arousal differences and reflect sustained elaborate processing of high-arousal stimuli (Cuthbert et al., 2000; Schupp et al., 2000, 2004a, 2004b), presumably caused by their higher motivational significance. However, this interpretation has been challenged by studies showing LPC effects for stimuli of different valences although their arousal level had been controlled for (Conroy and Polich, 2007; Delplanque et al., 2004; Yuan et al., 2007). In addition, a number of studies have reported differences in ERP modulations for positive as compared with negative pictures (Delplanque et al., 2005, 2006; Ito et al., 1998) and words (Herbert

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0167-8760/$ – see front matter
doi:10.1016/j.ijpsycho.2010.09.004

et al., 2006, 2008; Kissler et al., 2009). Taken together, these results do not support an unequivocal conclusion about the relative influences of emotional valence and arousal on LPC amplitudes, but suggest a more complex modulation than by mere variations of arousal.

Although emotion effects have typically been observed in EPN and LPC components, it is noteworthy that emotion has also been reported to influence the N400, an enhanced negativity over centro-parietal electrode sites. The N400 amplitude is inversely related to the degree of semantic fit between a word and its preceding context (e.g. van Berkum et al., 1999). Kanske and Kotz (2007) reported decreased N400 amplitudes for emotional words in a lexical decision task, indicating facilitated processing of emotional as compared to neutral words. The authors concluded that within the stream of randomly presented emotional and neutral single words, emotional words have been more easily integrated into the current context. Other studies showed that the effect of emotional valence on the N400 is also modulated by subjects' mood, resulting in larger N400 amplitudes for mood-congruent than -incongruent emotional words (Chung et al., 1996; Kiefer et al., 2007).

An important aspect of research on language and emotion processing concerns the linguistic unit of the stimulus materials employed. Apart from two reports using word pairs (Fischler and Bradley, 2006; Schacht and Sommer, 2009a), all studies mentioned above investigated emotion effects only for single words. However, semantic meaning in language is usually conveyed by sentences or texts, units that are considerably more complex than single words (e.g., Murphy, 1990). As compared to words embedded within sentences or other contexts, the meaning of isolated words is less constrained and may therefore be more ambiguous at least in many cases. Further, sentential context information leads to faster and more accurate word processing by pre-activating relevant lexical or conceptual features (Federmeier and Kutas, 1999). In two experiments, Schacht and Sommer (2009a) have shown a facilitation of initial EPN effects to emotional verbs when these verbs were embedded into a minimal semantic context – provided by preceding neutral nouns – as compared with single emotional verbs. This indicates that non-emotional linguistic context information can strongly modulate the dynamics of emotion effects in word processing. So far, no study has investigated a possible modulation of EPN and LPC effects to emotional words that are embedded into larger context as provided by sentences.

The internal structure of "emotion" is a very controversial issue, as can be seen in the numerous unreconciled theories of emotion (e.g. Moors, 2009). Of particular relevance in current emotion research are dimensional models of affect that are widely used both as theoretical framework as well as for stimulus categorization. These models assume a two-dimensional structure of affect defined by hedonic valence and arousal/activation (Barrett and Russell, 1998; Lang et al., 1998; Russell, 1980). These theories largely agree on the role of the valence dimension as denoting the degree of pleasure or displeasure of affective states or emotional stimuli, respectively. However, there has been considerable disagreement concerning the role of arousal/activation, especially, regarding its relation to valence. Thus, the affective circumplex model of Russell (1980) depicts valence and arousal as orthogonal, bipolar, and independent dimensions. The two dimensions build the axes of the circumplex; affective states arrange in a circle around those axes. Empirical evidence supporting this structure comes from multidimensional scaling of emotion words, facial, and verbal expressions, as well as from factor analysis of self-reported affect (Russell and Barrett, 1999). It is also supported by imaging studies, which suggest distinct neural systems for the processing of valence and arousal (Anders et al., 2004; Lewis et al., 2007; Kensinger and Corkin, 2004). Recently, similar distinctions were also reported for EEG data (Gianotti et al., 2008), where a microstate analysis revealed different dynamics and neural assemblies for the processing of valence and arousal.

In contrast to Russell's conceptualization, Lang et al. (1993) postulate the existence of two motivational systems in the brain, appetitive and aversive, determining the general direction of affect, corresponding to the valence dimension. The second dimension, arousal, merely depicts the intensity of activation of the respective motivational system and is therefore not viewed as an independent dimension (Lang et al., 1998). This concept is supported by normative ratings for affective pictures (Lang et al., 1999), words (Bradley and Lang, 1999), and sounds (Bradley et al., 1998), where emotional arousal and valence judgments are strongly related via a U-shaped distribution function within two-dimensional affective space (Lang et al., 1998).

The basic assumptions regarding the relationship of valence and arousal in these models of affect have differential implications for empirical predictions. The motivated emotion model by Lang and coworkers predicts that emotion effects can only arise from a combination of valence and arousal (as stimuli of high emotional valence by definition also have high arousal values). In contrast, the circumplex model provides a framework that implies that arousal effects may be obtained independently of valence effects. Nonetheless, so far, no study has directly tested these predictions.

The aim of the present study was twofold. First, we wanted to extend research on emotion effects in reading from single words and word pairs to larger linguistic units. Therefore, negative and neutral verbs where embedded into sentence contexts that provided actor-object information and were emotionally neutral. In comparison to studies that used single words and word pairs, respectively, we expected shorter latencies of emotion effects at least in early ERPs (namely the EPN). Alternatively, it seemed conceivable that the processing of the sentence context might interfere with the reflex-like allocation of attention held to be elicited by emotional meaning.

Second, we aimed to investigate the specific contribution of arousal to ERP effects in the processing of emotional word material. According to Lang's model of motivated emotion, high arousal always co-occurs with extreme valence, and emotion effects can therefore only emerge from a combined variation of both dimensions, that is by comparing highly valenced, high-arousal stimuli and neutral, low-arousal stimuli. Hence, our first comparison compared negative, high-arousal and neutral, low-arousal verbs, allowing for the replication of emotion effects reported in previous studies. Against the background of circumplex models of affect, one would expect arousal effects to be separable of valence effects. Further, arousal effects should also be traceable even within one valence category by comparing stimuli at a constant valence level differing only in arousal. Thus, a second comparison contrasted high- and low-arousal words that did not differ in their valence level.[1] Following the predictions of the circumplex model and further assuming that emotion effects are related to arousal differences, we would expect those effects to be similarly elicited for high- and low-arousal words of the same valence. On the other hand, if emotion effects were bound to a combination of high valence and high arousal, as Lang's model would suggest, emotion effects should only emerge in the comparison of high-arousal negative and neutral, low-arousal words.

Stimulus valence is strongly related to facial muscle activity as reflected in recordings of the electromyogram (EMG). EMG activity of the *Corrugator* muscle (frowning) increases with more negative valence ratings; conversely, activity of the *Zygomaticus* muscle (smiling) increases with positive valence ratings (e.g., Lang et al., 1998). This activation pattern has not only been shown for affective

[1] Negative valence was chosen because of the uneven distribution of verbs in German language. Negative verbs extend further towards the extremes of both the valence and arousal dimension than positive verbs, allowing the investigation of maximal differences to neutral, low arousal verbs. In addition, there is a larger number of negative than positive verbs in the German language (see BAWL-R; Vo et al. (2009) for the distribution of verbs in German language).

pictures (Bradley et al., 2001; Cuthbert et al., 2000) but also for words and tones (Larsen et al., 2003). We therefore expected enhanced *Corrugator* muscle activity for more negative target words, that is, for the comparison of negative high-arousal and neutral low-arousal words, but not in the comparison of high- and low-arousal words at constant valence level, as the latter were indistinguishable with respect to overall valence ratings.

2. Method

2.1. Participants

Twenty-one persons (11 women; mean age = 25.3 years) participated in this experiment. Two further data sets had to be excluded from analysis due to excessive artifacts. Three participants were employees, all others were students. All were native German speakers with normal or corrected-to-normal vision and without any neurological or neuropsychological disorders according to self-report. Apart from three left-handers all were right-handed (according to Oldfield, 1971). Participation was reimbursed with course credits or 8 Euro per hour.

2.2. Evaluation and selection of stimulus materials

In a first step, we constructed 328 semantically and syntactically correct German sentences. All sentences followed the same structure in Future I: [determiner – actor – auxiliary – determiner – object] – [verb], for example, [Die (the) – Frau (woman) – wird (will) – den (the) – Mann (man)] [anrufen (call)]. The sentence-final verbs varied in their emotional connotations (neutral, negative). Most of them were chosen from our own database and previous experiments (Schacht and Sommer, 2009a, 2009b). Twenty students (11 female, mean age = 27.2), not overlapping with the sample of the main experiment, evaluated the emotional valence and the emotional arousal of each of these 328 sentences on a five-point scale using a computerized versions of the Self-Assessment Manikin (SAM; Bradley and Lang, 1994). Arousal ratings were always followed by valence ratings in separate blocks. An additional set of 22 sentences with positive sentence-final verbs was presented for the ratings. These sentences merely served as fillers in order to facilitate the utilization of the complete valence scale but were not used further on because of their relatively small number.

Ratings revealed the typical relationship between valence and arousal as shown by Lang and colleagues for English emotional words (ANEW; Bradley and Lang, 1999) and affective pictures (IAPS; Lang et al., 1999), that is, arousal values increase from neutral to intermediately to highly negative items. From the 350 stimuli of the rated set, 262 sentences were selected, which were consistently judged for a given emotional valence ($SDs<1.4$) and arousal ($SDs<1.1$) value. For this remaining stimulus material, valence and arousal ratings were highly correlated, $r = -.88$, $p<.001$. Regression analyses revealed a strong linear, $F(260) = 880.9$, $p<.001$, $r^2 = .772$, as well as quadratic relationship, $F(259) = 439.2$, $p<.001$, $r^2 = .772$, between both dimensions. Because of this high correlation, an orthogonal classification of the sentences was not possible. Therefore, two subsets of stimuli were selected from the entire sentence material for statistical analyses. The first subset included 100 sentences; half of them were emotionally negative with high arousal values, the other half consisted of neutral sentences with low arousal values. Rating values of these subsets significantly differed on both valence, $t(98) = 58.3$, $p<.001$, and arousal dimension, $t(98) = 74.8$, $p<.001$. For the second subset, 48 pairs of sentences were selected. Sentences of a given pair had identical valence ratings, but differed significantly in arousal ratings, $Ms = 3.3$ vs. 2.1, $SDs = .7$, $t(94) = 8.7$, $p<.001$. Although valence and arousal differed between sentence pairs, averaged over all pairs, high- and low-arousal sentences showed indistinguishable mean valence ratings, $Ms = 2.3$ vs. 2.4, $SD<.6$, $t(94) = -.6$, $p>.5$. The distribution of all stimuli presented in the experiment is shown in Fig. 1, for descriptive statistics for these selected subsets see Table 1. Within each subset, the two stimulus categories were matched for the control variables word frequency and word length (number of letters, number of syllables), all $ts<1.5$, $ps>.05$. Note that although all statistical analyses reported here apply to these two subsets, we presented the complete set of 262 sentences with consistent negative or neutral ratings in the experiment.

For the semantic decision task of the experiment, a second set of 262 sentences was constructed with identical neutral sentence contexts but semantically inappropriate final verbs, for example [the – woman – will – the – man] [spill]. Target verbs in these incorrect sentences were matched to those in correct sentences with regard to word length and frequency (CELEX; Baayen et al., 1995), $ts(522)<1$.

In an additional rating study involving 20 further students (14 female, mean age 26.7 ± 5.04 years), all verbs were evaluated with respect to their expectedness within the actor-object context. Participants were sequentially presented with the sentence context and the target verbs according to the trial scheme of the experiment (see below) and should decide to which extent the presented verb might be expected in the given context, using a 5-point rating scale ranging from 0 (unexpected) to 4 (highly expected).

2.3. Procedure

During the experiment, participants were seated in a dimly lit, sound-attenuated chamber facing a computer monitor. The screen was situated at a distance of approximately 1 m from the participant's eyes. All stimuli were presented in black letters (Arial font; font size 24) against a light-gray background at the center of the screen. Vertical size of the letters was 8 mm. The use of lowercase and capital letters conformed to the rules of German orthography. A trial started with a fixation cross displayed for 1 s, followed by the actor-object phrase of the sentence (e.g., [The-woman-will-the-man]) for 1 s. After a further fixation cross (500 ms) the target verb was presented, which disappeared with the response or after 2 s if no response was given. After 4 s (blank screen) the next trial started. All sentences were delivered

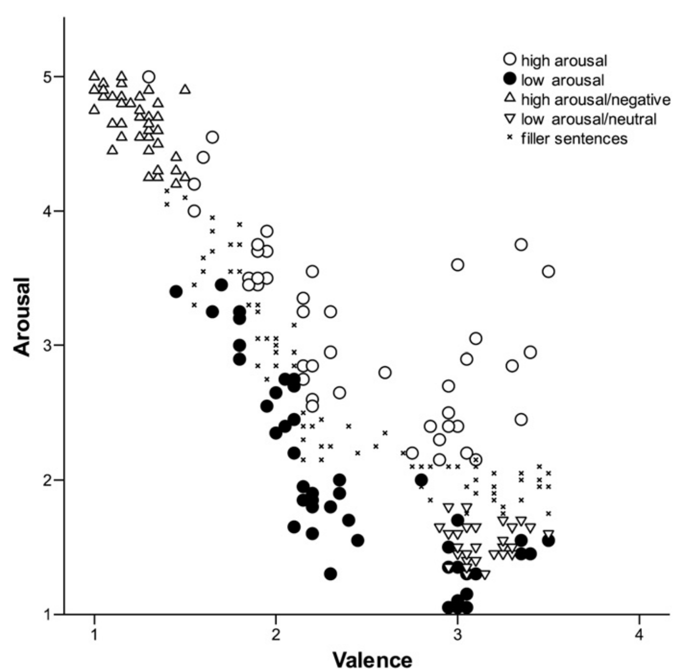

Fig. 1. Distribution of experimental stimuli on the dimensions of valence and arousal.

Table 1
Descriptive statistics for control variables and rating results for the stimulus material.

	Subset 1		Subset 2		Total set of stimuli	
	Negative/high arousing (N = 50) *M* (*SD*)	Neutral/low arousing (N = 50) *M* (*SD*)	High arousal (N = 48) *M* (*SD*)	Low arousal (N = 48) *M* (*SD*)	Semantically correct (N = 262) *M* (*SD*)	Semantically incorrect (N = 262) *M* (*SD*)
Emotional valence (range 1–5)	1.2 (.2)	3.1 (.1)	2.3 (.6)	2.4 (.5)	2.8 (1.1)	–
Arousal (range 1–5)	4.7 (.2)	1.5 (.2)	3.3 (.7)	2.1 (.7)	2.3 (.8)	–
Expectancy (range 1–5)	2.9 (.6)	3.9 (.6)	3.5 (.8)	3.7 (.6)	3.6 (.7)	1.1 (.1)
Word length (number of letters)	9.5 (1.8)	9.0 (1.8)	9.3 (2.0)	9.1 (1.8)	9.2 (1.9)	9.2 (1.9)
Word length (number of syllables)	3.0 (0.7)	3.1 (0.7)	3.0 (0.7)	3.0 (0.5)	3.0 (0.6)	3.0 (0.6)
Word frequency (1/1 000 000, CELEX)	16.7 (49.6)	17.5 (18.4)	20.8 (73.6)	20.5 (37.8)	26.9 (94.4)	26.2 (94)

Rating values correspond to the target verbs in the context provided by the actor–object structure. Word length and frequency correspond only to target verbs.

randomly in eight blocks of 60 each and one final block of 44 items[2]; short breaks were allowed between blocks.

Participants were instructed to read each sentence carefully and to evaluate its correctness by pressing one of two keys as fast and as accurately as possible. The assignment of condition (correct vs. incorrect verb) to responding finger was counterbalanced. A practice block consisting of 12 trials was given prior to the first experimental block.

2.4. Psychophysiological recording and processing

The *electroencephalogram* (EEG) was recorded from 58 Ag/AgCl electrodes mounted in an electrode cap (Easy-Cap™); additional electrodes were placed at the left and right mastoid and – for monitoring the horizontal vertical and electrooculograms – at the outer canthi of the eyes and below the left and right eye. ECI electrode gel (Expressive Constructs Inc., Worcester, MA) was used for contact; electrode impedance was kept below 5 kΩ. Initially, all channels were referenced to the left mastoid; signals were band pass filtered at 0.05–70 Hz and sampled at 500 Hz. Offline, the continuous EEG record was segmented into epochs of 1100 ms, starting 100 ms prior to stimulus onset, and recalculated to an average reference montage. Epochs containing artifacts were discarded. After applying a 30-Hz low pass filter, average ERPs were calculated for each participant, electrode, and experimental condition, considering only trials with correct responses. All ERP waveforms were referred to a 100-ms prestimulus baseline.

ERP segmentation proceeded according to visual inspection of global field power (GFP; Lehman and Skrandies, 1980) and global map dissimilarity (GMD; Brandeis et al., 1992). GFP reflects the overall ERP activity across the scalp at any given moment, that is, the root mean square of averaged voltages at all electrodes. GMD reflects the dissimilarity between scalp topographies of adjacent time points and demarcates the temporal borders between periods of relatively stable topographies. Within these periods similar brain areas are active. Because strongest effects of both valence and arousal should appear to high-arousal negative verbs compared with low-arousal/neutral verbs, GMDs were calculated from GFP to these extreme groups. GMD peaks identified different microstates in the ERPs with transitions at 96, 130, 150, 224, 276, 326, and 426 ms (see Fig. 2). These transition times were used as the borders of time segments for which mean ERP amplitudes were calculated. As depicted in Fig. 2, clear segment borders, indicated by GMD peaks, only appeared until 426 ms. Therefore, after this time point mean amplitudes were calculated for consecutive time periods of 100 ms duration each.

EMG Activity of the M. Corrugator supercilii was measured above left eye with sensormedics miniature Ag/AgCl electrodes using the placement recommended by Fridlund and Cacioppo (1986). The raw EMG signals were amplified by 30.000 at a band pass of 8 Hz to 10 kHz, using a Coulbourn V75-04 bio-amplifier. The raw signals were rectified and integrated using a Coulbourn V76-23 contour following integrator, with a time constant of 100 ms. Off-line, a low-pass filter of 100 Hz was applied, and 600-ms epochs were analyzed, referring to a 100-ms prestimulus baseline. Epochs containing eyeblink artifacts were discarded. Activity was quantified as mean amplitude in the two time segments from target onset to 300 ms and from 300 to 600 ms.

ERP and EMG amplitudes as well as the percentage of wrong classifications and mean reaction times (RTs) for correct responses were assessed by two types of repeated measures analysis of variance (ANOVAs), assessing (1) the combined effect of emotional valence and arousal (negative/high-arousal vs. neutral/low-arousal), and (2) the effect of arousal within pairs of sentences, differing only in arousal (high- vs. low-arousal) but not in valence. A third ANOVA was conducted to compare behavioral and psychophysiological parameters between all semantically correct versus all incorrect sentences.

Mean ERP amplitudes in selected time segments were assessed with the three ANOVAs described above, including an additional factor electrode with 58 levels. By definition, the average reference sets the mean value of the ERP amplitude to zero across all electrodes within a given condition. Therefore, whenever all electrodes are entered into the ANOVA, only effects in interaction with electrodes are meaningful. Interactions between an experimental factor and electrode in these ANOVAs may reflect either differences in overall ERP activity (amplitude) or differences in the scalp distributions between experimental conditions. To assess whether the emotion effects obtained in the ANOVAs within a given domain differ in scalp distributions, overall amplitude differences were eliminated by normalization of difference waves by the voltage range across electrodes within each condition and participant (profile analyses;

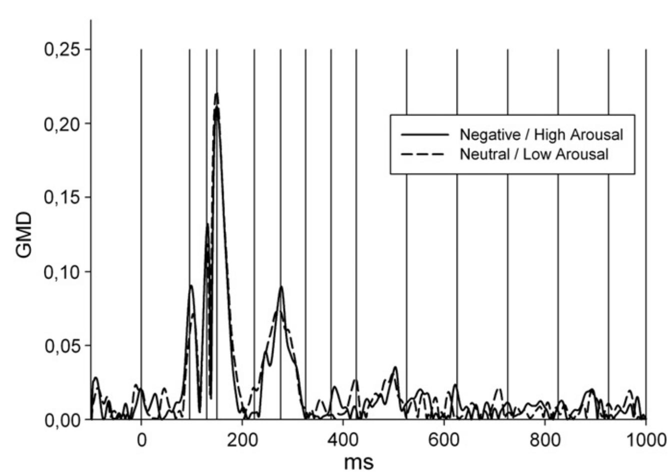

Fig. 2. Global Map Dissimilarity (GMD) of ERPs contrasted for emotionally negative, high-arousal and neutral, low-arousal target verbs. The vertical lines mark the segment borders, defined by GMD peaks.

[2] An equal number of items per block was not possible because of the total number of items (N = 524).

Table 2
Reaction Times (RTs) in ms and error rates in % (Mean values with Standard Deviations).

	Subset 1		Subset 2		Total set of stimuli	
	Negative/high arousing (N = 50) *M* (*SD*)	Neutral/low arousing (N = 50) *M* (*SD*)	High arousal (N = 48) *M* (*SD*)	Low arousal (N = 48) *M* (*SD*)	Semantically correct (N = 262) *M* (*SD*)	Semantically incorrect (N = 262) *M* (*SD*)
RTs	788.0 (134.0)	783.6 (124.1)	813.4 (129.5)	809.0 (130.7)	796.9 (125.9)	909.1 (178.4)
Error rates	2.8 (2.3)	2.5 (2.0)	4.3 (2.9)	3.5 (2.5)	6.0 (3.5)	6.2 (5.2)

McCarthy and Wood, 1985). In these ANOVAs, a significant interaction between electrode and experimental factor(s) indicates topographical differences between the ERPs of experimental conditions, independent of overall ERP activity. In order to test whether any obtained significant condition x electrode interactions in ANOVAs on non-normalized data originated from differences in amplitude rather than mere topography, we conducted additional analyses of regions-of-interest (ROIs) over relevant electrode sites in relevant time segments. For effects of arousal and semantic correctness these sites were the central electrodes Cz, FC1, FC2, CP1, and CP2; for the LPC they were the parieto-occipital electrodes Pz, P3, P4, POz, PO3, and PO4.

Huynh-Feldt correction was applied to adjust the degrees of freedom of the *F*-ratios. Please note that ANOVA results will be reported with corrected *p*-values but uncorrected degrees of freedom.

3. Results

3.1. Ratings

Expectancy ratings clearly differed between semantically correct and incorrect sentences, $t(522) = 54.4$, $p < .001$, and also between sentences with emotionally negative/high-arousal and neutral/low-arousal target verbs, $t(97) = 8.6$, $p < .001$, as neutral targets were more expected than negative verbs in the context of the actor-object phrase. In contrast, within the subset of pure arousal variation high- and low-arousal sentence-final verbs did not differ in terms of expectancy, $t(94) = -1.6$, $p > .1$ (see Table 1).

3.2. Performance

Descriptive statistics for behavioral data are given in Table 2. ANOVAs revealed no significant effects of factors valence/arousal or arousal — neither on RTs, $Fs(1,20) < 2.6$, $ps > .05$, nor on error rates, $Fs(1,20) < 3.7$, $ps > .05$. RTs to semantically incorrect sentences were significantly longer as compared to correct sentences, $F(1,20) = 27.3$, $p < .001$, whereas error rates did not differ, $F(1,20) < .1$.

3.3. Event-related potentials

ANOVA results for mean ERP amplitudes are presented in Table 3. Statistical comparison of ERPs to sentences with negative/high-arousal and neutral/low-arousal target verbs revealed significant differences in all time segments between 376 and 926 ms, $Fs > 2.7$, $ps < .05$, $0.7 > \varepsilon < .08$. ROI ANOVAs within these time segments indicated that emotionally negative target verbs elicited larger amplitudes at parietal electrode sites compared to neutral verbs (see Fig. 3A), between 426 and 826 ms, $Fs > 5.2$, $ps < .05$, $.2 > \varepsilon < .5$.

Significant effects of arousal equated for valence appeared between 326 and 426 ms, $Fs(57,1140) > 2.4$, $ps < .05$, $.08 > \varepsilon < .09$. In contrast to the valence/arousal effect, this effect of pure arousal consisted in an enhanced negativity at central electrode sites (see Fig. 3B), which was confirmed by ROI ANOVAs, $Fs > 5.8$, $ps < .05$, $.2 > \varepsilon < .3$.

Significant differences between semantically correct and incorrect sentences started at 276 ms $Fs > 3.0$, $ps < .05$, $.06 > \varepsilon < .09$, (see Fig. 3C). This effect consisted in a long-lasting enhanced negativity at centro-parietal electrode sites elicited by semantically incorrect sentences, $Fs > 7.8$, $ps < .05$, $.3 > \varepsilon < .7$, as obtained in ROI ANOVAs.

As depicted in Fig. 3A–C, the ERP effect to emotionally negative relative to neutral target verbs showed an enhanced centro-parietal positivity, which is typical for the LPC. This centro-parietal positivity appeared to differ from the centro-parietal negativities found for arousing as well as for semantically incorrect verbs. This was corroborated by ANOVAs on normalized ERPs (McCarthy and Wood, 1985) within the time segments 376–926 ms for the LPC, and 326–426 ms for the effects of pure arousal and semantic correctness. As expected, the emotional LPC effect differed from the effect of both, pure arousal, $F(57,1140) = 5.0$, $p < .01$, $\varepsilon = .08$, as well as semantic correctness, $F(57,1140) = 13.7$, $p < .001$, $\varepsilon = .11$. The scalp distributions of the pure arousal effect shows a more frontal and more right lateralized negativity than the semantic correctness effect; this visual impression of topographic differences was statistically corroborated, $F(57,1140) = 2{,}6$, $p < .01$, $\varepsilon = .13$.

3.4. Corrugator activity

Fig. 4 depicts mean activity of the *Corrugator* muscle for all conditions. ANOVAs confirmed that emotionally negative/high-arousal verbs enhanced *Corrugator* activity between 300 and 600 ms, $F(1,20) = 3.4$, $p < .05$, one-tailed, but not before 300 ms, $F(1,20) = 2.1$, $p > .05$. In contrast, no significant effects of arousal on EMG activity appeared to target verbs equated for emotional valence, $Fs < 3.0$, $ps > .10$. Further, no significant differences were obtained as a function of semantic congruency of the target verbs with the sentence context, all $Fs(1,20) < 1.0$.

Table 3
ANOVA results for mean amplitudes in selected time segments, involving the factors emotional valence/arousal (emotionally negative/high arousing vs. neutral/non-arousing, ANOVA 1), arousal (high vs. low arousing, ANOVA 2) and semantic correctness (semantically correct vs. incorrect sentences, ANOVA 3).

Time segments [ms]		−276	276–326	326–376	376–426	426–526	526–626	626–726	726–826	826–926	926–1000
ANOVA 1 Emotion/arousal	F	n.s.	n.s.	n.s.	2.6*	7.2***	10.4***	10.7***	6.0***	3.1*	n.s.
ANOVA 2 Arousal	F	n.s.	n.s.	2.5*	2.4*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
ANOVA 3 Correctness	F	n.s.	4.1*	11.1***	14.6***	23.0***	25.2***	13.9***	8.2***	4.5*	3.0*

Only interactions with the electrode factor are reported. *p*-values are Huynh–Feldt adjusted, where appropriate to correct for violations of the sphericity assumption: *$p < .05$; **$p < .01$; ***$p < .001$.

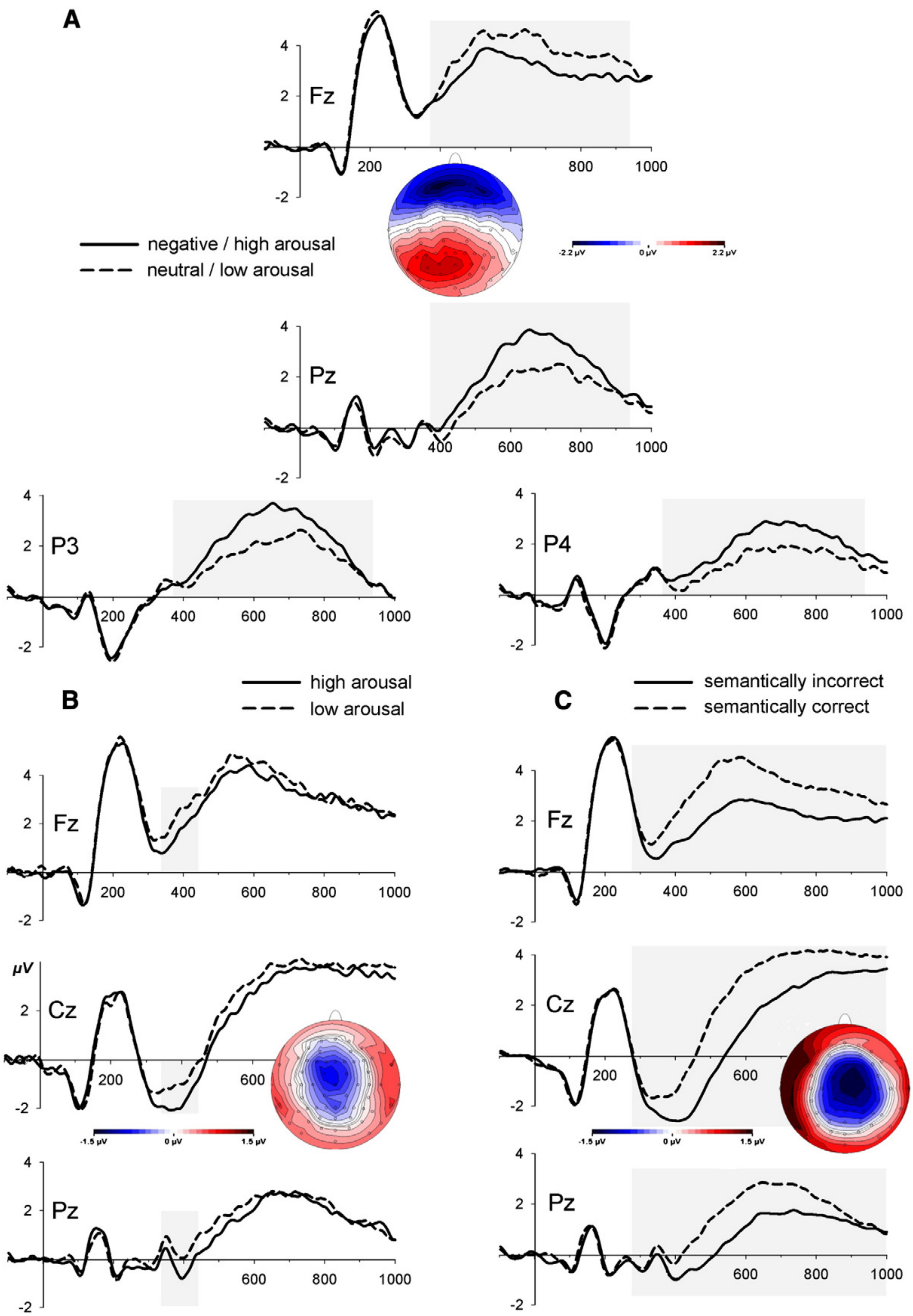

Fig. 3. ERPs as a function of emotional valence, arousal, and semantic correctness. A) Grand mean ERP waveforms to negative, high-arousal and neutral, low-arousal target verbs from selected electrode sites. The embedded head depicts the scalp distribution of the ERP differences waves between negative, high-arousal minus neutral, low-arousal verbs. B) Grand mean ERPs as a function of arousal, and scalp distribution of difference waves between ERP for high- versus low-arousal target verbs with equal emotional valence. C) ERPs to semantically correct and incorrect targets verbs and distribution of the N400 component as elicited by semantically incorrect target verbs. Grey boxes mark time windows of significant effects.

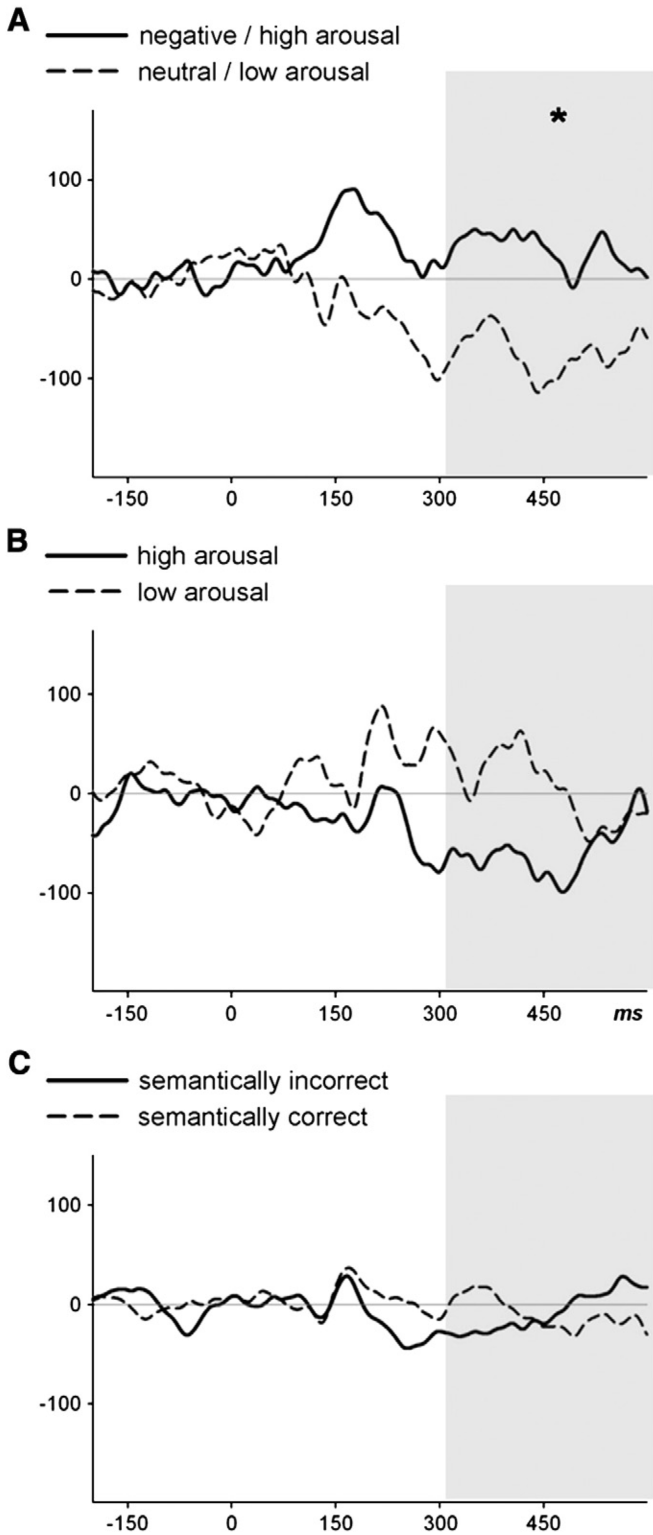

Fig. 4. Mean *Corrugator* activity in μV to negative, high arousal versus neutral, low arousal (A), to high versus low arousal (B), and semantically correct versus incorrect target verbs (C). The grey boxes correspond to the time window between 300 and 600 ms, where significant effects appeared only in the comparison between negative, high-arousal and neutral, low-arousal target verbs.

4. Discussion

The present study addressed two major issues. The first aim was to investigate emotional verb processing in semantic contexts provided by short sentence structures. Therefore, emotionally negative and neutral German verbs were presented at sentence final positions following emotionally neutral actor-object phrases. Second, we aimed to specify the influence of emotional valence and arousal on language processing, that is, whether emotion effects require a combination of both high arousal and strong valence, or whether they also emerge in a pure arousal variation at a constant valence level. In order to localize these effects within the processing stream, ERPs were measured. In addition, *Corrugator* muscle activity was recorded as a peripheral indicator of negative valence.

A first main result of the present study is the strong relationship between emotional arousal and valence obtained in the ratings. Sentences with neutral verbs were judged as less arousing than sentences with emotionally negative verbs. This finding represents one arm of the U-shaped valence-arousal distribution often reported for affective pictures (e.g. Lang et al., 1999) and emotional single words (Bradley and Lang, 1999). Consequently, statistical comparisons of emotion effects focused on two subsets of stimuli. First, analyses contrasted target verbs that differed maximally in both arousal and valence. Second, two subsets of context-verb phrases were selected that differed in arousal but not in valence.

The finding of enhanced *Corrugator* activity to emotionally negative but not to high-arousal verbs corroborates previous findings (e.g. Dimberg and Pettersen, 2000; Lang et al., 1998; Larsen et al., 2003) and provides additional evidence for the valence sensitivity of facial muscle activity, particularly, in language perception. In contrast, *Corrugator* activity did not differ between high- and low-arousal stimuli, validating the obtained ratings. Since semantically correct and incorrect sentences produced similar effects on *Corrugator* activity, one might assume that semantic violations as employed here are not accompanied by negative emotions.

4.1. Negative valence/high-arousal versus neutral/low-arousal verbs

In ERPs, first effects in the comparison of stimuli varying in both valence and arousal emerged at about 380 ms after verb onset and lasted for about 550 ms: emotionally negative, high-arousal verbs elicited larger LPC amplitudes than neutral, low-arousal verbs. This effect replicates previous reports on emotional LPC modulations in single word processing (e.g., Fischler and Bradley, 2006, Schacht and Sommer, 2009a, 2009b) and may reflect the continued perceptual analysis of intrinsically relevant stimuli (Cuthbert et al., 2000). Our results extend these findings to verb processing in sentence contexts (cf. Schacht and Sommer, 2009a).

In contrast to previous studies reporting earlier EPN effects of emotion in single word processing (e.g., Herbert et al., 2006; Kissler et al., 2007; Schacht and Sommer, 2009a, 2009b), such early ERP modulations were not present in our comparison of negative, high-arousal and neutral, non-arousing verbs. This finding is surprising considering that we had used mostly identical word material as in our previous studies (Schacht and Sommer, 2009a; Schacht and Sommer, 2009b) and that the LPC found here was, if anything, larger than in these previous studies. Therefore, we consider it unlikely that the absence of an EPN in the present data is due to a lack of power.

In the present study, a semantic context of high complexity was presented preceding the target verbs, which needed to be encoded and maintained until the verb appeared for successful task performance. These processes, elicited by task requirements demanding cognitive resources or attention, probably compete with the involuntary attention capture by emotion. Therefore, the absence of early ERP effects of emotion in the present study might provide first evidence that also the demands of a single task to be performed on the emotional stimuli themselves require attentional resources modulating the contribution of attention to emotional words. Further research will be needed to specify the interaction of emotional processes and other task-relevant cognitive operations.

With respect to the comparison of negative/high-arousal and neutral/low-arousal verbs it should be mentioned that the former were also less expected in the sentence context, denoting an additional confound between the sets of sentences. This confound might be difficult to avoid, as it is hard to imagine a strongly negative, highly arousing scene, as described in a sentence, which is just as expected as a neutral scene. This issue may apply not only to the present study, but to emotional stimulus material in general, although it may not be very evident in studies with single words. Assuming a specific influence of expectancy, it is not likely to appear in the form of enhanced LPC amplitudes for negative/high-arousal words. Typically, semantically unexpected words within a context elicit a more pronounced negativity peaking around 400 ms, as can be seen in our N400 effect for incorrect compared to correct words. In contrast, emotionally negative, high-arousal, unexpected words in our study should yield more positive amplitudes than neutral, expected words within this time range.

4.2. High versus low arousal at constant valence level

Stimuli varying in terms of arousal (but not valence) modulated a negative-going ERP deflection over centro-parietal electrode sites starting at about 320 ms. Clearly, this was not a modulation of the LPC. This result might imply that the emotional influence on LPC amplitudes does not derive solely from differences in the arousal level of stimuli, but also requires valence differences. This interpretation is in line with other ERP studies reporting late emotion effects for negative compared to neutral stimuli at constant arousal level (Delplanque et al., 2004; Conroy and Polich, 2007; Yuan et al., 2007), denoting the influence of valence and suggesting that arousal differences are neither necessary nor sufficient for late emotion effects. In addition, previous studies showed that several other factors might also modulate emotional LPC effects. For instance, in superficial tasks LPC enhancements for emotional stimuli vanished as compared to semantic or explicit emotional judgment tasks (e.g., Naumann et al., 1997; Schacht and Sommer, 2009a). However, it is noteworthy that the arousal difference between sentences that only varied in arousal (but not in valence) was lower than the arousal difference between negative, high-arousal and neutral, low-arousal words. Therefore, it remains to be determined whether emotional LPC modulations could also derive from pure valence manipulations, or from a combination of valence and arousal, or whether they require a minimal difference along the arousal-dimension that is larger than the one realized in the present arousal comparison.

A second relevant aspect is the nature of ERP effect obtained for pure arousal variation within the time window of the N400. It is not comparable to earlier emotional ERP effects reported in the literature as, for instance, the EPN (e.g., Schupp et al., 2007; Kissler et al., 2007). Our topographical analyses also indicate this effect to differ from the LPC effect described above, as well as from the N400 elicited by semantically incongruent verbs in distractor sentences with unexpected verbs. As indicated by statistical comparisons of control variables, lexico-semantic differences due to word length, word frequency, or expectancy can be ruled out as confounding factors. The effect of pure arousal also considerably differs from an emotion effect in the N400 reported by Kanske and Kotz (2007). In their study, decreased N400 amplitudes for emotional single words resulted from a facilitated integration into a context of previous emotional and neutral single words. In contrast, in our study neutral first sentence parts provided the context for the target verbs. This indicates that, if anything, high-arousal words are more difficult to integrate into a preceding neutral context than low-arousal words of the same valence, even in the absence of expectancy differences.

Somewhat surprisingly, the effect that showed up in the comparison of ERPs to high-and low-arousal words was not present in the comparison between negative, high-arousal and neutral, low-arousal verbs, although the difference between mean arousal ratings to these two subsets was larger than the arousal difference between high- and low-arousal verbs. Possibly, in this comparison the arousal effect was obscured by the large LPC to the highly negative items.

To the best of our knowledge, as yet there is no evidence for pure arousal effects in ERPs to linguistic stimuli. Further research will be needed to clarify whether this effect is solely caused by the arousal variation or whether it is due to other lexico-semantic variables that have not been controlled yet. Tentatively we suggest that the arousal effect observed in the present study is not due to physiological arousal of the participant but reflects the knowledge about arousal. This would also be in line with the late onset of the arousal component and with the resemblance – albeit not identity – of its topography with that of the N400 component proper.

In conclusion, the present study confirms that also emotional variations in sentence contexts modulate the LPC amplitude in a similar and, considering the duration of the effect, possibly more pronounced way as reported previously for single words and one-word contexts. This indicates that emotional processing at later stages is similar for stimuli of varying complexity, at least in the verbal domain. Importantly, such LPC effects only emerged in the comparison of negative, high-arousal and neutral, non-arousing stimuli, suggesting that the appearance of the “classical” emotion effect in the LPC does indeed require a combination of both extreme valence and high arousal. This finding, as well as the U-shaped distribution of stimuli along the valence and arousal dimension supports the postulate of Lang et al. (1993) of two motivational systems. It argues, however, against the notion that LPC modulations originate from arousal differences alone. Further, pure arousal induced a hitherto unobserved effect in the N400 time window, probably reflecting the knowledge about arousal rather than the experience of arousal. The finding that arousal modulations at a constant valence level elicited significant effects in ERPs supports Russell's (1980) assumptions, even if these effects do not appear in the form of EPN or LPC modulations, at least on sentence level. This is, however, not surprising considering the fact that no other study directly compared arousal modulations independently of valence. A further unexpected finding was the absence of early emotion effects that had been prominent in previous research on emotion effects of both pictures and words. Possibly, sentence context may constitute a special condition, due to syntactic structure or additional memory load, providing a caveat on generalizing from single word studies on sentence-context processing.

Acknowledgments

We thank Nele Adler and Arne Fesche for assisting in data collection, and Rainer Kniesche and Thomas Pinkpank for technical support.

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