Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/brainres

Research Report

Emotion word recognition: Discrete information effects first, continuous later?

Benny B. Briesemeister[a,*], Lars Kuchinke[b], Arthur M. Jacobs[a,c]

[a]Freie Universität Berlin, Allgemeine und Neurokognitive Psychologie, Center for Applied Neuroscience, Habelschwerdter Allee 45, 14195 Berlin, Germany

[b]Ruhr-Universität Bochum, Experimentelle Psychologie und Methodenlehre, Universitätsstraße 150, 44780 Bochum, Germany

[c]Dahlem Institute for Neuroimaging of Emotion (D.I.N.E.), The Cluster of Excellence 'Languages of Emotion', Habelschwerdter Allee 45, 14195 Berlin, Germany

ARTICLE INFO

Article history:
Accepted 29 March 2014
Available online 5 April 2014

Keywords:
Discrete emotions
Affective dimensions
Sequential affective processing
EEG
Lexical decision

ABSTRACT

Manipulations of either discrete emotions (e.g. happiness) or affective dimensions (e.g. positivity) have a long tradition in emotion research, but interactive effects have never been studied, based on the assumption that the two underlying theories are incompatible. Recent theorizing suggests, however, that the human brain relies on two affective processing systems, one working on the basis of discrete emotion categories, and the other working along affective dimensions. Presenting participants with an orthogonal manipulation of happiness and positivity in a lexical decision task, the present study meant to test the appropriateness of this assumption in emotion word recognition. Behavioral and electroencephalographic data revealed independent effects for both variables, with happiness affecting the early visual N1 component, while positivity affected an N400-like component and the late positive complex. These results are interpreted as evidence for a sequential processing of affective information, with discrete emotions being the basis for later dimensional appraisal processes.

1. Introduction

Two main conceptions have been proposed to best describe human emotions, each being in accordance with convincing empirical data. On the one hand, a class of theories assumes that emotions are processed along a limited number of affective dimensions (Russell, 2003; Wundt, 1896). The 'core affect' theory (Barrett and Bliss-Moreau, 2009; Russell, 2003; 2005; 2009), for example, assumes that emotions are "grounded in continuous and fluctuating affective states described as pleasant or unpleasant, with some level of arousal" within the core of the body (cf. Wilson-Mendenhall et al., 2013, p. 1). Within this class of theories, two affective dimensions, i.e. valence (ranging from a pleasant to an unpleasant pole) and arousal underlie human

*Correspondence to: Department of Psychology, Freie Universität Berlin, Habelschwerdter Allee 45, 14195 Berlin, Germany. Fax: +49 30 838 556 20.

E-mail addresses: benny.briesemeister@fu-berlin.de (B.B. Briesemeister), lars.kuchinke@rub.de (L. Kuchinke), ajacobs@zedat.fu-berlin.de (A.M. Jacobs).

http://dx.doi.org/10.1016/j.brainres.2014.03.045
0006-8993/

emotional experiences and evaluations, which is well in line with many empirical findings (Barrett and Bliss-Moreau, 2009; Russell, 2003). Discrete emotion theories, on the other hand, assume a limited set of functionally distinct emotion categories (Darwin, 1872; Ekman, 1992; Panksepp, 1998), which is primarily supported by studies that compared affective responses across different cultures (Elfenbein, 2013) and species (Panksepp, 1998). The existence of discrete emotions like fear, anger, disgust, sadness, and happiness is widely accepted, even though less consensus is reached regarding further emotions (like pride) or a common definition.

Even though discrete emotion models and dimensional models of affective space have traditionally been proposed as opposing viewpoints, several more recent models seek to integrate both conceptions in a single theoretical framework (Panksepp, 2008; Russell, 2005). The core affect theory mentioned above, for example, explicitly distinguishes between the two-dimensional core affect, which is seen as the first order state underlying continuous fluctuations in emotional life, and second order emotional meta-experiences that are derived from it (Russell, 2005). Discrete emotions, in this view, "are complex Gestalts that typically include simpler, more primitive feelings of Core Affect" (cf. Russell, 2005, p. 27), i.e. they depend on and are derived from the core affect. An alternative unifying framework is provided by Panksepp (2008), whose model is based on neurophysiological and neuroanatomical evidence for discrete emotional states in the mammalian brain (Panksepp, 1998). Panksepp assumes that discrete emotions are genetically ingrained basal processes that originate in subcortical circuits, such as the periaqueductal gray (PAG), while affective dimensions depend on neocortical circuits such as the dorsolateral prefrontal cortex. In the neocortex, discrete emotions are adapted to and shaped by sociocultural demands, with one important function being to "cluster [the formally discrete emotions] into constellations of positive and negative affect" (cf. Panksepp, 2006, p. 22). Following this view, affective dimensions are clearly derived from more basal discrete emotions, which is the exact opposite sequence when compared to the core affect model. Moreover, Panksepp explicitly emphasizes that three (temporally succeeding) levels-of-analysis must be distinguished: (a) a primary process—level where discrete emotions arise from subcortical processes, (b) a secondary process—level where emotions from the first process-level are transformed into conditioned responses based on classical and instrumental conditioning (e.g. fear-conditioning in LeDoux, 2000) and (c) a tertiary process—level that represents interactions of the previous levels with higher-order, neocortical cognitive processing (Panksepp and Watt, 2011).

The most obvious discrepancies between these two unifying frameworks relate to the different time frames of emotion processing, which is why temporally more fine-grained analyses have been asked for (Barrett and Wager, 2006). According to Russell (2005; 2009), discrete emotions are derived from fluctuating states best described in terms of affective dimensions, which implies a succession with temporal priority for the dimensional core affect. The hierarchical model suggested by Panksepp (2008), in contrast, predicts a temporal order of processing where discrete emotions based at first and second level precede a third one related to affective dimensions. To test these opposing predictions, we employed an event-related potentials (ERP) study of emotion effects in word recognition using a lexical decision task (LDT).

Previous research on visual word processing using the ERP methodology documents that electroencephalography (EEG) recordings provide an excellent measure to investigate the temporal dynamics of implicit affective processing as triggered by the LDT (for a review, see Citron (2012)). Different temporally early and late ERP components have been identified to reveal effects related to emotional processing. The N1 component, peaking around 100 ms, is sensitive to differences in early attentional resource allocation for positive versus negative stimulus categories (words: Hofmann et al., 2009; pictures: Foti et al., 2009). Such early effects are visible before the stimulus is analyzed in full detail, and in case of emotional words, have been shown to result from conditional learning (Fritsch and Kuchinke, 2013) as it would be expected by secondary level processes (Panksepp and Watt, 2011). Similarly, a negative deflection peaking between 200 and 300 ms is visible in word recognition tasks around the time frame of word identification (early posterior negativity, EPN; Citron, 2012), modulated by implicit and automatic processing of affective information irrespective of its polarity (e.g., Kissler et al., 2009; pictures: Foti et al., 2009). Later components that reflect emotional processing like the N400 and the LPC (late positive complex, around 500–800 ms) are discussed to indicate higher-order evaluative processes (words: Kanske and Kotz, 2007; pictures: Foti et al., 2009), in accordance with the description of Panksepp's tertiary process-level.

While there is a history of dimensional emotion effects in word recognition (Citron, 2012), recent work suggests that word processing is also affected by discrete emotion information when the material is controlled for dimensional emotion effects (Briesemeister et al., 2011a, 2011b; see also Ponz et al., in press; Silva et al., 2012). With an orthogonal manipulation, it should thus be possible to examine temporal differences of dimensional and discrete emotion processing and their role in differentiating words from nonwords. Based on Panksepp's model of hierarchical emotion processing (Panksepp, 2006) we predicted that (conditioned) discrete emotion information affects early ERP components (N1, EPN), whereas dimensional emotion information affects later ERP components (N400, LPC) as these address post-lexical cognitive evaluations at the tertiary process-level in neocortex (Panksepp and Watt, 2011). The reverse result-pattern would be supported by the core affect theory (Wilson-Mendenhall et al., 2013).

2. Results

2.1. *Pilot study*

A repeated measures ANOVA for LDRTs yielded significant main effects of happiness ($F(1,21)=11.995$, $p=0.002$, $\eta^2=0.364$) and positivity ($F(1,21)=5.206$, $p=0.033$, $\eta^2=0.199$), but no significant interaction ($F(1,21)=2.270$, $p=0.147$, $\eta^2=0.098$). Words highly rated on happiness (highHap) were processed faster ($M=623$ ms, $SD=97$ ms) than words weakly related to happiness (lowHap; $M=643$ ms, $SD=109$ ms). Neutral words (neu; $M=627$ ms, $SD=101$ ms) were processed faster than positive words (pos; $M=640$ ms, $SD=105$ ms). Planned pairwise comparisons revealed three significant effects, that is slower responses for lowHap+pos words ($M=654$ ms, $SD=111$ ms) when compared with lowHap+neu ($M=633$ ms, $SD=108$ ms; $t(21)=-3.266$, $p=0.004$), with highHap+pos ($M=625$ ms, $SD=100$ ms; $t(21)=-4.373$, $p<0.001$), and with highHap+neu words ($M=622$ ms, $SD=98$; $t(21)=-3.562$, $p=0.002$).

In the ER analysis a significant main effect of positivity with fewer errors for neutral words (neu: $M=3.0$, $SD=1.8$; pos: $M=4.1$, $SD=2.6$; $F(1,21)=5.570$, $p=0.028$, $\eta^2=0.210$) and a significant happiness × positivity interaction ($F(1,21)=11.307$, $p=0.003$, $\eta^2=0.350$) were observed. The main effect of happiness did not reach significance ($F(1,21)=1.184$, $p=0.289$, $\eta^2=0.053$). Paired comparisons revealed smaller ER for lowHap+neu ($M=2.6$, $SD=1.8$) than for highHap+neu ($M=3.4$, $SD=2.0$; $t(21)=2.667$, $p=0.014$), as well as greater ER for lowHap+pos ($M=4.7$, $SD=3.1$) than for highHap+neu ($t(21)=-2.450$, $p=0.023$), for highHap+pos ($M=3.4$, $SD=2.6$; $t(21)=-2.668$, $p=0.014$) and for lowHap+neu words ($t(21)=-3.856$, $p=0.001$).

In summary, participants responded faster to neutral than to positive and faster to highHap than to lowHap words. This was accompanied by fewer errors to neutral than to positive words, as well as fewer errors for lowHap than for highHap within the neutral words and more errors for lowHap than for highHap within the positive words.

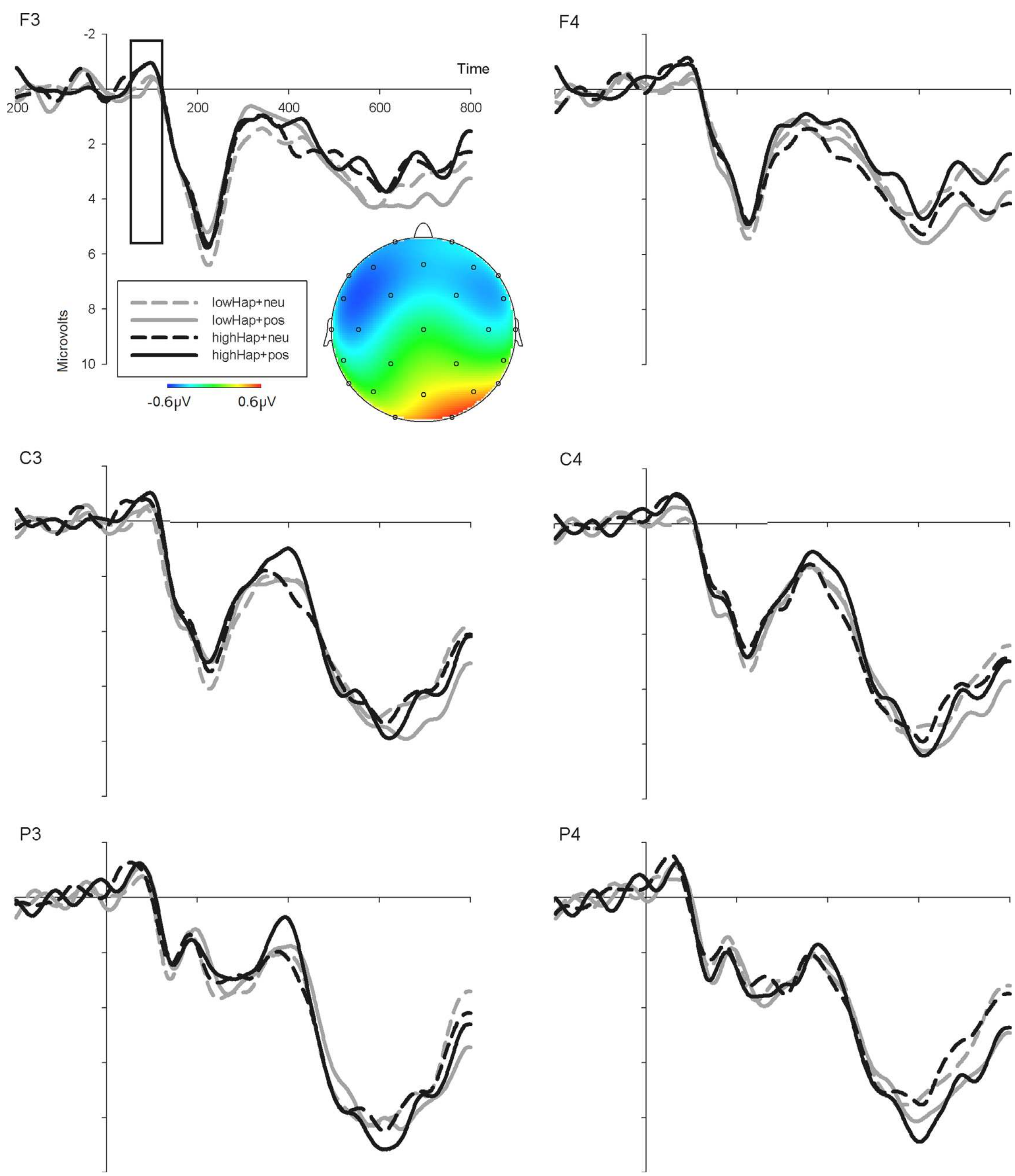

Fig. 1 – Event-related potentials for all four conditions Overview of six scalp electrodes, including the topographies for the early happiness effect.

2.2. Behavioral results EEG study

The repeated measures ANOVA for LDRTs yielded a significant main effect of positivity (neu: $M=617$ ms, $SD=74$ ms; pos: $M=625$ ms, $SD=77$ ms; $F(1,17)=4.629$, $p=0.046$, $\eta^2=0.214$), but no main effect of happiness ($F(1,17)=0.890$, $p=0.359$, $\eta^2=0.050$). The happiness × positivity interaction reached significance ($F(1,17)=5.287$, $p=0.034$, $\eta^2=0.237$). Pairwise comparisons revealed greater LDRTs for lowHap+pos ($M=636$ ms, $SD=91$ ms) than for lowHap+neu ($M=612$ ms, $SD=75$ ms; $t(17)=2.919$, $p=0.010$), as well as a trend indicating greater LDRTs for lowHap+pos than for highHap+pos ($M=614$ ms, $SD=70$ ms; $t(17)=1.847$, $p=0.082$) and for highHap+neu ($M=621$ ms, $SD=76$; $t(17)=1.652$, $p=0.117$).

The ER analysis revealed a significant main effect of positivity (neu: $M=1.9$, $SD=1.4$; pos: $M=3.0$, $SD=2.1$; $F(1,17)=4.674$, $p=0.045$, $\eta^2=0.216$), but no main effect of happiness ($F(1,17)=0.418$, $p=0.526$, $\eta^2=0.024$) and no interaction ($F(1,17)=0.797$, $p=0.384$, $\eta^2=0.045$). In summary, participants responded faster and more accurately to neutral than to positive words. Moreover, a trend for faster processing of highHap words when compared to positive lowHap words was observed.

2.3. ERPs

The ERPs are depicted in Figs. 1 and 2. A repeated measures ANOVA for the N1 comprising the within subject factors happiness (highHap/lowHap), positivity (neu/pos) and laterality (left/right) revealed a significant main effect of happiness ($F(1,17)=6.612$, $p=0.020$, $\eta^2=0.280$), indicating an enhanced bilateral N1 amplitude for highHap ($M=-1.3$ microV, $SD=1.1$) versus lowHap words ($M=-0.8$ microV, $SD=1.3$ microV), but no main effect ($F(1,17)=0.091$, $p=0.767$, $\eta^2=0.005$) or interactions related to positivity (hap*pos: $F(1,17)=0.117$, $p=0.736$, $\eta^2=0.007$).

The repeated measures ANOVA for the EPN revealed no significant main effects for positivity ($F(1,17)=0.008$, $p=0.931$, $\eta^2<0.001$) or happiness ($F(1,17)=0.492$, $p=0.493$, $\eta^2=0.028$) and no significant interactions (hap × pos: $F(1,17)<0.001$, $p=0.995$, $\eta^2<0.001$).

A repeated measures ANOVA of the N400-like negative deflection including the within subject factors happiness, positivity, laterality and anteriocity (anterior/posterior) revealed no main effects of positivity ($F(1,17)=2.763$, $p=0.115$, $\eta^2=0.140$) or happiness ($F(1,17)=0.033$, $p=0.858$, $\eta^2=0.002$). Happiness and positivity did not interact ($F(1,17)=0.960$, $p=0.341$, $\eta^2=0.053$), but the positivity × laterality interaction reached significance ($F(1,17)=5.314$, $p=0.034$, $\eta^2=0.238$, see Fig. 2). Follow-up analyses for each cluster separately revealed trends towards positivity effects in the left anterior (neu: $M=1.8$ microV, $SD=3.6$ microV; pos: 1.1 microV; $SD=3.8$ microV; $F(1,17)=3.853$, $p=0.066$) and posterior cluster (neu: $M=1.9$ microV, $SD=3.8$ microV; pos: 1.3 microV; $SD=3.6$ microV; $F(1,17)=4.214$, $p=0.056$), indicating

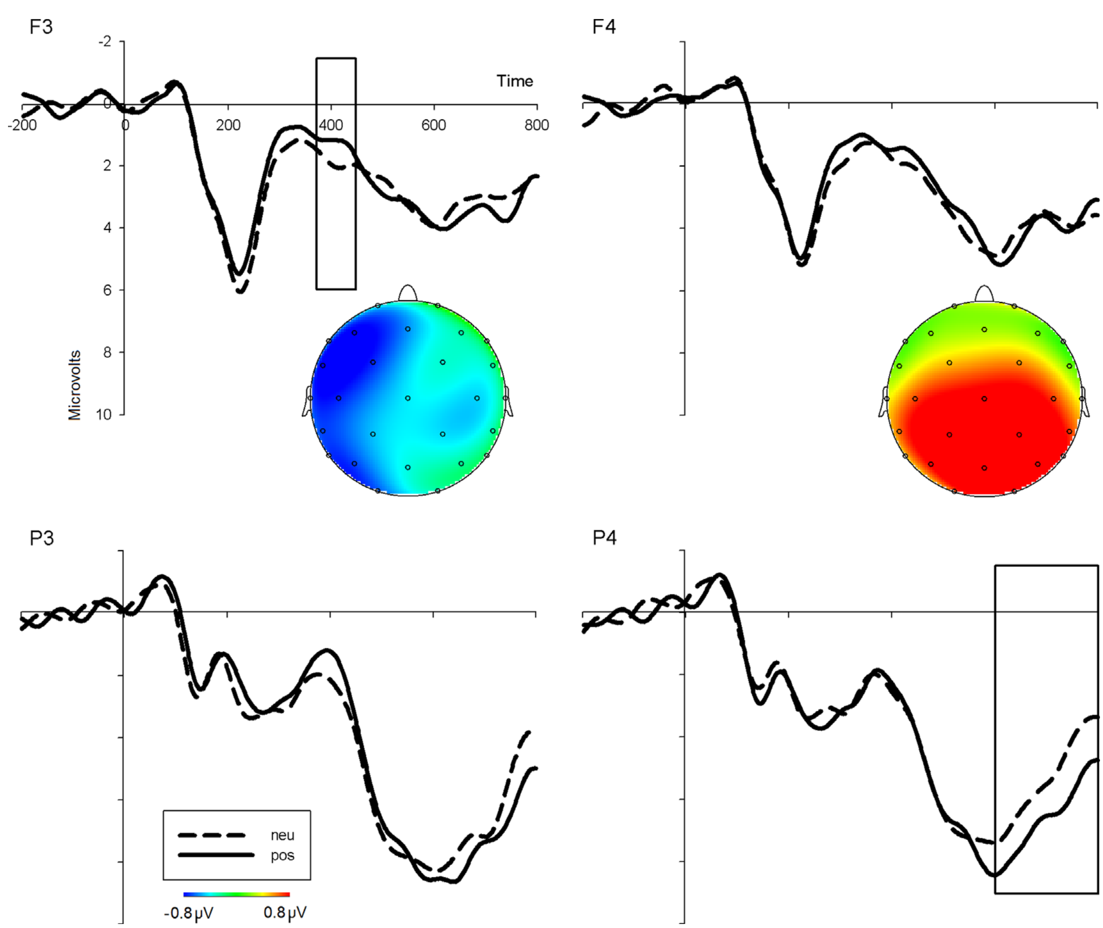

Fig. 2 – N400-like and LPC effects for positivity Event-related potentials from four scalp electrodes, including the topographies for the N400-like and LPC effects.

greater negativity for positive words in left hemispheric clusters. Also for the LPC, a significant main effect of positivity ($F(1,17)=7.319$, $p=0.015$, $\eta^2=0.301$) but no main effect of happiness ($F(1,17)=0.087$, $p=0.771$, $\eta^2=0.005$) and no interaction ($F(1,17)=0.325$, $p=0.576$, $\eta^2=0.019$) were observed, indicating a more positive-going LPC for positive (7.1 microV; SD=3.0 microV) than for neutral words (M=6.1 microV, SD=3.0 microV). In summary, a greater bilateral anterior N1 component for highHap in comparison to lowHap words, as well as a greater left hemispheric N400-like deflection and a greater LPC for positive in comparison to neutral words were observed, but not interactions between happiness and positivity.

To analyze the effect of stimulus type, a repeated measures ANOVA over the N400 time window (380–700 ms) comprising the within subject factors word type, laterality and anteriocity was calculated. It revealed a main effect of word type ($F(1,17)=6.303$, $p=0.022$, $\eta^2=0.270$) driven by generally greater N400 amplitudes for nonwords (M=2.9 microV, SD=2.7) than for words (M=3.8 microV, SD=2.6; see Fig. 3). The interactions of stimulus type with anteriocity ($F(1,17)=5.374$, $p=0.033$, $\eta^2=0.240$) and laterality ($F(1,17)=7.538$, $p=0.014$, $\eta^2=0.307$) as well as the triple interaction ($F(1,17)=37.673$, $p<0.001$, $\eta^2=0.689$) were also found to be significant. Follow-up analyses for each cluster separately revealed significant differences in right hemispheric anterior (words: $M=3.0$ microV, SD=3.2 microV; nonwords: 1.8 microV; SD=3.3 microV; $t(1,17)=3.335$, $p=0.004$) and posterior clusters (words: $M=4.5$ microV, SD=2.4 microV; nonwords: 3.4 microV; SD=2.4 microV; $t(1,17)=2.862$, $p=0.011$) as well as posterior left electrode clusters (words: $M=5.2$ microV, SD=2.8 microV; nonwords: 4.0 microV; SD=2.8 microV; $t(1,17)=2.946$, $p=0.009$).

2.4. *Correlation analyses*

Correlating the net LDRT effects with the emotion effects for the *N1* (correlations ranging from $r(16)=-0.221$ to $r(16)=0.249$, p-values between 0.304 and 0.765) and the LPC component (for happiness: $r(16)=-0.206$, $p=0.411$; for positivity: $r(16)=-0.253$, $p=0.312$) revealed no significant correlations. In case of the N400-like negative deflection, the right anterior electrode cluster comprising Fp2, F8, F4, FC6, and FC2 was negatively correlated with the individual net LDRT effect for positivity ($r(16)=-0.544$, $p=0.020$). Since the N400-like component is a negative ERP deflection, the negative correlation

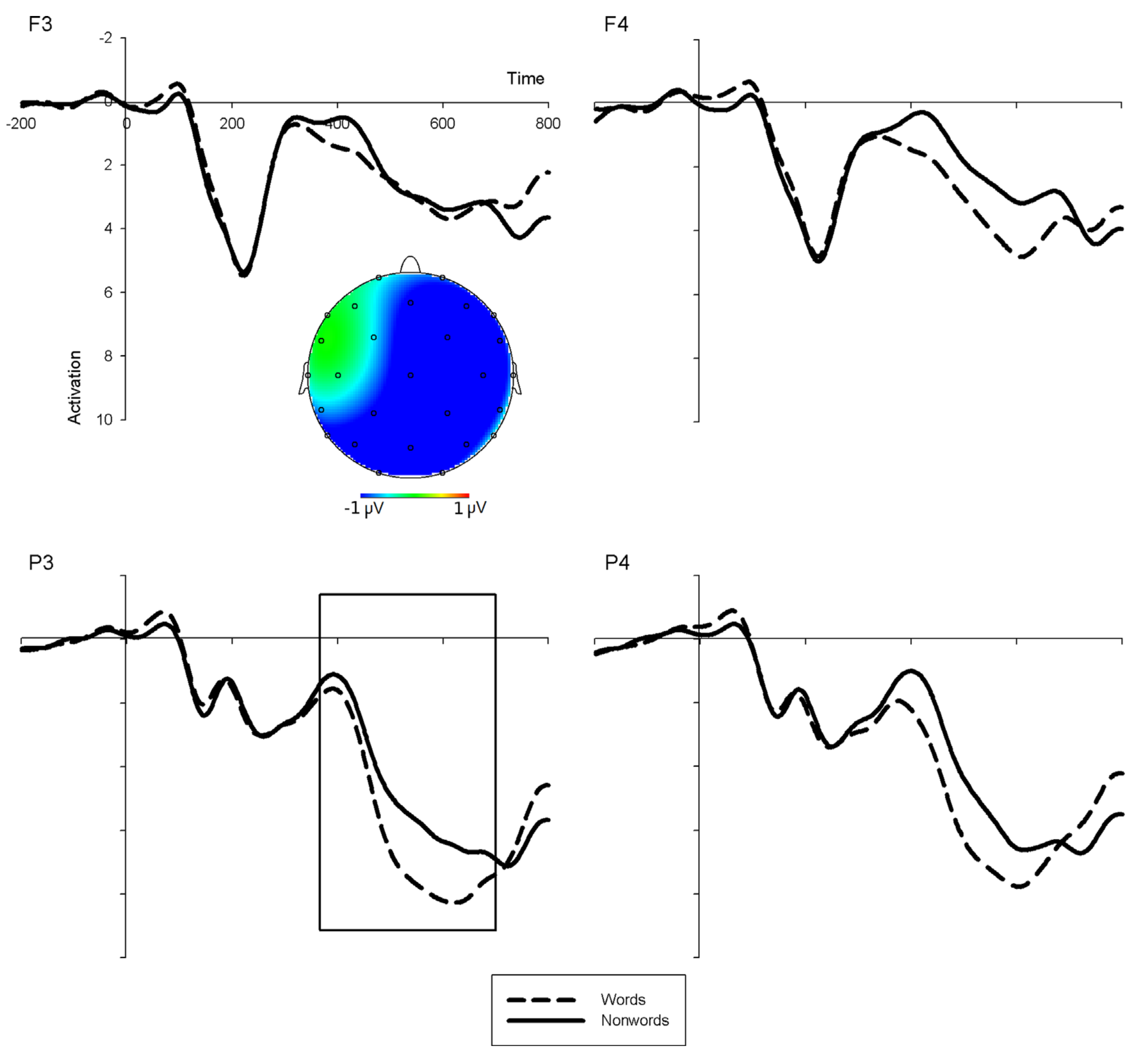

Fig. 3 – N400 effect for the word versus nonword contrast. Event-related potentials from four scalp electrodes, including the topographies for the stimulus type N400 effect.

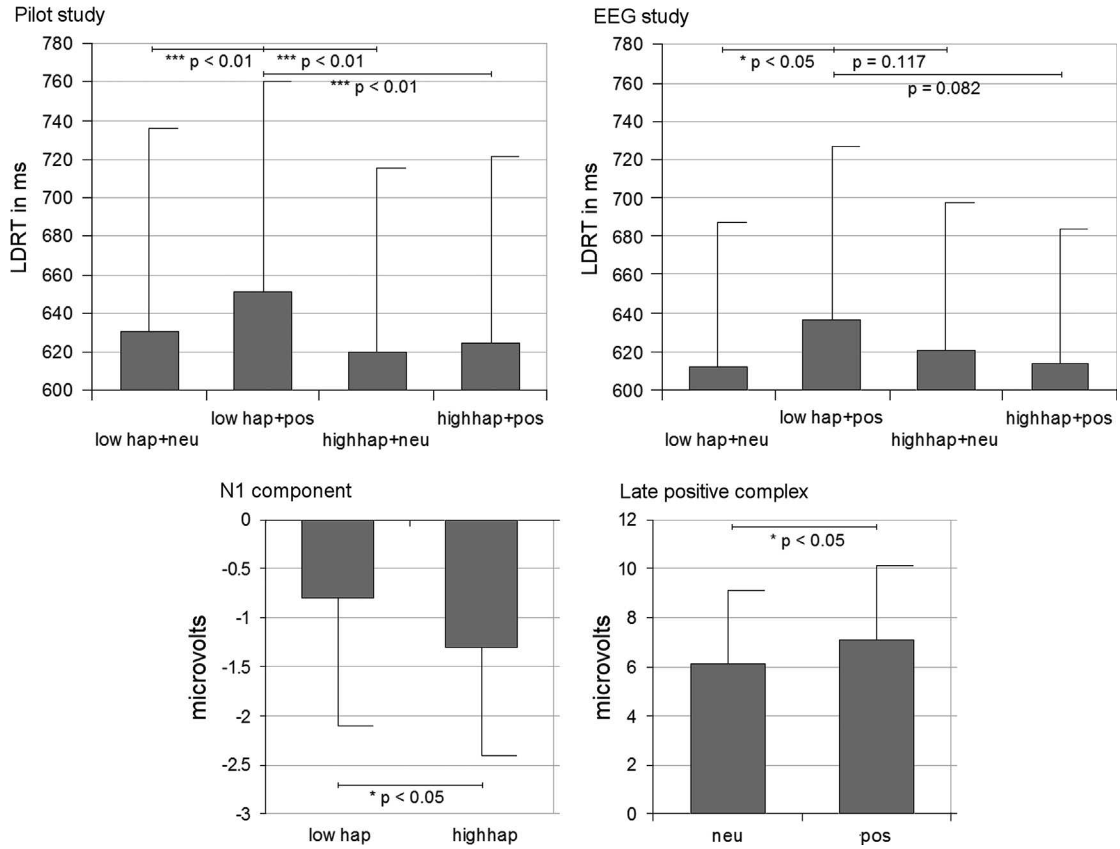

Fig. 4 – Overview of the most important effects Upper left: Lexical decision response times (LDRT) for the pilot study. Upper right: LDRT for the EEG study. Lower left: Main effect of happiness on the N1 ERP component Lower right: Main effect of positivity on the late positive complex.

indicates a stronger N400-like negativity with increasing LDRT differences between positive and neutral words. No other significant correlations between any N400-like cluster and positivity (correlations ranging from $r(16) = -0.081$ to $r(16) = -0.386$, p-values between 0.113 and 0.750) or happiness (correlations ranging from $r(16) = -0.021$ to $r(16) = -0.395$, p-values between 0.105 and 0.935) were observed. Fig. 4.

3. Discussion

The present study examined predictions of Panksepp's hierarchy of emotion processing levels in word recognition. Based on the view that affective dimensions are the result of neocortical processing circuits which rely on preceding emotional processing, the hypothesis was derived that discrete emotion effects are visible earlier in the processing stream compared to dimensional emotion effects. The ERP data clearly support this notion by revealing discrete emotion effects occurring earlier than the dimensional effects when orthogonally manipulated, and in particular in a time window (70–130 ms) that has previously been shown to be affected by conditioned emotional effects in visual word recognition (Fritsch and Kuchinke, 2013).

In detail, main effects of dimensional positivity were found in the behavioral analyses of both experiments, indicated by slower processing of positive than neutral words across both discrete emotion happiness conditions. An additional main effect of happiness was observed in the pilot study, driven by significantly faster processing of highHap words, which was replicated as a tendency in the pairwise comparisons in the ERP study. These effects together cannot be explained by either a discrete or a dimensional emotion model alone based on the orthogonal manipulation of both factors, showing the necessity of combined approaches in emotional evaluation (Panksepp, 2008; Russell, 2005). The facilitative happiness effects replicate previous discrete emotion findings (Briesemeister et al., 2011a, 2011b), while for the dimensional contrast facilitative and not inhibitory processing of positive words would have been expected based on the literature (Hofmann et al., 2009; Kanske and Kotz, 2007). So far, inhibitory LDRT effects are best documented for negative words (Briesemeister, Kuchinke, Jacobs, 2011a; Hofmann et al., 2009), which is explained by a need of more elaborated processing for potentially threatening and thus subjectively significant information. The explanation for the slow-down of positive compared to neutral word processing might follow comparable lines: When the material is controlled for discrete emotion measures that facilitate lexical decisions, the information conveyed by positive words at low levels of discrete emotion information require additional tertiary-level semantic (N400, LPC) evaluation and integration processes. Following Panksepp (2008), the processing of affective dimension information follows that of discrete emotion information (see discussion below) and thus relies on the availability of discrete emotion signals (see the correlation of the two variables in Briesemeister et al., 2011a). A positive connotation like that of lowHap+pos words that gains no support from available discrete emotion signals therefore would demand additional evaluation, leading to the slower response times in both, the pilot and the ERP study. Of note is that based on the present data it seems likely that previous facilitatory effects in dimensional examinations of positive words are biased by the (sub-)category of facilitative happiness-related information.

More importantly, the ERP analyses clearly support the predicted sequential effects, with a main effect of the discrete emotion happiness on the early N1 preceding the effects of dimensional positivity on later post-lexical ERP components (N400, LPC). Early emotional ERP effects around 100 ms in word recognition are discussed to index initial attentional resource allocation to quickly process potentially meaningful information (Citron, 2012). The word has not been fully identified at this processing stage, as also indexed by the later N400 effect in a word versus nonword contrast, leading to the suggestion that the activation spreads along conditioned emotionally charged lexico-semantic associations (Fritsch and Kuchinke, 2013). As the early N1 effect is only visible for the discrete emotion category, this speaks for a conditioned response based on discrete emotion information as predicted by Panksepp's secondary process-level. A similar effect is not visible for words high or low in positivity, a result that is difficult to explain in terms of the core affect theory. The core affect theory assumes that discrete emotion information is categorized by controlled processing from bodily valence-arousal states to constitute human experiences (Wilson-Mendenhall et al., 2013), and hence should not precede dimensional effects. Moreover, valence and arousal are controlled for in the happiness contrast (see Table 1), and an explicit processing account is unlikely at this very early processing stage.

In contrast, later controlled processing at a time assumed to follow lexical access shows a predicted effect of the dimensional emotion variable. Both, the N400 component, which is known to require at least a minimum of lexico-semantic processing and is shown to differentiate words from nonwords in the present study, and, to a greater extent, the LPC as being indicative of higher-order neocortical evaluative processes (Citron, 2012) reveal this influence. The temporal sequence of these effects is consistent with the assumption that dimensional emotion information is derived from available discrete emotion information from lower-level subcortical processing through interactions with higher-order neocortical semantic processing (Panksepp and Watt, 2011). It should be noted that in emotion word recognition often smaller N400 amplitudes are reported for emotional compared to neutral words (Citron, 2012; Kanske and Kotz, 2007), whereas greater N400 amplitudes to emotionally arousing words embedded in sentences have been documented (Holt et al., 2009). With the greater N400 amplitudes to positive words derived from the dimensional approach, these results mirror that of the behavioral data and lead to the observed correlation between the positivity related N400 and LDRT effects over right-anterior electrodes. Thus, although no positivity related N400 effect was observed in the right anterior cluster, a strong relationship with the behavioral data is visible. This discrepancy seems related to a reversal of the N400 positivity effect (see Fig. 5). In accordance with the significant correlation, some studies indicate that bilateral frontal electrodes explain response time variability in cognitively demanding tasks. For example, Gerson, Parra and Sajda (2005) report that response times variability is closely related to activity differences measured over bilateral frontal electrodes. Of note is that in the present study a similar negative N400-LDRT correlation is visible over the anterior-left cluster, though not significant ($r(16) = -0.386$, $p = 0.113$).

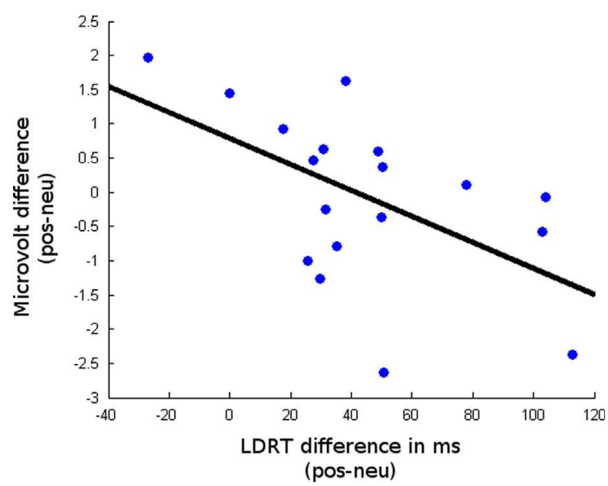

Fig. 5 – Correlation between the net positivity effect and the N400-like effect.

Table 1 – Stimulus characteristics.

	lowHap+neu	lowHap+pos	highHap+neu	highHap+pos	*F*-value	*p*-value
Log frequency	2.3 (2.1)	1.8 (1.9)	1.8 (1.4)	2.2 (1.7)	0.747	0.526
Letters	6.1 (1.4)	6.2 (1.2)	6.1 (1.4)	5.9 (1.2)	0.358	0.783
Syllables	2.0 (0.7)	2.1 (0.5)	2.1 (0.8)	2.0 (0.6)	0.287	0.834
Phonemes	5.4 (1.3)	5.7 (1.3)	5.4 (1.4)	5.3 (1.2)	0.721	0.541
Arousal	2.4 (0.3)	2.5 (0.6)	2.6 (0.6)	2.5 (0.8)	0.572	0.634
Imageability	4.7 (1.3)	4.6 (1.5)	4.9 (1.4)	4.9 (1.5)	0.256	0.857
Bigram frequency	182953 (129198)	224222 (166890)	196547 (158145)	164361 (133714)	0.871	0.458
Ortho. neighbors (*N*)	1.7 (1.9)	2.2 (3.4)	2.2 (3.6)	1.2 (2.2)	0.915	0.436
Frequency of *N*	116.8 (317.7)	210.6 (568.6)	161.2 (463.2)	127.9 (524.7)	0.233	0.873
Higher frequent *N* (*HN*)	0.5 (1.4)	0.6 (1.2)	0.9 (1.6)	0.4 (1.3)	0.537	0.658
Frequency of *HN*	82.4 (295.0)	192.6 (533.7)	157.7 (456.2)	115.4 (505.7)	0.333	0.801

Nonetheless, the majority of the results indicate an extended initial semantic analysis at post-lexical processing stages (Holt et al., 2009) for positive versus neutral words, which is further supported by the N400 effect for nonwords, which starts at the exact same point in time. Behavioral and electrophysiological indicators agree in the fact that the processing of positive words and its integration in the lexico-semantic task context is slowed-down, once the stimulus material is controlled for happiness. The LPC findings complement the N400 results. Enhanced LPC amplitudes to positive words are often reported in emotional word recognition (e.g. Citron, 2012) and commonly agreed to reveal post-lexical controlled evaluations as would be predicted, both by a psychological construction approach and by Panksepps tertiary process-levels.

As it was not possible to manipulate positive and negative dimensional and discrete emotional words within one stimulus set, we decided to focus on positive valence and happiness in the present study. Thus, it remains to be tested whether the reported results also extend to the processing of negatively valenced stimulus material. Both, the core affect theory and the Panksepp (2008) model assume that sequential processing does not differ between positive and negative emotions, and the data presented by LeDoux (2000) suggest sequential processes for fear conditioning as well. We thus hypothesize that a manipulation of negativity and disgust, for example (Briesemeister et al., 2011a; Ponz et al., in press; Silva et al., 2012), would lead to comparable results.

Since the hierarchical model remains mute with respect to the second major affective dimension, affective arousal, the stimulus set used in the present study was controlled for its influence. Previous research highlights, however, that the N1 and other early ERP components are sensitive to arousal manipulations (Hofmann et al., 2009; Scott et al., 2009), which raises the question of the relationship between discrete emotions and arousal. Initial studies comparing the predictive power of both models for visual word processing indicate that they account for merely the same variance, with slight advantages for discrete emotions, suggesting that arousal should have no effect beyond a discrete emotion manipulation (Briesemeister et al., 2011a, 2012). Taken together with the rigorously controlled stimulus material (see Table 1), we are confident that the present results indeed document the impact of happiness, not arousal. Future research should however investigate possible interactions of discrete emotions (i.e. happiness) and arousal, thereby explicitly addressing their role in early (Hofmann et al., 2009) and late processing stages (Olofsson et al., 2008).

In summary, the present study found clear evidence in support of Panksepp's hierarchy of emotion processing levels in both behavioral and electrophysiological word recognition data. The effects reported here, in particular the observed behavioral interactions between the discrete and the dimensional affective information in the stimulus set and the specific sequentiality of the ERPs, cannot easily be explained in terms of the traditional discrete emotion or affective dimension theories alone. We believe that unifying frameworks like Panksepp's hierarchy of emotion processing are promising starting points to bridge the gap between these theories–that still denote the need for further experimental examinations of the dynamics and the interactions predicted by current models describing emotional effects within and beyond visual word recognition research.

4. Experimental procedure

4.1. *Stimulus material*

The stimulus material consisted of 120 German 4-to-8-letter nouns and an equal number of nonwords. A 2(happiness) $\times$ 2 (positivity) within-subject design was employed, with 30 items per condition. Happiness norms were derived from the DENN-BAWL database (Briesemeister et al., 2011b) and valence norms from the BAWL-R (Võ et al., 2009). Words with happiness ratings below 2.6 on a 5-point Likert scale were classified as weakly related to happiness (lowHap), words with happiness greater than 2.6 as high happiness words (highHap). Words with valence ratings between -0.7 and 0.7 were classified as neutral (neu), and words with valence ratings between 1 and 3 as positive (pos). This resulted in four orthogonal conditions with uncorrelated happiness and valence scores throughout the entire stimulus set ($r=0.09$). LowHap+neu (e.g. “HUHN”, engl. “CHICKEN”; happiness=2.3, positivity=0.5), lowHap+pos (e.g. “PRIVILEG”, engl. “PRIVILEGE”; happiness=2.4, positivity=1.3), highHap+neu (e.g. “SATIRE”, engl. “SATIRE”; happiness=2.9, positivity=0.5) and highHap+pos conditions (e.g. “EKSTASE”, engl. “ECSTASY”; happiness=2.9, positivity=1.4) were controlled for their average level of arousal, imageability, (log-) frequency per million, bigram frequency, orthographic neighborhood size, frequency of orthographic neighbors, frequency of higher frequent orthographic neighbors, as well as their mean number of letters, syllables, phonemes and higher frequency orthographic neighbors using ANOVAs (all F's <1). Where possible, highhap words were chosen to actually elicit a good feeling, while positive words described generally desirable things. To ensure the orthogonality of the manipulation, the means of all the control variables were also matched for the highHap versus lowHap, and for the neu versus pos contrasts as verified by means of pairwise *t*-tests (all t's <1). These stimulus characteristics are summarized in Table 1. Pronounceable but meaningless nonwords were constructed by changing one letter from 120 words that were not part of the stimulus set, matched to the words on number of letters and syllables (t's <1).

4.2. *Pilot study participants*

Before the EEG study, a behavioral pilot study was run. Twenty-three participants (18 female) were recruited at the Ruhr-University Bochum. All reported having a dominant right hand, normal or corrected-to-normal vision, German as their first language, no current medication affecting the central nervous system and no reading disorders. Their mean age was 26 years (SD=5, range 19–38). One participant aborted the experiment and was thus excluded from all analyses.

4.3. EEG study participants

For the EEG study, nineteen participants (13 female) were recruited at the Free University Berlin. All reported having a dominant right hand, normal or corrected-to-normal vision, German as their first language, no current medication affecting the central nervous system and no reading disorders. Their mean age was 26 years (SD=5, range 20–42). One participant was excluded from all analyses because of overall noisy data (error rate >15%, noisy ERPs).

4.4. Ethics

The study was approved by the local ethics committee. All experiments were conducted in accordance with the principles expressed in the Declaration of Helsinki. Informed consent was obtained from all participants.

4.5. Procedure

The pilot and the EEG study used the exact same stimulus material and followed the same procedures, except for the EEG preparation described below. The experiment started with nine training trials that were not part of the stimulus set to familiarize the participants with the task. Each trial began with the foveal presentation of a fixation cross (+) for 500 ms, followed by the stimulus (500 ms) at the same position. If the response (left CTRL=nonword, right CTRL=word) was not given within the stimulus duration, the stimulus was replaced by a fixation cross (1000 ms), resulting in a maximum trial duration of 2000 ms. Between trials, a fixation cross (jittered 0–500 ms) served as inter-stimulus interval. All stimuli were presented in randomized order in black uppercase Arial 24 font (~0.56° vertical visual angle) on a light gray background, controlled by Presentation 14.9 software (Neurobehavioral Systems Inc., Canada). Participants were instructed to respond as fast and as correct as possible.

For the EEG study, data was collected in a session comprised of three different experiments. The LDT was always the last experiment of the session, with none of the previous experiments being related to lexical or emotional processing. Continuous EEG data were recorded by 27 active electrodes (actiCap system, Brain Products, Germany) attached to a 32-channel amplifier (Brainamp, Brain Products, Germany, sampling rate 500 Hz). They were placed according to the international 10–20 system at the positions FP1, FP2, F3, F4, F7, F8, FC1, FC2, FC5, FC6, Fz, CP1, CP2, CP5, CP6, P3, P4, P7, P8, Pz, C3, C4, Cz, T7, T8, O1 and O2 and referenced to the right mastoid (with an additional electrode being placed on the left mastoid for later re-referencing). Four electrodes were placed above and below the right eye and on the outer canthus of each eye to record the eye movements. The impedances were kept below 18 kΩ for all electrodes.

4.6. Data preparation

Mean lexical decision response times (LDRTs) were calculated for each condition and each participant after exclusion of nonresponders, behavioral errors and outliers, defined as responses outside 2 SD of the individual mean LDRT. ERs were calculated as summed errors per condition and participant.

EEG raw data were filtered (0.1–30 Hz, 50 Hz notch filter) and corrected for artifacts, drifts and amplifier blocking via visual inspection using BrainVision Analyzer software (BrainProducts, Germany). Blinks and eye movements were removed using independent component analysis, and remaining artifacts defined as amplitudes greater than 60 μV or smaller than −60 μV were excluded using an automatic detection procedure after re-referencing to averaged mastoids. The remaining data (~93–120 trials per subject) were segmented relative to the stimulus onset (−200–800 ms), with all stimuli excluded from behavioral analysis being excluded from EEG analysis as well. Finally, baseline corrected (−200–0 ms) averages were calculated per participant and per condition.

Based on visual inspection of the ERPs and in accordance with the literature, four components were exported for further analysis of emotion related effects. Based on Hofmann et al. (2009), who report an emotion related modulation of the N1 at 100 ms (see also Fritsch and Kuchinke, 2013), an automatic peak detection procedure was used to identify the individual global negative deflection peak in the time window between 70 and 130 ms. The time window surrounding the individual peaks ±20 ms was exported and averaged for analysis. Topographies suggested a bilateral fronto-central effect, thus the electrodes Fp1, F7, F3, FC5 and FC1, as well as Fp2, F8, F4, FC6 and FC2 were clustered together. For the analysis of the EPN, the data was re-referenced to the average of all electrodes. Then, the individual global negative deflection peak in the time window between 200 and 330 ms was identified. Given that the EPN is characterized as a broad negative deflection, the individual peaks ±40 ms were exported and averaged for two occipito-temporal clusters including the electrodes O1, P3, P7, and T7, as well as O2, P4, P8, and T8 (Kissler et al., 2009).

Visual inspection of the grand averages revealed a small N400-like negative deflection (380–440 ms) and averaged amplitudes over this time window were exported for analysis. Following Kanske and Kotz (2007), electrodes were summarized in four clusters: anterior-left (Fp1, F7, F3, FC5, FC1), anterior-right (Fp2, F8, F4, FC6, FC2), posterior-left (CP5, CP1, P7, P3, O1) and posterior-right (CP6, CP2, P8, P4, O2). A similar approach was chosen for the analysis of the LPC in the 600–800 ms interval. Based its centro-parietal distribution (Citron, 2012), a cluster comprising the electrodes P3, P4, Pz, CP1, CP2, Cz, C3, and C4 was used for LPC analyses.

In addition to the emotion related differences, a word versus nonword contrast was calculated to allow for a better interpretation of the results and their relation to semantic processing. Visual inspection of the ERPs revealed greater, slightly right-lateralized negativity for nonwords between 380 and 700 ms peaking around 400 ms, which is well in line with the N400 literature (Braun et al., 2006; Briesemeister et al., 2009; Holcomb, Grainger and O'Rourke, 2002). Based on Braun et al. (2006) and Holcomb et al. (2002), who both report a stimulus type main effect for the words versus nonwords contrast on the entire scalp, the same four electrode clusters as for the N400-like analysis described above were used.

Finally, a correlation analysis was conducted for each ERP component that revealed a significant emotion effect. For each participant and each electrode cluster the happiness contrast (highHap–lowHap) and the positivity contrast (pos–neu) was correlated with the net LDRT emotion effects, calculated as LDRT(highHap)–LDRT(lowHap), and LDRT(pos)–LDRT(neu), respectively (see Silva et al., 2012 for a detailed description). All analyses were computed using SPSS 13.0 (SPSS Inc., USA) at an a-priori significance level of 0.05.

REFERENCES

Barrett, L.F., Bliss-Moreau, E., 2009. Affect as a psychological primitive. In: Zanna, Mark P. (Ed.), Advances in Experimental Social Psychology. Academic Press, Burlington.

Barrett, L.F., Wager, T.D., 2006. The structure of emotion. Evidence from neuroimaging studies. Curr. Dir. Psychol. Sci. 15 (2), 79–83.

Braun, M., Jacobs, A.M., Hahne, A., Ricker, B., Hofmann, M., Hutzler, F., 2006. Model-generated lexical activity predicts graded ERP amplitudes in lexical decision. Brain Res. 1073–1074, 431–439.

Briesemeister, B.B., Hofmann, M.J., Kuchinke, L., Jacobs, A.M., 2012. The BAWL databases in research on emotional word processing. In: Würzner, K.-M., Pohl, E. (Eds.), Lexical resources in psycholinguistic research: Potsdam Cognitive Science Series, Vol. 3. Universitätsverlag, Potsdam, Germany, pp. 61–66.

Briesemeister, B.B., Hofmann, M.J., Tamm, S., Kuchinke, L., Braun, M., Jacobs, A.M., 2009. The pseudohomophone effect: Evidence for an orthography–phonology-conflict. Neurosci. Lett. 455 (2), 124–128.

Briesemeister, B.B., Kuchinke, L., Jacobs, A.M., 2011a. Discrete emotion effects on lexical decision response times. PLoS ONE 6 (8), e23743.

Briesemeister, B.B., Kuchinke, L., Jacobs, A.M., 2011b. Discrete emotion norms for nouns: Berlin affective word list (DENN–BAWL). Behav. Res. Methods 43 (2), 441–448.

Citron, F., 2012. Neural correlates of written emotion word processing: a review of recent electrophysiological and hemodynamic neuroimaging studies. Brain Lang. 122 (3), 211–226.

Darwin, C., 1872. The expression of the emotions in man and animals. John Murray, London, England.

Ekman, P., 1992. An argument for basic emotions. Cognit. Emot. 6, 169–200.

Elfenbein, H.A., 2013. Nonverbal dialects and accents in facial expressions of emotions. Emot. Rev. 5 (1), 90–96.

Foti, D., Hajcak, G., Dien, J., 2009. Differentiating neural responses to emotional pictures: evidence from temporal-spatial PCA. Psychophysiology 46, 521–530.

Fritsch, N., Kuchinke, L., 2013. Acquired affective associations induce emotion effects in word recognition: an ERP study. Brain Lang. 124, 75–83.

Gerson, A.D., Parra, L.C., Sajda, P., 2005. Cortical origins of response time variability during rapid discrimination of visual objects. NeuroImage 28, 342–353.

Hofmann, M.J., Kuchinke, L., Tamm, S., Võ, M.L.-H., Jacobs, A.M., 2009. Affective processing within 1/10th of a second: high arousal is necessary for early facilitative processing of negative but not positive words. Cognit. Affect. Behav. Neurosci. 9, 389–397.

Holcomb, P.J., Grainger, J., O'Rourke, T., 2002. An electrophysiological study of the effects of orthographic neighborhood size on printed word perception. J. Cognit. Neurosci. 14 (6), 938–950.

Holt, D.J., Lynn, S.K., Kuperberg, G.R., 2009. Neurophysiological correlates of comprehending emotional meaning in context. J. Neurosci. 21 (11), 2245–2262.

Kanske, P., Kotz, S.A., 2007. Concreteness in emotional words: ERP evidence from a hemifield study. Brain Res. 1148, 138–148.

Kissler, J., Herbert, C., Winkler, I., Junghofer, M., 2009. Emotion and attention in visual word processing – An ERP study. Biol. Psychol. 80, 75–83.

LeDoux, J.E., 2000. Emotion circuits in the brain. Ann. Rev. Neurosci. 23, 155–184.

Olofsson, J.K., Nordin, S., Sequeira, H., Polich, J., 2008. Affective picture processing: an integrative review of ERP findings. Biol. Psychol. 77 (3), 247–265.

Panksepp, J., 1998. Affective neuroscience: The foundations of human and animal emotions. Oxford University Press, New York.

Panksepp, J., 2006. The core emotional systems of the mammalian brain: The fundamental substrates of human emotions. In: Corrigall, J., Payne, H., Wilkinson, H. (Eds.), About a Boy: Working With the Embodied Mind in Psychotherapy. Routledge, Hove, United Kingdom, pp. 14–32.

Panksepp, J., 2008. Cognitive conceptualism – Where have all the affects gone? Additional corrections for Barrett et al. (2007). Perspect. Psychol. Sci. 3 (4), 305–308.

Panksepp, J., Watt, D., 2011. What is basic about basic emotions? Lasting lessons from affective neuroscience. Emot. Rev. 3 (4), 387–396.

Ponz A., Montant M., Liegeois-Chauvel C., Silva C., Braun M., Jacobs A.M. and Ziegler J.C., Emotion processing in words: a test of the neural re-use hypothesis using surface and intracranial EEG, Social Cognit. Affect. Neurosci. http://dx.doi.org/10.1093/scan/nst034, in press (First published online, March 2013).

Russell, J.A., 2003. Core affect and the psychological construction of emotion. Psychol. Rev. 110, 145–172.

Russell, J.A., 2005. Emotion in human consciousness is built on core affect. J. Conscious. Stud. 12 (8–10), 26–42.

Russell, J.A., 2009. Emotion, core affect, and psychological construction. Cognit. and Emot. 23, 1259–1283.

Scott, G.G., O'Donnell, P.J., Leuthold, H., Sereno, S.C., 2009. Early emotion word processing: evidence from event-related potentials. Biol. Psychol. 80 (1), 95–104.

Silva, C., Montant, M., Ponz, A., Ziegler, J.C., 2012. Emotions in reading: disgust, empathy, and the contextual learning hypothesis. Cognition 125 (2), 333–338.

Võ, M.L.-H., Conrad, M., Kuchinke, L., Urton, K., Hofmann, M.J., Jacobs, A.M., 2009. The Berlin Affective Word List Reloaded (BAWL-R). Behav. Res. Methods 41, 534–538.

Wilson-Mendenhall, C.D., Barrett, L.F., Barsalou, L.W., 2013. Neural evidence that human emotions share core affective properties. Psychol. Sci. 24 (6), 947–956.

Wundt, W., 1896. Grundriss der Psychologie. Engelmann, Leipzig.