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Emotion Effects in Visual Language Processing

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Abstract

Emotional meaning impacts the processing of written words, leading to facilitated processing that is visible not only in behavioral parameters, but also in event-related potentials (ERPs). It has been suggested that this processing benefit occurs because emotional stimuli involuntarily attract attention, possibly based on their higher intrinsic relevance. The present work investigates the conditions of emotion effects in word recognition, focusing on the time course of emotional processing, on the involvement of autonomic activation, and on contributions of emotional dimensions valence and arousal.

In ERPs, emotion effects were evident from approximately 100 ms after stimulus onset, providing evidence for a fast and automatic detection and facilitation of emotional words. The time course and topography of emotion effects is in parallel to findings for affective pictures and suggests the existence of a common system for the extraction of emotional content across stimulus domains. In line with these findings, interactions of stimulus-triggered attention and emotion during word recognition are highly similar to interactions in picture processing. Due to the symbolic nature of words, this finding implies that emotion detection is less dependent on biological relevance than previously assumed. Apart from these analogies, the present results revealed a difference in emotional processing across stimulus domains. While affective pictures have frequently been reported to elicit augmented activity in the autonomic nervous system, evidence from pupillary responses indicates that emotional words do not mandatorily trigger autonomic activation. Instead, the processing advantage visible in behavioral measures seems to result from cognitive facilitation of emotional words.

Keywords: Emotion, word recognition, event-related potentials, pupillary responses, valence, arousal

Zusammenfassung

Emotionale Bedeutung erleichtert die Verarbeitung geschriebener Sprache. Dies zeigt sich sowohl in Verhaltensmaßen als auch in ereigniskorrelierten Potenzialen (EKPs) und resultiert vermutlich aus automatischer Aufmerksamkeitszuweisung auf Grund der hohen intrinsischen Relevanz von emotionalen Reizen. Die vorliegende Arbeit untersucht die Mechanismen von Emotionseffekten in geschriebener Sprache, insbesondere den Zeitverlauf der Emotionseffekte, die Beteiligung des peripheren Nervensystems, sowie die Rolle der Emotionsdimensionen Valenz und Erregung.

Emotionseffekte in EKPs beginnen mit einer Latenz von 100 ms nach Stimulusonset. Dies deutet auf die Existenz eines schnellen und automatischen Erkennungssystems für emotionale Wörter hin. Der Zeitverlauf und die Verteilung der Emotionseffekte weisen große Ähnlichkeit zu Befunden für emotionale Bilder auf und lassen auf die Existenz eines domänenübergreifenden Systems zur Emotionserkennung schließen. In Übereinstimmung mit dieser Annahme zeigen sich weitere Ähnlichkeiten in der Verarbeitung emotionaler Wörter und Bilder in einer Studie, die die Interaktion von stimulusbasierter Aufmerksamkeit und emotionaler Verarbeitung in der Wortverarbeitung untersuchte. Auf Grund des arbiträren Charakters von Schriftsprache legen die Ergebnisse dieser Studie den Schluss nahe, dass der Verarbeitungsvorteil für emotionale Reize zu einem geringeren Anteil als bisher vermutet auf biologischer Relevanz beruht. Neben diesen Ähnlichkeiten zeigen die vorliegenden Ergebnisse einen domänenspezifischen Unterschied in der Emotionsverarbeitung. Während die Darbietung emotionaler Bilder oft mit erhöhter Aktivierung des autonomen Nervensystems einhergeht, zeigen Befunde zur Pupillenaktivität, dass die Verarbeitung emotionaler Wörter nicht zwangsläufig zu autonomer Aktivierung führen muss. Stattdessen scheint der Verarbeitungsvorteil für emotionale Wörter darauf zu beruhen, dass weniger kognitive Ressourcen für deren Verarbeitung nötig sind, was sich auf der Verhaltensebene unter anderem in schnelleren Reaktionszeiten und besserer Gedächtnisleistung widerspiegelt.

Schlagwörter: Emotion, Worterkennung, ereigniskorrelierte Potenziale, Pupillenaktivität, Valenz, Arousal

Introduction

Humans seek emotional information. We read thrilling books, we enjoy amusing movies, we are looking out for stories that cause excitement and joy, make us laugh or cry. This human trait, which we all know from our everyday behavior, seems to have its foundation in the way we perceive emotional content on the neuronal level: A vast body of research using event-related potentials (ERPs) suggests that the preferential processing of emotional stimuli can be traced back as far as to the level of sensory encoding. However, written language differs in many respects from other sources of emotional information. For pictures and emotional facial expressions, emotion processing was explained from an evolutionary perspective, proposing a biological preparedness to detect emotional information (Öhman & Mineka, 2001). However, a similar mechanism cannot be assumed for written words, since word recognition requires the translation of arbitrary symbols before emotional information can be extracted. Nonetheless, the influence of emotional meaning in words is visible in behavioral measures and ERPs (e.g., Fischler & Bradley, 2006; Kissler, Herbert, Peyk, & Junghöfer, 2007; Schacht & Sommer, 2009a). But while it is by now firmly established that emotional content affects the processing of written language, the boundary con–ditions of emotional facilitation remain to be fully understood.

The present work aims to shed light on the mechanism of emotion processing in visual word recognition using ERPs and pupillary response measures. In three experiments, it focuses a) on the time course of emotion effects, b) on contributions of emotional dimensions valence and arousal, and c) on domain-specific mechanisms of emotion effect in word recognition. Finally, it proposes an integration of present results and discusses their implications for current theories of emotion processing.

Theoretical Background

The attempt to classify the concept "emotion" has generated a multitude of theories. Among them, dimensional theories are of particular interest in research of emotional information processing. Instead of assuming discrete emotional categories (e.g., fear, anger, joy), they propose the existence of underlying dimensions in order to classify emotional states (Osgood, Suci, & Tannenbaum, 1957; Russell, 1980, Barrett & Russell, 1998). An established dimensional theory is the 'motivated attention theory' by Lang and colleagues (Lang, Bradley, & Cuthbert, 1997), which assumes a two-dimensional structure of affect defined by hedonic valence and arousal. It proposes the existence of two underlying motivational systems which correspond to the valence dimension: The approach system responds to pleasant stimuli, while the avoidance system is activated by unpleasant or threatening stimuli. The arousal dimension merely depicts the strength of activation of the respective motivational system, and thus is not perceived as an independent dimension. Evidence for this assumption comes from normative ratings for affective pictures (Lang, Bradley, & Cuthbert, 2008), words (Bradley & Lang, 1999a), or sounds (Bradley & Lang, 1999b), which show a U-shaped relation between valence and arousal judgments, with increasing arousal ratings from neutral stimuli to both ends of the valence dimension.

According to the theory of motivated attention, the processing advantage of emotional information is based on its intrinsic motivational relevance for the organism: From an evolutionary perspective, positive as well as negative stimuli represent survival-relevant information (e.g., food, aggressors) and thus involuntarily attract the individual's attention. On the behavioral level, the processing advantage of emotional information is evident, for example, in enhanced memory performance for emotional compared to neutral stimuli (for review, see Phelps, 2006), as well as in faster reaction times (RT) for positive and negative relative to neutral stimuli (e.g., Schacht & Sommer, 2009a; Scott, O'Donnell, Leuthold, & Sereno, 2009).

The interest in the neuronal mechanisms underlying the behavioral facilitation of emotional content motivated the use of event-related potentials (ERPs), which provide an excellent temporal resolution in the range of milliseconds. While ERP amplitudes provide an intensity measure reflecting the activity in neuronal assemblies, onset latencies reflect the timing of ERP components, and scalp distributions allow estimating the coarse localization of involved brain systems.

In ERPs, emotion effects in visual word recognition are evident in at least two components with distinguishable time course and topography. Starting around 200 ms after stimulus onset, emotional content increases the amplitude of a negative-going potential at posterior electrode sites, the so-called early posterior negativity (EPN; e.g., Kissler et al., 2007; Schacht & Sommer, 2009a, 2009b). It shows temporal and topographical similarities to a ERP component elicited by voluntary, top-down attention allocation to non-emotional stimulus features like shape or color (Hillyard & Anllo-Vento, 1998), and was therefore suggested to reflect involuntary attention allocation that enhances perceptual processing (Junghöfer, Bradley, Elbert, & Lang, 2001). Furthermore, this attention allocation was suggested to occur automatically, i.e. independent of task demands and voluntary attention allocation, since EPN effects to emotional words were evident even in tasks not requiring lexical or semantic processing (Schacht & Sommer, 2009a, 2009b). In contrast to top-down attention, picture studies suggest that the EPN is sensitive to manipulations of stimulus-triggered, bottom up attention (Codispoti & De Cesarei, 2007; Codispoti, Ferrari, & Bradley, 2006), but so far no study addressed this question for emotional words. In order to bridge this gap, study 3 of the present work investigates the interactions of stimulus-driven attention and emotional content for written words.

At a later processing stage, starting around 300 ms after stimulus onset and lasting for several hundred milliseconds, emotional stimuli have been shown to increase the amplitudes of a centro-parietal positivity termed late positive complex (LPC; e.g., Bayer, Sommer, & Schacht, 2010; Fischler & Bradley, 2006). This component was suggested to reflect sustained elaborate processing of emotional content (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). With a similar scalp distribution and topography, augmented amplitudes of the P300 component are an indicator of attention allocation and task-relevance (Johnson, 1988). As the LPC is elicited even if attention is not explicitly directed to emotional stimuli, it was suggested to reflect the intrinsic relevance of emotional information (Cuthbert et al., 2000). In contrast to the EPN, the LPC is highly dependent on task demands. While LPC modulations frequently occur in semantic tasks and explicit emotion decisions, they are often absent in structural and superficial task, suggesting that lexico-semantic processing might be a prerequisite for late emotion effects (Fischler & Bradley, 2006; Naumann, Bartussek, Diedrich, & Laufer, 1992; Naumann, Maier, Diedrich, Becker, & Bartussek, 1997; Schacht & Sommer, 2009a).

Investigating the neural structures of emotional facilitation, research provides evidence that the amygdala is a key structure in allocating attention to emotional stimuli (Dalgleish, 2004; Vuilleumier, Richardson, Armony, Driver, & Dolan, 2004). It was further suggested that reentrant projections from the amygdala to the extrastriate cortex might be responsible for the enhanced activity in visual areas visible in the EPN component (Sabatinelli, Lang, Bradley, Costa, & Keil, 2009). A number of studies indicate that amygdala activation is not limited to negative or positive stimuli, but responds to emotional arousing stimuli irrespective of valence (Kensinger & Schacter, 2006b; Sabatinelli, Bradley, Lang, Costa, & Versace, 2007; Sabatinelli, Lang, Keil, & Bradley, 2007). ERP studies revealed a similar pattern of results, showing comparable modulations for both pleasant and unpleasant, high-arousing stimuli (e.g., Dillon, Cooper, Grent-'t-Jong, Woldorff, & LaBar, 2006; Junghöfer et al., 2001; Kissler et al., 2007; Scott et al., 2009). As a result, emotional arousal was suggested to play a crucial role in affective processing as an indicator of motivational significance, and was even referred to as "the foundation of emotion" (Lang & Bradley, 2010, p.438). However, a number of recent studies suggest a more complex interaction of valence and arousal in affective processing, especially in the verbal domain. Here, emotion effects in ERPs have often been limited to positive words, suggesting a processing advantage for pleasant material instead of high arousal independent of valence (Herbert, Junghöfer, & Kissler, 2008; Herbert, Kissler, Junghöfer, Peyk, & Rockstroh, 2006; Hinojosa, Carretié, Valcárcel, Méndez-Bértolo, & Pozo, 2009; Schacht & Sommer, 2009b). Such a "positivity bias" has not only been reported for ERPs, but was also evident in amygdala activity (Herbert et al., 2009) and in RTs (Hinojosa, Méndez-Bértolo, & Pozo, 2010; Kuchinke et al., 2005; Schacht & Sommer, 2009a). However, to this point there is no direct evidence for the roles of valence and arousal in emotional language processing, since no study so far used stimuli orthogonally varying both emotional dimensions. Instead, most studies compared high-arousing stimuli of negative and positive valence with neutral, low-arousing stimuli. In order to clarify contributions of valence and arousal to emotion effects in word recognition, studies 1 and 2 employ orthogonal variations of both dimensions.

In addition to the activity of the central nervous system as reflected in ERPs, emotional content has been reported to impact the activity of peripheral emotion-sensitive parameters; furthermore, the pattern of results suggests specific contributions of valence and arousal. Initially concentrating on the processing of affective pictures and sounds, the activity of the autonomic nervous system was related to the arousal dimension. For example, high-arousing stimuli have been found to elicit increased electrodermal reactions (e.g. Bradley, Codispoti, Cuthbert, & Lang, 2001; Cuthbert et al., 2000; Löw, Lang, Smith, & Bradley, 2008) as well as pupillary responses (Bradley, Miccoli, Escrig, & Lang, 2008; Partala & Surakka, 2003). In contrast, the activity of facial muscles *M. Corrugator supercilii* (frowning) and *M.*

Zygomaticus major (smiling) has been related to the valence dimension, showing specifically increased activity in response to either negative (Corrugator) or positive (Zygomaticus) stimuli (Bradley et al., 2001; Cuthbert et al., 2000). However, in the case of written words, the impact of emotional content on peripheral parameters seems considerably diminished as compared to affective pictures and sounds. For example, the correlation between the activity of Corrugator and Zygomaticus and rated valence has been shown to be reduced for emotional words relative to affective pictures or sounds (J.T. Larsen, Norris, & Cacioppo, 2003). Similarly, research on skin conductance responses suggests that electrodermal reactions to emotional words might be limited to specific designs and participant groups (for discussion, see Bayer, Sommer, & Schacht, 2011). In the case of pupillary responses, evidence for the impact of emotional content in written words is sparse, but suggests that high-arousing stimuli may elicit smaller rather than larger pupillary reactions than low-arousing stimuli (Kuchinke, Vo, Hofmann, & Jacobs, 2007; Siegle, Granholm, Ingram, & Matt, 2001; Vo et al., 2008). Since pupillary responses are not only an indicator of emotional arousal, but also of cognitive load, diminished responses to emotional stimuli may reflect the reduced processing difficulty and thus cognitive facilitation of emotional stimuli rather than autonomic arousal. However, confounds in stimulus materials and experimental designs so far prevent an unequivocal interpretation about the impact of emotional content on pupillary responses. Therefore, study 2 aimed to shed light on this question by disentangling the influences of cognitive load and emotional meaning.

An important question concerning emotional processing of written words is the functional locus of emotion effects, especially whether emotional content can be activated prior to lexical access. This term refers to the stage in visual word recognition where a lexical representation is activated by the orthographical input code, which results from the perceptual analysis of the visual input (Zwitserlood, 1989). According to classical, serial reading models, lexical features of a word are not accessed prior to lexical access around 200 ms after stimulus onset (for review, see Barber & Kutas, 2007). In accordance with this assumption, the onset of EPN effects is considerably delayed for emotional words as compared to affective pictures. While the negative-going deflection for emotional pictures starts around 150 ms after stimulus onset (Junghöfer et al., 2001), EPN effects have not been reported to start prior to 200 ms (Herbert et al., 2008; Kissler et al., 2007), and often show an even later onset (Schacht & Sommer, 2009a). Furthermore, data from lexical decision tasks (LDT) on emotional words provided direct evidence for the post-lexical locus of EPN effects, showing that EPN modulations directly followed the effects of lexicality around 200 ms after stimulus onset

(Palazova, Mantwill, Sommer, & Schacht; Schacht & Sommer, 2009a). In contrast to these findings, a small number of studies reported emotion effects within 200 ms after stimulus onset (Hofmann, Kuchinke, Tamm, Vo, & Jacobs, 2009; Scott et al., 2009). These findings are in line with a growing body of evidence suggesting that not only orthographic, but also lexical and semantic information can be accessed within the first 200 ms after stimulus onset (for review, see Pulvermüller, Shtyrov, & Hauk, 2009). Relatively late ERP components like the N400 on the other hand, classically interpreted as first indicator of semantic information processing (Friederici, 1995), were instead supposed to reflect recurrent, feedback-driven processes (Sereno & Rayner, 2003). Taken together, a growing body of evidence suggests that semantic information can be accessed within the first 200 ms after stimulus onset, but evidence for effects of emotional meaning in this early time range is scarce. Thus, study 1 aimed to identify the boundary conditions of early emotion effects concerning their task-dependency as well as contributions of valence and arousal.

Time course and boundary conditions of emotion effects in ERPs

Little is known about the boundary conditions of emotion effects within the first 200 ms after stimulus onset. So far, only two studies reported emotion effects in this time window, affecting the P1 time range at approximately 100 ms after stimulus onset (Hofmann et al., 2009; Scott et al., 2009). Both studies employed a lexical decision task, suggesting that active lexical processing might boost very early emotion effects. On the other hand, many other studies also using LDT reported emotion effects only after access to lexical features, that is around 250 ms after stimulus onset (e.g., Palazova, Mantwill, Sommer, & Schacht, 2011; Schacht & Sommer, 2009a).

In order to shed light on the delimiting conditions of emotion effects during visual word recognition, particularly concerning different levels of linguistic processing, **Study 1** employed two tasks of different processing demands, namely LDT and a reading task. Furthermore, we aimed to clarify relative contributions of valence and arousal to emotion effects. To this aim, we selected stimuli that orthogonally combined valence (positive, neutral, and negative) and arousal (high, low), resulting in six stimulus categories (according to the BAWL-R, Vo et al., 2009). Examples for stimulus nouns are *Rekord* (record; positive, high arousal), *Weisheit* (wisdom; positive, low arousal), *Vulkan* (volcano; neutral, high arousal), *Klingel* (bell; neutral, low arousal), *Skandal* (scandal; negative, high arousal) and *Staub* (dust; negative, low arousal). Importantly, all stimulus categories were matched with regard to lexical variables known to affect word recognition, for example word length, word frequency (Baayen, Piepenbrock, & Gulikers, 1995), and imageability ratings (according to BAWL-R).

In ERPs, effects of emotional content were visible from 100 ms after word onset. Independent of task demands, that is both for LDT and reading task, positive valence increased the amplitudes of the P1 component. The P1 is generated in the extrastriate areas of the visual cortex and presumably reflects perceptual processing (Di Russo et al., 2007). Furthermore, P1 amplitudes have been reported to increase with visual attention (Hillyard & Anllo-Vento, 1998), suggesting that emotional content can involuntarily increase attention as early as 100 ms after stimulus onset.

Ranging from 280 to 380 ms, analysis revealed increased amplitudes of the EPN for high-arousing compared to low-arousing words irrespective of valence. In line with previous results, the EPN followed the effect of lexicality starting around 250 ms after stimulus onset, providing further evidence for its post-lexical locus. Interestingly, EPN effects only occurred in LDT, but not during reading, contradicting the assumption that EPN modulations occur automatically, that is independent of task requirements (see, for example, Kissler et al., 2007). Furthermore, our results provide direct evidence that the EPN reflects arousal-driven processes, since modulations occurred irrespective of word valence.

At a later processing stage, ranging from 420 to 520 ms, increased LPC amplitudes were elicited by positive compared to negative and neutral words. Independent of stimulus valence, high arousal also increased LPC amplitudes. The finding that both (positive) valence as well as high arousal contribute independently to the late positivity provides an explanation for the inconclusive pattern of results in previous studies, which attributed LPC effects either to positive valence (e.g., Herbert et al., 2006) or to arousal (Schacht & Sommer, 2009a, 2009b).

An advantage for positive valence was present in ERPs, but also in reaction times (RTs). It was previously assumed to reflect a ‘positivity bias’, describing the tendency to prefer positive information (Herbert et al., 2009). It is in contrast to reports of a ‘negativity bias’ for affective pictures, and presumably results from the generally lower arousal level of affective words (Liu, Jin, Wang, & Hu, 2010).

Autonomic arousal or cognitive facilitation? Evidence from pupillary responses

In ERPs, emotional words have been demonstrated to elicit emotion effects similar to affective pictures or emotional expressions in faces (Liu et al., 2010; Schacht & Sommer, 2009b). In contrast, the activity in peripheral emotion-sensitive parameters seems considerably reduced for emotional words (e.g., J. T. Larsen et al., 2003), suggesting a weaker impact of emotional content in written words, possibly due to their decreased relevance for the observer. The aim of **Study 2** was to investigate the relationship between cognitive processes and autonomic activation during emotional word recognition. To this aim, we recorded pupillary responses, which provide a measure for both cognitive load as well as autonomic arousal, while participants performed the same tasks as in Study 1, i.e. a reading task and a LDT on words varying in hedonic valence and arousal.

Autonomic arousal affects pupillary responses through the sympathetic nervous system, mediated by the amygdala and the lateral hypothalamus (Lang & Bradley, 2010), and leads to an increase in pupil diameter for affective pictures or sounds (Bradley et al., 2008; Partala & Surakka, 2003). Apart from emotional arousal, pupillary responses also indicate the amount of cognitive processing dedicated to a task: the more difficult a task, the larger the pupillary responses (e.g., Kahneman & Beatty, 1966; Van der Meer et al., 2010).

In the present study, high-arousing words elicited smaller pupillary responses than low-arousing words, thus exhibiting the opposite pattern of results than previously reported for affective pictures or sounds. This finding suggests that pupillary responses to emotional words do not indicate autonomic activation, but rather reflect cognitive facilitation for high-arousing content. In other words, smaller pupillary reactions indicate that less cognitive effort is necessary for the recognition of high-arousing words.

The cognitive facilitation of high-arousing words was not only evident in pupillary responses, but also on the behavioral level. In the LDT, reaction times were faster for high-arousing than for low-arousing words. Furthermore, participants correctly identified more high-arousing than low-arousing words in an unannounced recognition task that followed reading and LDT.

Taken together, these results suggest that emotional content, specifically high arousal, facilitates word recognition. This cognitive facilitation is evident in a) reduced pupillary responses, b) faster reaction times in the LDT and c) better memory performance for high-arousing words. Emotional content does not, however, mandatorily activate the autonomic nervous system to a similar degree as affective pictures or sounds.

Large letters, large emotions? The role of stimulus-driven attention in visual word recognition

The facilitated processing of emotional content visible in ERPs was suggested to result from *involuntary* attention allocation, presumably reflecting increased motivational relevance (Lang & Bradley, 2010). As outline above, this assumption was based on the similarity of emotion effects regarding their time course and topography to the effects of *voluntary* attention allocation. This is not only true for EPN and LPC, but also for modulations of P1 amplitudes reported in Study 1. Given this link between emotion and attention, how do both variables interact? Directing participants' top-down attention to affective stimuli has been reported to impact emotion processing particularly at higher-order stages, visible in modulations of the LPC. For example, instructing participants to evaluate the emotionality of a stimulus or to count stimuli of a certain valence leads to increased LPC amplitudes for both affective pictures and words, whereas the EPN is not modulated (Kissler, Herbert, Winkler, & Junghöfer, 2009; Schupp et al., 2007). Interestingly, a reverse pattern of results was reported for modulations of bottom-up, stimulus-triggered attention for emotional pictures: When emotional pictures where presented at different stimulus sizes, emotion effects at perceptual stages, that is in the EPN interval, were potentiated for larger pictures, while LPC and size effects showed an additive relationship (De Cesarei & Codispoti, 2006).

In **Study 3**, we aimed to investigate the interaction of stimulus-triggered attention and emotional content for word stimuli. Since the potentiation of emotion effects by stimulus size reported for affective pictures was suggested to result from enhanced biological relevance of seemingly "closer" objects (Codispoti & De Cesarei, 2007), a similar interaction is unlikely to occur for written words. Stimuli consisted of 24 positive, high-arousing, neutral, low-arousing and negative, high arousing nouns selected from the BAWL-R database (Vo et al., 2009), which were presented in two font sizes (*small*: 28 points, *large*: 125 points). Participants were instructed to attentively read the words in order to classify them in a randomly interspersed 1-back task.

Emotion effects in ERPs were modulated by stimulus size. The EPN started earlier, was more pronounced and lasted longer for large words compared to small words. At a later processing stage, effects of emotion and size were additive, i.e. LPC modulations were similarly pronounced for emotional compared to neutral words of both sizes. These results are in accordance with findings from affective pictures, where stimulus size similarly potentiated EPN effects, but influenced LPC amplitudes in an additive manner. These findings suggest that the emotion-driven facilitation of attention at perceptual stages is not limited to biologically relevant stimuli, but also occur for symbolic stimuli with acquired meaning.

Summary and integration of results

General and domain-specific mechanisms in emotion processing

Prior evidence suggests the existence of a common mechanism underlying the processing of emotional words and affective pictures. Both stimulus types elicit emotion effects in ERPs with a highly similar time course and topography, namely an early negativity, which was suggested to reflect perceptual facilitation, and a late positivity that presumably indicates higher-order stimulus evaluation. Furthermore, imaging data shows the involvement of similar brain systems in affective processing of both pictures and words (Kensinger & Schacter, 2006a; Vuilleumier, Armony, Driver, & Dolan, 2001), suggesting the existence of a domain-unspecific system for emotion-induced facilitation of attention. The present work provides further evidence for this assumption by revealing an additional *functional* similarity across stimulus domains: Despite the symbolic nature of written words, the manipulation of stimulus-triggered attention modulates EPN effects, demonstrating that early, perceptual interactions of attention and emotion are not limited to biologically relevant stimuli. In the case of pictures, increased emotion effects for larger stimuli have been related to the putatively higher motivational relevance of a closer object; the closer an aggressor, for example, the more dangerous he is for the individual (Codispoti & De Cesarei, 2007). Our results now suggest that perceptual facilitation – but probably also affective processing per se – may be less dependent on biological relevance than previously assumed, but may rather respond to a more general form of stimulus relevance - for example stimulus size -, which extends to symbolic stimuli.

Apart from these functional similarities in the processing of affective pictures and words, the results of Study 1 revealed another analogy concerning the time course of emotion effects. Similar to affective pictures, emotional words increased the amplitude of the occipital P1 component. Previous evidence for emotion effects within the first 200 ms after stimulus onset is scarce, and suggested that emotional processing might be associated with reduced rather than increased amplitudes of the P1 component, but differences in stimulus characteristics seem to impede an unambiguous interpretation of results concerning the interrelations of valence, arousal and word frequency (see Hofmann et al., 2009; Scott et al., 2009). Here, we provide evidence that written words can *increase* the amplitudes of the P1 component. Augmented P1 amplitudes are supposed to reflect amplification of sensory information processing in the visual cortex (Hillyard & Anllo-Vento, 1998; Luck, Woodman, & Vogel, 2000), and have often been reported for affective pictures (Delplanque, Lavoie, Hot, Silvert, & Sequeira, 2004; Smith, Cacioppo, J. T. Larsen, & Chartrand, 2003; Versace et al., 2011). Our finding of enhanced P1 amplitudes for positive words shows that involuntary attention allocation in the visual cortex is not limited to pictorial stimuli, and suggests the existence of a domain-unspecific detection mechanism for emotional content. Supporting this assumption, a recent study by Rellecke and colleagues (Rellecke, Palazova, Sommer, & Schacht, 2011) reported increased amplitudes for emotional stimuli in the slope of the P1 component irrespective of stimulus category, that is for both emotional words and emotional facial expressions.

The finding of emotion effects in the P1 component does not only have implications for the mechanism of emotion detection, but is also relevant concerning the time course of word recognition in general. Emotion effects in the P1 time range are at variance with serial models of language processing, which assume that lexical features are not accessed within the first 200 ms after stimulus onset (e.g., Holcomb & Grainger, 2006). However, recent evidence points to a much faster word recognition process, where the relatively late components like the N400 may reflect recurrent and feedback-driven processes (Sereno & Rayner, 2003). Interestingly, most recent evidence indicates that even the P1 component can be modulated by (non-emotional) semantic features of written words, suggesting that word meaning can influence even the earliest – allegedly exogenous – stages of word recognition (Rabovsky, Sommer, & Abdel Rahman, 2011). Emotion effects in the P1 component are in accordance with these findings and might thus be interpreted as indicator of recurrent feedback-driven processes in the visual cortex. However, instead of very fast semantic access, it is conceivable that associative learning of symbolic, i.e. non-linguistic word features may contribute to P1 emotion effects. Most recently, Schacht and colleagues (Schacht, Adler, Guo, & Sommer, accepted) provided evidence for early modulations for symbolic stimuli based on outcome conditioning. Formerly unfamiliar Chinese characters, which were experimentally associated positive valence, elicited enhanced amplitudes in the P1 time range, demonstrating that associative learning of symbolic stimuli can a) be established after a limited number of presentations and b) affect early visual processing. Taken together, two possible explanations arise for emotion effects in the P1 time range. First, they might indicate very fast semantic processing, which is presumably based on recurrent feedback to the visual cortex. Second, associative learning of symbolic word features, which is not dependent on the word recognition process, may contribute to effects in the P1 time range. To that point, however, our results do not allow definite conclusions about the underlying mechanism of early emotion effects, but this question will clearly constitute an important field of future research.

As discussed above, the current work presents several functional and temporal analogies in the processing of affective words and pictures and thus provides further evidence for a domain-unspecific detection mechanism for emotional information. However, it also sheds light on a presumable difference in the processing of affective pictures and words. Despite highly similar emotion effects visible in ERPs, prior evidence indicates that the activity in peripheral emotion-sensitive parameters might be considerably reduced for affective words as compared to pictures (e.g., J. T. Larsen et al., 2003). Investigating emotional word processing with pupillary responses, Study 2 demonstrated that emotional content in written words does indeed not mandatorily trigger activation of the autonomic nervous system. Instead, high-arousing words were associated with reduced pupillary responses, indicating that cognitive facilitation was responsible for emotion effects visible in behavioral parameters. Reduced peripheral activation for written words is in accordance with theoretical considerations defining emotions as action dispositions that prepare the individual for appropriate behavior (Bradley et al., 2001). According to this view, the magnitude of emotional reactions is related to the relevance of emotional stimuli, and may therefore be reduced for written words, which are merely carrying symbolic meaning. On the anatomical level, the finding of similar cortical activation for affective pictures and words might result from comparable activations of the basolateral nuclei of the amygdala, which receive thalamic and cortical input and are supposed to be responsible for back-projections to visual areas (Amaral, Behniea, & Kelly, 2003; Lang & Bradley, 2010). In contrast, activity in the central nucleus, the amygdala's output area that influences autonomic activity via projections to the lateral hypothalamus (Lang & Bradley, 2010; Whalen, 1998), might be reduced for words relative to pictures and thus insufficient to trigger autonomic responses.

Contributions of valence and arousal

One aim of the present work was to investigate the contributions and possible interactions of hedonic valence and arousal to emotion effects in ERPs and pupillary responses. Interestingly, interactions of valence and arousal were evident in neither of both measures, suggesting independent contributions of both dimensions. This finding is at variance with the motivated attention theory (Lang, Bradley, & Cuthbert, 1997), which assumes that arousal is not an independent dimension, but merely indicates the degree of activation within a valence-related subsystem. However, the notion of independent and orthogonal dimensions is not new (Russell, 1980), although it has recently received little attention. In line with the assumption of independent dimensions, a number of prior studies indicated arousal effects at constant valence levels both in ERPs and behavioral parameters (Hofmann et al., 2009; R. J. Larsen, Mercer, Balota, & Strube, 2008; Rozenkrants, Olofsson, & Polich, 2008). Furthermore, valence and arousal have been related to distinct brain structures (Anders, Lotze, Erb, Grodd, & Birbaumer, 2004; Kensinger & Corkin, 2004; Lewis, Critchley, Rotshtein, & Dolan, 2007) and temporal dynamics (Codispoti, Ferrari, & Bradley, 2007; Gianotti et al., 2008; for review see Olofsson, Nordin, Sequeira, & Polich, 2008). Taken together, a vast body of research supports the notion of independent contributions of valence and arousal to emotion effects visible in behavioral, electrophysiological and hemodynamic parameters. These findings argue against the notion of motivational systems as building blocks of emotional processing (Lang et al., 1997) and suggest that the arousal dimension does not merely depict the degree of valence-related activation, and thus call for theoretical reconsiderations concerning the structure of the affective space.

Emotion processing: an adaptive system for relevance detection

So far, the present work concentrated on *general* features of emotion processing in word recognition, suggesting temporal, anatomical and functional similarities to the processing of affective pictures in the central nervous system, but profound differences in peripheral activation. However, it is important to note that the process of emotion detection and attention facilitation is not a rigid and invariable mechanism, which is executed whenever emotional information is encountered, but a highly adaptive system. Among the variables known to influence emotional processing are, for example, personal relevance of stimuli (Bonnet & Naveteur, 2006; van den Hout, De Jong, & Kindt, 2000), inter-individual differences (Stemmler & Wacker, 2010; van den Brink et al., 2010), and context information (Schacht & Sommer, 2009a). The present work provides new evidence about another factor frequently reported to modulate emotion effects, which is level of processing. While higher-order emotion effects strongly depend on task requirements, it was previously assumed that the EPN occurred irrespective of attentional resources and processing demands (e.g., Schacht &

Sommer, 2009a). Contradicting this assumption, a number of recent studies reported that EPN modulations were limited to tasks requiring lexical analysis, but were not elicited when the emotional words were presented in highly superficial tasks (Hinojosa et al., 2009; Hinojosa et al., 2010; Palazova et al., 2011; Rellecke et al, 2011). The present results line up with these findings, showing that the EPN was evident in the LDT, but not during uninstructed reading, and suggest that task requirements may play a more important role than previously considered. However, up to this point, evidence does not allow unequivocal interpretations of the often heterogeneous body of results. In order to gain full understanding about emotional processing, future research has to address the delimiting conditions of emotion effects, including, among others, the contributions and interrelations of task demands, individual differences, and context information.

In summary, the present word provides evidence for the existence of a domain-general mechanism that allocates attention to emotional content. Similar to emotional pictures, emotional words increased the amplitudes of the P1 component, suggesting augmented attention allocation in the visual cortex despite the arbitrary character of written words (Study 1). Furthermore, Study 3 revealed that interactions between stimulus-driven attention and emotional meaning are not limited to emotional pictures, but also occur for written words. Both findings suggest that emotion-driven facilitation of attention might be less dependent on biological relevance than it was previously assumed by the 'motivated attention theory' of emotion (Lang et al., 1997). Moreover, the present results contradict the theory's assumption concerning the structure of the affective space by providing evidence for independent contributions of valence and arousal to emotion effects in ERPs and pupillary responses (Studies 1 and 2). Finally, shedding light on a presumable difference in the processing of emotional words and affective pictures, Study 2 suggests that emotional words might not mandatorily trigger activation of the autonomic nervous system. Instead, the behavioral advantage for arousing words seems to result from cognitive facilitation.

List of submitted original manuscripts

1. Bayer, M., Sommer, W., & Schacht, A. (in revision). P1 and beyond: Functional Separation of multiple emotion effects in word recognition.

2. Bayer, M., Sommer, W., & Schacht, A. (2011). Emotional Words Impact the Mind but not the Body: Evidence from Pupillary Responses. Psychophysiology, 48 (11), 1554-1562

3. Bayer, M., Sommer, W., & Schacht, A. (submitted). Font Size Matters: Emotion and Attention in Cortical Responses to Written Words

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Appendix

Publication List

Peer-reviewed journals

Bayer, M., Sommer, W., & Schacht, A. (2011). Emotional Words Impact the Mind but not the Body: Evidence from Pupillary Responses. Psychophysiology, 48 (11), 1554-1562.

Bayer, M., Sommer, W., & Schacht, A. (2010). Reading emotional words within sentences: The impact of arousal and valence on event-related potentials. International Journal of Psychophysiology, 78, 299–307.

Conference contributions

Bayer, M., Sommer, W. & Schacht, A. (2011). Pupillary responses to emotional words. 17th Meeting of the European Society for Cognitive Psychology (ESCOP), San Sebastian, Spain *[Poster]*

Bayer, M., Sommer, W. & Schacht, A. (2011). Very Early Emotion Effects for Positive Words in Event-Related Brain Potentials. Ninth Göttingen Meeting of the German Neuroscience Society, Göttingen, Germany *[Poster]*

Bayer, M., Sommer, W. & Schacht, A. (2010). Automatischer Einfluss der Emotion in der Wortverarbeitung? TeaP 2010, Saarbrücken, Deutschland *[Vortrag]*

Bayer, M., Sommer, W., & Schacht, A. (2009). Effects of emotional valence and arousal in word processing: Evidence from event-related brain potentials and peripheral indicators. ISRE 2009 conference, Leuven, Belgium *[Poster]*

Bayer, M., Sommer, W., & Schacht, A. (2009) Emotion in Word Processing: Valence and Arousal in Event-Related Brain Potentials and Peripheral Indicators. SPR annual meeting, Berlin, Germany *[Poster]*

Bayer, M., Schacht, A., Sommer, W. (2008). Contributions of emotional valence and arousal to visual word processing in sentences: Central and peripheral psychophysiological indicators. ICP2008, Berlin, Germany *[Vortrag]*

Bayer, M., Schacht, A., & Sommer, W. (2007). Effekte von Arousal und Valenz auf die Sprach-verarbeitung. TeaP2007, Trier, Germany *[Poster]*

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Eidesstattliche Erklärung

Hiermit erkläre ich an Eides statt,

1) dass ich die vorliegende Arbeit selbständig und ohne unerlaubte Hilfe verfasst habe,
2) dass ich mich nicht anderwärts um einen Doktorgrad beworben habe und noch keinen Doktorgrad der Psychologie besitze,
3) dass mir die zugrunde liegende Promotionsordnung vom 3. August 2006 bekannt ist.

Berlin, den 21.09.2011

Mareike Bayer