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On pleasure and thrill: The interplay between arousal and valence during visual word recognition

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ABSTRACT

We investigated the interplay between arousal and valence in the early processing of affective words. Event-related potentials (ERPs) were recorded while participants read words organized in an orthogonal design with the factors valence (positive, negative, neutral) and arousal (low, medium, high) in a lexical decision task. We observed faster reaction times for words of positive valence and for those of high arousal. Data from ERPs showed increased early posterior negativity (EPN) suggesting improved visual processing of these conditions. Valence effects appeared for medium and low arousal and were absent for high arousal. Arousal effects were obtained for neutral and negative words but were absent for positive words. These results suggest independent contributions of arousal and valence at early attentional stages of processing. Arousal effects preceded valence effects in the ERP data suggesting that arousal serves as an early alert system preparing a subsequent evaluation in terms of valence.

1. Introduction

From the gratification experienced while reading a poem to the aggression expressed with an insult, words are fundamental means to elicit and express emotions. Many theories have taken the challenge to understand and classify emotion stimuli and emotional responses. According to dimensional models of affect (e.g., Osgood, Suci, & Tannenbaum, 1957; Russell, 1980; Wundt, 1896), an emotional experience can be described in terms of its position within an affective space defined by certain dimensions. The two most largely accepted dimensions to account for emotional experiences are valence and arousal. The appetitive/aversive model of Lang, Bradley, and Cuthbert (1997) considers valence a bipolar dimension that defines stimuli in terms of pleasure and displeasure and activates two motivational brain systems, either appetitive or aversive, eliciting basic reactions of approach and withdrawal (Lang et al., 1997). Arousal is considered an unipolar dimension that defines the intensity in the activation of the respective motivational system quantitatively. Normative ratings of visually presented words have shown that differences in valence seem to be more salient than differences in arousal, hence, depicting the relation between the two in a U-shaped distribution (Bradley & Lang, 1994, 1999; Lang, Bradley, & Cuthbert, 1999). This finding has been consistently replicated in other languages, and so has the finding that correlations between the two variables are high when looking at the domains of positive and negative valence separately (e.g., Schmidtke, Schröder, Jacobs, & Conrad, 2014). Although the use of both dimensions has provided a useful theoretical background, there are reasons to assume that the relations between valence and arousal are more complex. For example, ratings of German words (e.g., Schmidtke et al., 2014; Võ, Jacobs, & Conrad, 2006; Võ et al., 2009) show that the correlation between valence and arousal differs considerably between the positive and negative domain: an increase in negative valence is normally accompanied by an increase in arousal, that is, the more negative a stimulus, the more arousing it tends to be. For positive words, however, the correlation between valence and arousal appears much attenuated, reflecting that both exciting and calm events can be perceived as highly pleasant. Similar asymmetries have been found for ratings of affective pictures (Keil et al., 2002).

These asymmetries in the relation between valence and arousal observed in large scale rating databases are in line with the view that both positive valence and low arousal generate responses of approach, whereas stimuli of either negative valence or high arousal elicit withdrawal (Robinson, 1998). The author demonstrated

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that congruent combinations (i.e., positive low-arousal or negative high-arousal) are responded faster to than incongruent ones (i.e., positive high-arousal or negative low-arousal), likely because they are easier to process and demand fewer resources (Robinson, Storbeck, Meier, & Kirkeby, 2004). Similarly, Cacioppo (2004) used the term *positivity offset* to describe that the approach system is typically activated in situations of low arousal, providing the basis for exploration and curiosity. At a high level of arousal, instead, a *negative bias* is assumed, as the withdrawal system responds strongly at high levels of arousal (see also Ito & Cacioppo, 2000). Studies using affective pictures and faces have supported this negative bias and positivity offset with behavioral and cortical responses (see Norris, Gollan, Berntson, & Cacioppo, 2010, for a review). However, it is unclear whether the same asymmetries apply to the processing of emotional words (Kissler, Assadollahi, & Herbert, 2006).

From a theoretical perspective, such asymmetries involving more specific or fine grained valence and arousal effects are more in line with models of emotion that consider valence and arousal as orthogonal, bipolar and independent from each other (e.g., Russell, 1980). According to Russell's (1980) circumplex model, affective space forms a circle of emotional states organized around two bipolar axes, one for valence (positive, negative), and one for arousal (activation, calm). Behavioral studies using multidimensional scaling and factorial analyses provided empirical support for the independence assumption (e.g., Russell & Barrett, 1999). Neuroimaging and electroencephalogram (EEG) studies have also indicated separate neural routes for valence and arousal, although with some inconsistencies in the results (Anders, Lotze, Erb, Grodd, & Birbaumer, 2004; Colibazzi et al., 2010; Gianotti et al., 2008; Kensinger & Corkin, 2004; Kensinger & Schacter, 2006; Lewis, Critchley, Rotshtein, & Dolan, 2007).

Data from ERP studies support the idea of several stages in visual word processing (for reviews see Kissler et al., 2006; Ponz et al., 2013). Previous evidence has shown that emotion-laden words can modulate cortical responses at all stages (see Citron, 2012, for a review). Recent studies have helped to identify which variables (i.e., word class, word frequency) impact the time course of the processing of emotional meaning (Palazova, Mantwill, Sommer, & Schacht, 2011). Consistently, differences in ERP amplitudes for emotional relative to neutral words appear at around 200–350 ms in the form of a negative deflection, which is maximal at posterior electrode sites, called early posterior negativity (EPN; Bayer, Sommer, & Schacht, 2010; Conrad, Recio, & Jacobs, 2011; Herbert, Kissler, Junghöfer, Peyk, & Rockstroh, 2006; Kissler, Herbert, Peyk, & Junghöfer, 2007; Kissler, Herbert, Winkler, & Junghöfer, 2009; Schacht & Sommer, 2009a, 2009b; Scott, O'Donnell, Leuthold, & Sereno, 2009). This enhanced EPN for emotion-laden words reflects improved visual processing in the visual cortices and allocation of attention to the emotional content of the stimuli due to their higher motivational significance (e.g., Kissler et al., 2006).

At later stages of processing following 400 ms after stimulus onset, emotional words elicit larger positivities than neutral ones at central electrodes, in the so-called late positive complex (LPC), which is thought to reflect enhanced *motivated attention* (see Lang et al., 1997) and evaluation of emotional words (e.g., Conrad et al., 2011; Herbert et al., 2006; Schacht & Sommer, 2009a, 2009b). Larger LPC amplitudes to affective words have been attributed not only to the manipulation of valence, but also to differences in arousal (see Dillon, Cooper, Grent-'t-Jong, Woldorff, & LaBar, 2006; Fischler & Bradley, 2006). Fischler and Bradley (2006) reported a latency delay of 150 ms for the LPC when participants were engaged in a classification task based on valence, as compared to when they were asked to classify the arousal of the same words, and concluded that the LPC primarily reflects the intensity of arousal, rather than differences in valence. Similar findings have been observed with affective pictures (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000).

Based on the assumption that high arousal co-occurs with extreme valence (Lang et al., 1997), in the majority of studies investigating emotion effects, stimuli were selected to maximize the contrast between emotional and neutral conditions using conjoint manipulations of the two variables. Namely, high-arousal words of either positive or negative valence were compared with low arousal, neutral words. Findings obtained under such manipulations document, in general, the largest emotional effects, but do not allow more fine-grained attributions concerning their source. Moreover, other theories (e.g., Russell, 1980) and empirical data indicate independence of the two dimensions valence and arousal (e.g., Anders et al., 2004; Gianotti et al., 2008). Hence, it is unclear whether the emotional modulation of the EPN and LPC reported previously is due to the processing of either valence or arousal alone, or rather to a combination of both. In an attempt to solve this problem, several ERP studies – mostly using affective pictures – have analyzed valence effects while keeping constant the level of arousal, not only between positive and negative, but also between emotional and neutral conditions (e.g., Conroy & Polich, 2007; Delplanque, Lavoie, Hot, Silvert, & Sequeira, 2004; Huang & Luo, 2006; Yuan et al., 2007). Overall, they indicate that negative images are preferentially processed at high and medium levels of arousal, demonstrated in the larger amplitudes of ERP components for these conditions at early and later stages of processing, and congruent with the idea of a negative bias (Cacioppo, 2004).

Despite the growing interest in the investigation of the emotion–cognition coupling in language processing, to our knowledge, such fine-grained valence effects have rarely been investigated with visually presented words. Probably, the lack of comprehensive studies trying to disentangle specific effects of valence and arousal is due to a non-trivial methodological challenge in selecting the stimulus material. The relatively high correlation between valence and arousal – considering both the positive and the negative domain of valence separately – makes it difficult to independently manipulate the two factors, especially when only a limited number of words with corresponding emotion ratings are available.

Available studies attempting to disentangle the respective effects of valence on the one hand and of arousal on the other provide a heterogeneous picture of results concerning response latencies or ERP effects. For example, a behavioral study that compared words of different valence at similar – though not completely matched – arousal levels, reported a facilitation for positive and negative words of high arousal relative to neutral words of medium arousal, and no asymmetry between valence poles (Kousta, Vinson, & Vigliocco, 2009).

A recent ERP study investigating emotion effects on high and low arousal words with different valence (positive, negative, neutral) proposed three steps in the time course of emotional effects on ERPs. First, an early (100 ms) impact of (positive) valence in the P1 component, followed by an effect of (high) arousal within the EPN time window; and finally, simultaneous and additive effects of valence and arousal in later stages in the LPC (Bayer, Sommer, & Schacht, 2012). In line with Russell's model (1980), the effects of valence and arousal were independent from each other as they did not interact in any time window. Emotional modulations of the P1 have also been observed due to arousal while keeping valence constant, i.e., involving only negative words (Hofmann, Kuchinke, Tamm, Võ, & Jacobs, 2009). Additional data, also controlling for both dimensions – at least for negative and positive words – showed interactive effects of valence and arousal in the EPN time window, in form of an enhanced EPN for positive high-arousal and negative low-arousal words (Citron, Weekes, &

Ferstl, 2013). This finding would be in line with the notion that these combinations receive enhanced attention because they activate conflicting approach-avoidance orientations (Robinson, 1998). In sum, despite recent efforts to separate the contributions of arousal and valence to the emotional modulation of ERPs, results still appear rather inconsistent.

Here, we aimed to clarify these inconsistencies using a comprehensive design involving a complete manipulation of both variables in a three-step fashion contrasting positive, negative and neutral words as well as words of high, low and medium arousal. Such a design provides the advantage of allowing the investigation of effects of both dimensions independently from each other, considering the whole range of both variables. Recent progress in extending such normative databases (e.g., Võ et al., 2009) to a number of approximately 3.000 words for which valence and arousal ratings are provided made it possible to find a sufficient number of words serving as stimuli for an orthogonal design investigating independent effects of valence and arousal across the whole range of the two dimensions.

We investigated the time course of valence and arousal effects in word processing in a lexical decision task, and possible interactions between the two dimensions in behavioral and cortical responses. We expect, in general, larger EPN amplitudes for positive and negative words relative to neutral (e.g., Conrad et al., 2011), and for high-arousal relative to low-arousal words (e.g., Bayer et al., 2012). We are particularly interested in potential interactions of arousal with valence for the EPN (e.g., Citron et al., 2013) that would shed insight on the interplay between these two dimensions of affective space in the domain of language perception.

Trend analyses of the overall effects of valence and arousal should provide information concerning the structure of both dimensions. A bipolar dimension – like valence – should yield a quadratic trend, whereas unipolar dimensions – as suggested by Lang et al. (1997) for arousal – should show linear trends if ERP amplitudes increase gradually with the level of arousal.

Maximum emotion effects on ERPs might appear when comparing high-arousal, positive or negative words with low-arousal, neutral words, resembling the manipulation used in the majority of previous studies and replicating their findings. Pure effects of either valence or arousal could be observed for a given dimension while controlling for the other one. Hence, pure valence effects may arise in the present design when comparing positive, negative and neutral words at constant levels of arousal, and vice versa for pure arousal effects. For instance, larger EPN amplitudes for high-relative to low-arousal negative words might be expected according to previous studies (e.g., Citron et al., 2013; Hofmann et al., 2009). It has been suggested that arousal should have a major impact at early stages of processing (<300 ms) serving as an automatic alert system that drives the allocation of attentional resources independently from valence (Kissler et al., 2006). If this notion holds true, arousal effects should appear earlier in the ERP data than valence effects, which may appear later, as they reflect higher-order, evaluative processes (e.g., Citron, 2012).

2. Methods

2.1. Participants

Twenty-nine right-handed (Oldfield, 1971) native German speakers participated in the experiment. Data from two of them were excluded from the analyses due to excessive artefacts. Thus, data of 27 participants (18 women) mean age $M = 26.4$ years, $SD = 6.9$, were submitted to the analyses. Prior to the experimental session all participants read and signed consent to the study. None of them suffered from neurological or language problems, as indicated by self-report questionnaires. Most participants were students and their participation in the experiment was rewarded with course credits or money. The experiment was performed according to the standards of the Declaration of Helsinki (1964) and approved by an ethical committee.

2.2. Stimuli and design

Stimuli consisted of 477 words selected from the Berlin Affective Word List (BAWL reloaded, Võ et al., 2009). Words were divided into nine different cells of 53 items each according to the orthogonal combination of the three-level factors valence (positive, negative, neutral) and arousal (low, medium, high).

Emotional valence in the BAWL is rated on a Likert scale ranging from −3 to +3. Words were entered in the condition of positive valence if the mean normative valence rating was above 1, in the neutral valence condition between −1 and +1, and in the negative valence condition with scores below −1. Arousal in the BAWL is rated on a scale ranging from 1 to 5. Words were entered in the condition of low arousal if average ratings were below 2.6, in the condition of medium arousal if rated between 2.6 and 3[1], and in the condition of high arousal if rated above 3. Scores of the manipulated variables differed significantly between words from different levels of the respective dimension (valence: $F = 2386.8$, $p < .0001$, and arousal $F = 979.4$; $p < .0001$), but not across levels of the respective other dimension ($ps > .6$). Words were matched across all cells for frequency of occurrence, grammatical class (each cell contained 19 substantives, 24 adjectives, and 10 verbs), word length (letters and phonemes), syllables, number of orthographic neighbors, number of higher frequency orthographic neighbors and imageability. Item characteristics are presented in Table 1. Word frequencies were obtained from the Leipzig Wortschatz Projekt (Wortschatz Universität Leipzig, 2012). Phonological information and neighborhood computations are based on the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995). A set of 477 non-words (pronounceable letter strings) was presented – matching word stimuli on length and syllable number. Additionally, 53 pseudo homophones of German words were included in the non-word material to assure a high level of difficulty of the lexical decision task (see Grainger & Jacobs, 1996).

2.3. Procedure

Stimuli were presented in white letters (font: Times New Roman, size: 20) over black background on a 17-in. monitor placed at 80 cm from participants' eyes. Participants were instructed to read the combination of letters appearing in the screen and to respond as fast and as accurately as possible whether each item was a word or a non-word by pressing one of two buttons placed under their two index fingers. The assignment of word and non-word responses to the left or the right hand was balanced across participants. There was a practice block of 10 additional items. Each trial started with a fixation-cross presented during 300 ms, followed by the stimulus, which was present until participants responded. Then a blank screen was shown for 2000 ms before the next trial started[2]. Stimuli were presented in randomized order, with short pauses every 350 items.

[1] Note that the range for medium arousal values reflects the normal distribution of these values in the database where the majority of values are relatively close to the center of the scale. About 25% of all words in the database (Võ et al., 2009) fall inside the selected range for medium arousal.

[2] We used fixed inter-trial interval (ITI) as in most of previous studies investigating the processing of emotional words (e.g., Citron et al., 2013; Dillon, Cooper, Grent-'t-Jong, Woldorff, & LaBar, 2006; Schacht & Sommer, 2009a). Using variable ITI might have prevented from possible anticipation effects in the ERPs.

Table 1
Means and standard deviations for the manipulated emotion variables valence and arousal and for control variables for words in the different cells of the valence × arousal manipulation. Control variables are: imageability, frequency of occurrence per 1 million words in the Leipzig Wortschatz, number of letters, number of syllables, number of orthographic neighbors, and number of higher frequency orthographic neighbors.

Valence	Arousal	Valence	Arousal	Imageability	Frequency	Letters	Syllables	Neighbors	HF neighbors
Negative	High	−1.56 (0.46)	3.62 (0.39)	4.03 (0.74)	10.84 (20.09)	7.15 (1.38)	2.28 (0.57)	1.04 (1.44)	0.35 (0.79)
Negative	Low	−1.44 (0.33)	2.20 (0.31)	3.97 (1.07)	9.79 (23.07)	6.92 (1.47)	2.28 (0.60)	1.17 (1.75)	0.38 (0.84)
Negative	Medium	1.44 (0.34)	2.85 (0.11)	3.92 (0.96)	13.79 (28.34)	7.00 (1.53)	2.13 (0.65)	1.40 (1.87)	0.51 (1.30)
Neutral	High	−0.02 (0.37)	3.52 (0.32)	4.11 (1.06)	9.49 (20.85)	6.87 (1.45)	2.30 (0.54)	1.02 (1.62)	0.28 (0.69)
Neutral	Low	0.02 (0.41)	2.22 (0.27)	4.03 (1.35)	7.55 (16.89)	7.08 (1.62)	2.34 (0.55)	1.19 (1.93)	0.42 (1.12)
Neutral	Medium	0.06 (0.45)	2.80 (0.14)	3.87 (1.34)	18.54 (47.40)	6.98 (1.50)	2.45 (0.67)	1.15 (1.67)	0.37 (0.84)
Positive	High	1.68 (0.47)	3.50 (0.34)	3.87 (0.95)	12.96 (31.72)	7.17 (1.52)	2.42 (0.72)	0.94 (1.57)	0.36 (0.88)
Positive	Low	1.64 (0.40)	2.14 (0.31)	4.03 (1.15)	12.68 (35.19)	7.02 (1.54)	2.42 (0.57)	1.30 (1.98)	0.43 (0.95)
Positive	Medium	1.63 (0.40)	2.83 (0.11)	4.08 (1.22)	12.96 (26.63)	7.19 (1.57)	2.23 (0.67)	0.72 (1.52)	0.30 (0.77)

2.4. Psychophysiological recordings

EEG was recorded from 60 electrodes filled with gel (10-5 system) mounted on a cap, using two 32-channel amplifiers and referenced to the right mastoid. Four additional electrodes were attached under, above, and next to the eyes to record the vertical and horizontal electro-oculogram. Electrode impedance was kept below 5 kΩ. EEG was recorded at a 500 Hz sampling rate. All channels were filtered offline with a band pass filter 0.1–20 Hz, and recalculated to average reference. EEG continuous signal was segmented in 1400 ms epochs starting 200 before stimulus onset, which served as pre-stimulus baseline. Ocular artifacts were corrected using independent component analyses (ICA, Zhou & Gotman, 2005) with Analyzer 2.0 software (Brain Products, Germany). Differences in values >80 μV in intervals of 70 ms as well as amplitudes >50 or <−50 μV were considered artifacts. Only segments with correct responses and free of artifacts were averaged according to the experimental conditions. All participants had similar numbers of trials for all conditions, $M = 47.5$, $SD = 3.7$, *range* = 35–53.

2.5. Statistical analyses

Mean correct response latencies and percent of errors were submitted to analyses of variance (ANOVAs) with repeated measures. Response latencies deviating more than two standard deviations from the mean for participant and condition were considered outliers and removed from the analyses (4.52% of the data). One word was excluded from the analyses because of an exceeding error rate (higher than 50%). Averaged ERP mean amplitudes were segmented into four strategic time windows in which differences were maximal based on visual inspection of the data, 75–100 ms for the P1, 200–300 ms and 275–425 ms for the EPN; and 425–500 ms for the LPC. The two different time windows for the EPN were selected to address possible latency shifts of respective effects for valence and arousal. ANOVAs with repeated measures were calculated for these time windows of ERP data in clusters of electrodes in regions of interest (ROIs) where components were maximal, i.e., P9, P7, P8, P10, PO9, PO7, POz, PO8, PO10, O1, Oz, O2, Iz, for the P1 and EPN components, and FC1, FC2, FCz, C3, C4, Cz, CP1, CP2, CPz, P3, P4, Pz, for the LPC. The ANOVAs over ROI amplitudes included the factors valence (3 levels), and arousal (3 levels) and electrode site (13 and 12 levels for EPN and LPC, respectively). In the results section we report main effects of the factors valence and arousal as we were interested in the difference between the levels of each condition across all electrodes in the ROI. *P*-values were adjusted using the Huynh–Feldt correction for violations of sphericity, and the Bonferroni correction for multiple testing in all post hoc comparisons. Partial eta-squared (ηp^2) values are reported as estimates of effect sizes in the ANOVA. Post hoc polynomial contrasts were calculated to estimate linear and quadratic trends for the overall effects of valence and arousal.

3. Results

3.1. Behavioral data

Mean RTs and errors are presented in Fig. 1. Valence caused a significant main effect in the RT data, $F(2,52) = 25.38$, $p < .001$, $\eta p^2 = .49$. Correct responses to positive words were 22 ms faster than to neutral and 25 ms faster than to negative words. Post hoc comparisons revealed that only responses to positive words differed significantly from any of the other two conditions, $F(1,26) = 38.72$, $p < .001$ for the comparison between positive and negative words; $F(1,26) = 23.89$, $p < .001$, between positive and neutral words. This processing advantage for positive words was mirrored in the error data, $F(2,52) = 14.94$, $p < .001$, $\eta p^2 = .36$, where positive words provoked less errors (2.9%) than neutral (4.4%) or negative ones (5.6%) – all single comparisons of error rates between conditions resulted significant (all Fs > 6.9; all ps < .05). The factor arousal also yielded a significant main effect on RTs, $F(2,52) = 7.32$, $p < .003$, $\eta p^2 = .22$. Words with high arousal were responded to 12 ms faster than words with low arousal, $F(1,26) = 6.99$, $p < .05$, and 13 ms faster than medium-arousal words, $F(1,26) = 12.18$; $p < .006$. Again, this processing advantage for high arousal words was corroborated by a significant effect in the error data, $F(2,52) = 4.58$, $p < .02$, $\eta p^2 = .15$, with high arousal words provoking less errors (3.5%) than words with low (4.6% of errors; $F(1,26) = 6.34$; $p < .05$) or medium arousal (4.8% of errors; $F(1,26) = 7.65$; $p < .04$). Words of medium and low arousal did not differ.

Most interestingly, the effects of the two manipulated variables valence and arousal showed significant interactions on both RTs, $F(4,104) = 5.41$, $p < .001$, $\eta p^2 = .17$; and error rates, $F(4,104) = 4.73$, $p < .003$, $\eta p^2 = .15$. To further explore the nature of these interactions we analyzed the effects of valence and arousal separately within the three conditions of the respective other dimension.

3.1.1. Valence effects in low-arousal words

Valence caused a significant effect on response latencies, $F(2,52) = 10.53$, $p < .001$, $\eta p^2 = .29$. Positive words of low arousal received the fastest responses, followed by neutral ones, whereas negative low-arousal words were especially slow in being responded to. Post hoc comparisons revealed that mean differences between positive and negative words $F(1,26) = 15.32$, $p < .003$, and between negative and neutral words $F(1,26) = 19.57$, $p < .001$ were significant. Responses to positive and neutral words did not differ significantly. A similar effect was present in the error data, $F(2,52) = 15.88$, $p < .001$, $\eta p^2 = .38$; with the highest error rates

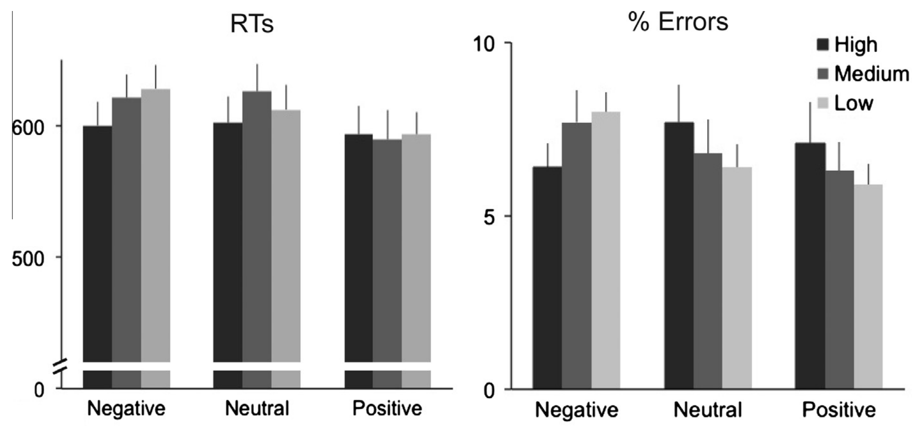

Fig. 1. Means for behavioral variables reaction time (RT) and percentage of errors (% errors) for words in the lexical decision task. Bars show standard errors.

for negative words followed by neutral and positive ones (all $Fs > 9.7$; all $ps < .03$).

3.1.2. Valence effects in medium-arousal words

Again, a significant valence effect was obtained on response latencies, $F(2,52) = 29.75$, $p < .001$, $\eta p^2 = .54$. Within a medium level of arousal, positive words were responded to significantly faster than neutral $F(1,26) = 59.74$, $p < .001$, and negative words $F(1,26) = 40.18$, $p < .001$. No significant differences were present between the two latter. A consistent effect in the error data, $F(2,52) = 7.91$, $p < .001$, $\eta p^2 = .23$, was revealed to be due to the increase in error rates between positive and negative words $F(1,26) = 14.12$, $p < .004$. We did not find any other significant effects.

3.1.3. Valence effects in high-arousal words

For high arousal words, no significant effects of valence were observed in either the RTs or the error data.

3.1.4. Arousal effects in negative words

Response latencies were significantly influenced by the factor arousal, $F(2,52) = 9.71$, $p < .001$, $\eta p^2 = .27$. Negative words with high arousal received especially quick responses, the respective differences were significant with regard to low- ($F(1,26) = 13.75$, $p < .004$), and medium-arousal words ($F(1,26) = 14.84$, $p < .003$). The two latter conditions did not differ significantly. Consistently, in the error data, negative high arousal words showed less errors than the other two conditions, $F(2,52) = 8.23$, $p < .002$, $\eta p^2 = .24$. Respective effects were only significant in the post hoc analyses compared to low, $F(1,26) = 12.77$; $p < .005$, and to medium arousal $F(1,26) = 14.42$, $p < .004$; low and medium conditions did not differ significantly.

3.1.5. Arousal effects in positive words

No effects of arousal within positive words were obtained on response latencies or on error rates.

3.1.6. Arousal effects in neutral words

A significant effect of the arousal manipulation was given on response latencies to neutral words, $F(2,52) = 6.30$, $p < .005$, $\eta p^2 = .19$. Within neutral words, those with high arousal also received the quickest responses, followed by low and medium arousal conditions. Post hoc comparisons resulted significant when comparing medium to low $F(1,26) = 8.81$, $p < .02$, and high arousal conditions $F(1,26) = 10.96$, $p < .009$). No effect was obtained on error rates.

3.2. ERP data

3.2.1. Main effects of valence and arousal and their interaction

Results from ANOVAs over ERP amplitudes at posterior electrodes did not show any significant effects from 75 to 100 ms, all $Fs < 1$. In the time window 200–300 ms, only the effect of arousal was significant, $F(2,52) = 3.54$, $p = .036$, $\varepsilon = 1$, $\eta p^2 = .12$. Between 275 and 425 ms, we found significant effects of valence, $F(2,52) = 17.04$, $p < .001$, $\varepsilon = .91$, $\eta p^2 = .39$, arousal, $F(2,52) = 4.18$, $p = .022$, $\varepsilon = .96$, $\eta p^2 = .14$, and a significant interaction between the effects of both factors, $F(4,104) = 2.66$, $p = .05$, $\varepsilon = 1$, $\eta p^2 = .09$. In the interval 425–500 ms, the ANOVA over central electrodes also revealed effects of valence, $F(2,52) = 5.81$, $p = .005$, $\varepsilon = 1$, $\eta p^2 = .18$, and arousal, $F(2,52) = 2.14$, $p = .012$, $\varepsilon = .92$, $\eta p^2 = .16$. The two-way interaction was not significant.

Pairwise comparisons confirmed the visual impression (see Fig. 2A) of larger EPN amplitudes for positive relative to both neutral and negative words between 275 and 425 ms, $Fs(1,26) > 13.93$, $ps < .003$, $\eta p^2s > .35$, and for the LPC interval between 425 and 500 ms, $Fs(1,26) > 7.96$, $ps < .036$, $\eta p^2s > .23$. Negative and neutral words did not differ significantly in any time interval.

As represented in Fig. 2B, EPN amplitudes to high-arousal words were larger than to low-arousal words. This difference yielded a trend between 200 and 300 ms, $F(1,26) = 4.85$, $p = .064$, $\eta p^2 = .16$, but was significant between 275 and 425 ms $F(1,26) = 7.13$, $p = .039$, $\eta p^2 = .21$. At central electrodes this comparison was significant in both later time intervals, $Fs(1,26) > 7.12$, $ps < .039$, $\eta p^2s > .21$. The difference between high arousal and medium arousal was significant for the ROI-EPN in time windows 200–300 and 275–425 ms, $Fs(1,26) > 6.99$, $ps < .03$, $\eta p^2s > .21$, and was a trend for the ROI-LPC between 425 and 500 ms, $F(1,26) = 4.89$, $p = .11$, $\eta p^2 = .15$. Medium- and low-arousal words did not significantly differ in any interval.

The trend analyses revealed a significant linear trend for arousal effects in all time intervals between 200 and 500 ms, $Fs(1,26) > 4.85$, $ps < .05$, $\eta p^2 > .16$. Quadratic trends were not significant for arousal. For valence effects however, both quadratic, $Fs(1,26) > 3.92$, $ps < .05$, $\eta p^2 > .13$ and linear trends $Fs(1,26) > 7.96$, $ps < .01$, $\eta p^2 > .23$ reached significance.

To further explore the interactions between the effects of valence and arousal, as with behavioral responses, effects of valence were calculated separately within each level of arousal and vice versa (Fig. 3) for the EPN in the interval where significant two-way interactions had been obtained, i.e., 275–425 ms.

3.2.2. Valence effects in low-arousal words

For low-arousal words, the factor valence was significant at posterior electrodes $F(2,52) = 4.18$, $p = .021$, $\varepsilon = .99$, $\eta p^2 = .14$. Pair

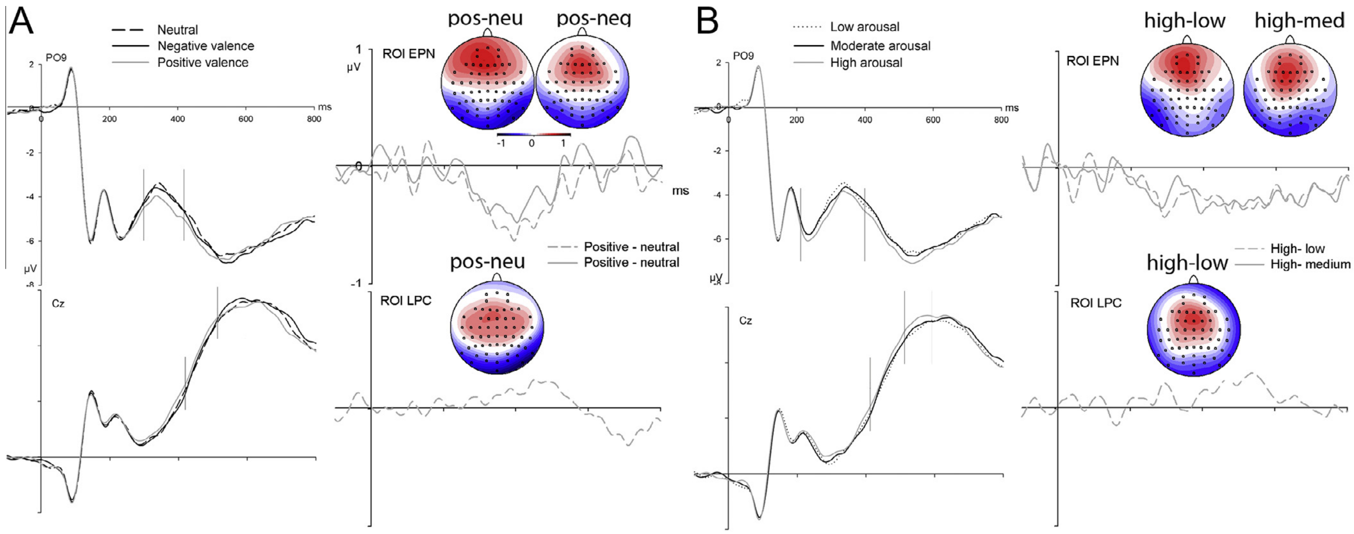

Fig. 2. (A) Valence effects collapsed across arousal levels for positive (pos) negative (neg) and neutral (neu) words. (B) Overall effects of arousal. Vertical bars show significant time windows represented in the topographies. All topographies have the same scale.

wise comparisons confirmed that positive words elicited a larger EPN than neutral words $F(1,26) = 9.60$, $p = .022$, $\eta p^2 = .27$. Differences between negative and neutral, or negative and positive were not statistically significant. However, as can be seen in Fig. 3, top panel, differences between negative and neutral words started somewhat later in time. To validate this visual impression, an additional ANOVA was calculated ad hoc for this comparison in a shorter time window, 375–425 ms. In this epoch, EPN amplitudes were enhanced for both positive and negative words in relation to neutral, $Fs(1,26) > 5.61$, $ps < .025$, $\eta p^2s > .18$.

3.2.3. Valence effects in medium-arousal words

For medium-arousal, valence effects were also significant, $F(2,52) = 16.27$, $p < .001$, $\varepsilon = 1$, $\eta p^2 = .38$, reflecting larger EPN amplitudes to positive than neutral and negative words $Fs(1,26) > 25.83$, $ps < .001$, $\eta p^2s = .50$. The comparison negative versus neutral was not significant.

3.2.4. Valence effects in high-arousal words

ERP amplitudes did not differ significantly between valence levels within high-arousal words.

3.2.5. Arousal effects in negative words

Fig. 3, bottom panel, depicts separate arousal effects for each condition of valence. For negative words, the factor arousal was significant $F(2,52) = 4.66$, $p = .045$, $\varepsilon = .96$, $\eta p^2 = .15$, reflecting larger EPN for high arousal in relation to medium arousal, $F(1,26) = 12.14$, $p = .006$, $\eta p^2 = .31$. Low and did not differ significantly high or medium arousal. Given the delay observed for valence effects in negative words of low arousal, we also analyzed here the time window 375–425 ms. Results showed no differences between high and low conditions, and a trend reflecting larger amplitudes for low-arousal conditions in relation to medium $F(1,26) = 5.42$, $p = .088$, $\eta p^2 = .17$.

3.2.6. Arousal effects in positive words

Arousal did not produce significant effects within positive words.

3.2.7. Arousal effects in neutral words

The ANOVA for neutral words revealed a marginally significant arousal effect across all three conditions, $F(2,52) = 3.15$, $p = .052$, $\varepsilon = 1$, $\eta p^2 = .11$, reflecting significantly larger EPN amplitudes for high-arousal in relation to both medium and low arousal conditions $Fs(1,26) > 4.62$, $ps < .041$, $\eta p^2 > .15$.

3.2.8. Additional analyses with emotion manipulation as in previous studies

As can be seen in Fig. 4, differences between emotional and neutral words were largest when comparing high-arousal emotional (positive or negative) to low-arousal neutral words, resembling the classical manipulation of emotional word content in most previous studies. Post hoc comparisons for this conjoint valence/arousal confirmed that both positive and negative high-arousal words elicited larger ERPs responses than neutral low-arousal words in both the EPN and LPC intervals, $Fs(1,26) > 5.40$, $ps < .05$, $\eta p^2s > 17$.

4. Discussion

Most previous studies on emotion effects in reading have compared positive and negative emotional words of high arousal with neutral words of low arousal (a review in Citron, 2012), assuming that this contrast best represents emotionality and matching the U-shaped distribution observed in ratings of affective stimuli (e.g., Bradley & Lang, 1999). In the present study we employed a full factorial design involving independent manipulations of the two emotional dimensions valence and arousal (with three distinct levels each) and increased the number of stimuli per condition as compared to previous studies. These improvements allowed us fine-grained estimations of emotion effects and their time course in visual word recognition.

4.1. Overall facilitation for positive valence and high arousal

Lexical decision responses in the present experiment were significantly faster for words of positive valence (compared to neutral and negative) and for words of high arousal (compared to medium and low), evidencing preferential processing of (1) positive and (2) exciting stimuli. Besides replicating the often reported processing advantage for positive stimuli, in this study, controlling for arousal when manipulating valence and vice versa we did not obtain a specific additional processing advantage for negative words (compared to neutral) reported in previous studies not controlling for

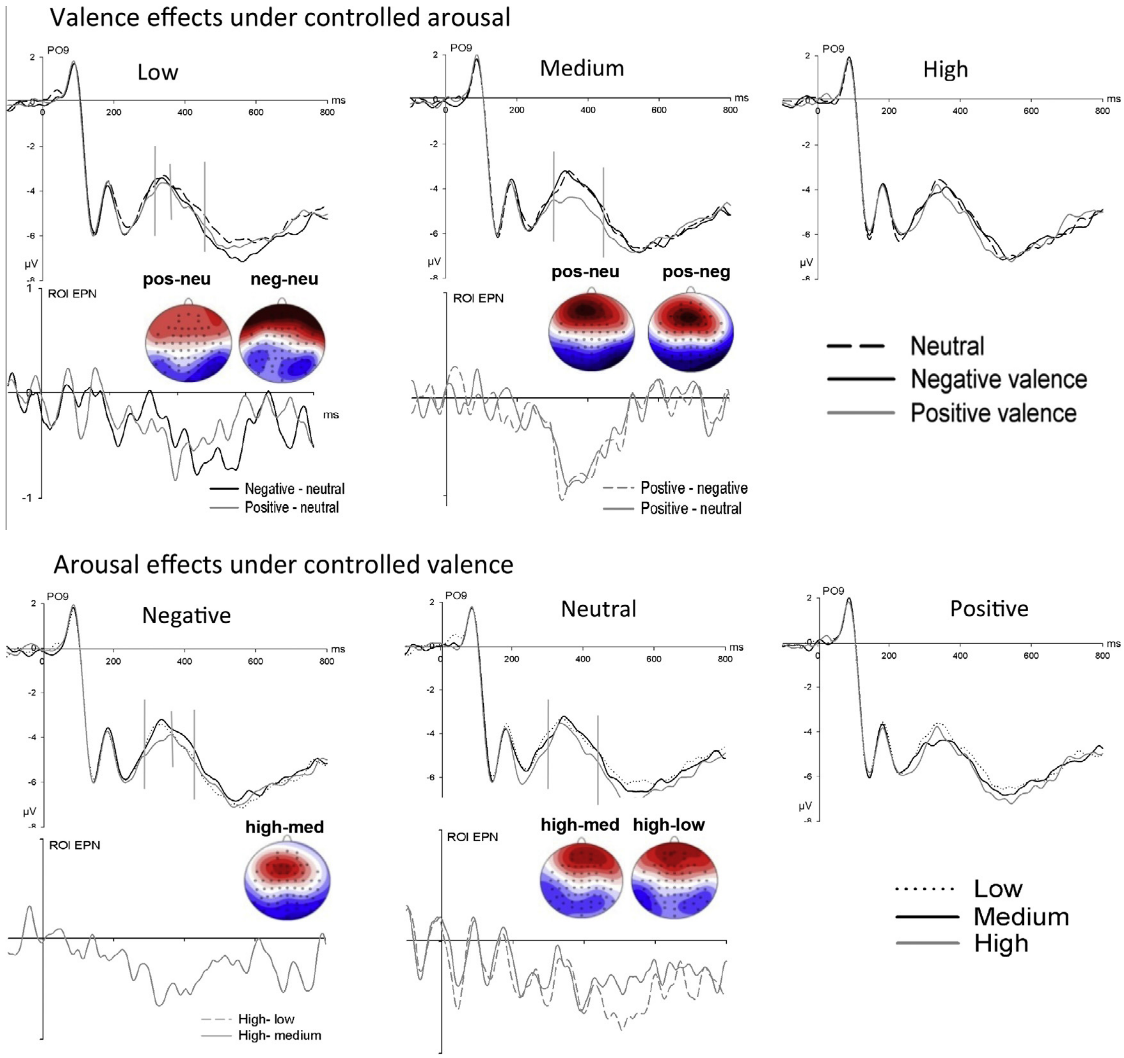

Fig. 3. Valence effects under controlled arousal and arousal (top panel), and arousal effect under controlled valence (bottom panel).

arousal between negative and neutral conditions (e.g., Citron et al., 2013; Conrad et al., 2011; Kousta et al., 2009). Still, in the present study, negative words with high arousal were also responded to faster than negative or neutral words with medium or low arousal. This leads to the conclusion that the processing advantage for negative over neutral material is due to respective differences in arousal. Consistently, the significant main effect for the factor arousal in our lexical decision data shows that arousal alone – when manipulated independently of valence – also speeds visual word recognition. Thus, our data show that both positive valence and high arousal are capable of speeding language processing when manipulated separately. Note that effects in the error data were always consistent with effects observed in reaction times, faster responses went together with increased accuracy, which makes the behavioral effects presented especially straightforward.

Congruent with our behavioral effects, the ERP data revealed larger EPN for both positive and high-arousal words relative to their respective control conditions on the same dimension, indicating enhanced visual processing and more efficient allocation of attention for these conditions. Regarding positive words, our data are in line with previous research where arousal had not been controlled for (e.g., Conrad et al., 2011; Herbert et al., 2006; Kissler et al., 2006; Schacht & Sommer, 2009a), and suggest a preference to process positive words, probably because they represent potentially rewarding events, i.e. a positivity bias. Concerning the opposite, a potential negativity bias, our data suggest that the larger EPN for negative relative to neutral words observed in some studies (e.g., Conrad et al., 2011) can be attributed to the generally increased arousal level of negative concepts (e.g., Schmidtke et al., 2014).

Indeed, the larger EPN amplitudes for high-arousal words indicate preferential visual processing for this condition. High arousal presumably triggers the mobilization of attentional resources, because it indicates events that are either highly enjoyable or potentially dangerous whereas words low in arousal often represent events in the environment that are less relevant (e.g., Bradley, Greenwald, Petry, & Lang, 1992).

Overall, this general facilitation for positive valence and high arousal in RTs and ERPs is in line with previous studies using sets of words involving – at least partially – mutual experimental control of both emotional dimensions (Bayer, Sommer, & Schacht, 2011; Bayer et al., 2012). Interestingly, our comprehensive 3 $\times$ 3 experimental design allowed us to observe that the enhanced visual processing does not further increase due to a change on the respective other dimension. Notably, no additional effects of arousal were obtained within positive words alone and, similarly, no valence effects were given within words of high arousal – in both the RT and the ERP data. It seems, thus, that either positive valence or high arousal alone, serve to enhance early visual processing while reading.

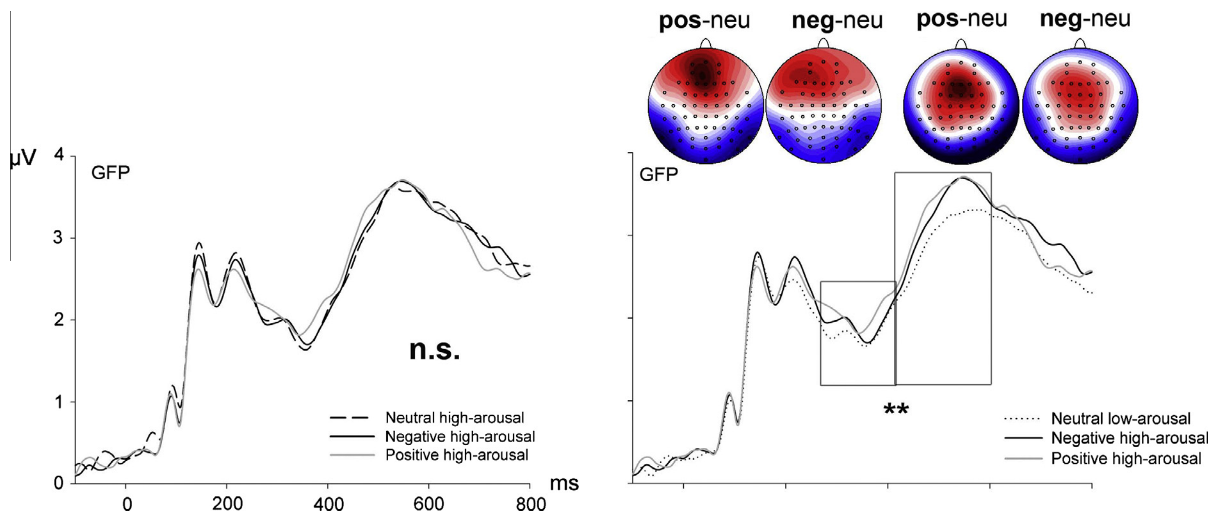

Fig. 4. Comparison of ERPs amplitudes, measured as global field power (GFP) for the comparisons emotional high-arousal versus neutral low-arousal (right panel) and versus neutral high-arousal (left panel).

The linear trend observed for effects of arousal suggests a unipolar structure for this dimension. Concerning valence, the quadratic trend indicates bipolarity (e.g., Briesemeister, Kuchinke, & Jacobs, 2012).

4.2. Time course and interactions of valence and arousal

Arousal effects in ERPs started at 200 ms, and were independent of valence in this early time window. Valence effects, on the other hand, started at around 275 ms and showed an interaction with arousal (also yielding significant main effects in this interval). This pattern of results is in accordance with the view of arousal as a valence-unspecific alerting system that operates at early stages of processing by triggering the allocation of attentional resources to prepare the organism for an evaluation of events in terms of pleasant/unpleasant and further emotional responses (e.g., Bradley & Lang, 1994; Kissler et al., 2006). Hence, arousal might not only modulate the intensity of an emotional reaction quantitatively, it rather seems to drive early visual processing, and the allocation of attentional resources, independently of valence. Concerning the time course of emotion effects in visual word recognition, our data, thus, point to different conclusions than the three steps (i.e., first valence, then arousal, and then the additive effect of both) proposed by Bayer et al. (2012).

4.2.1. Valence effects under controlled arousal

When arousal was controlled for, valence effects – reflecting a processing advantage for positive words – were present at low ($\eta p^2 = .14$) and larger in size at the medium level of arousal ($\eta p^2 = .38$), but were absent when arousal was high. The preferential processing of positive words at medium and low arousal levels observed in RT and ERP data between 275 and 425 ms is in line with the concept of a *positivity offset* suggesting that the approach system is activated when arousal is generally low (Cacioppo, 2004). Processing of positive words could be especially facilitated under these conditions, because such combinations are perceived as congruent (Citron et al., 2013; Robinson, 1998). However, in the case of low-arousal words, EPN amplitudes were increased not only for positive but also – somewhat delayed to the 375–425 ms interval – for negative words relative to neutral ones, suggesting enhanced visual processing of emotional words (both positive and negative) under these particular conditions. The EPN for negative low-arousal words suggests that respective concepts also receive enhanced visual processing at some moment during word recognition, despite being responded to more slowly. Indeed, negative words of low arousal might represent a very particular aspect of the affective space being typically related with depression, hopelessness or quiet suffering. The rather depressive appeal of semantic concepts of negative valence and low arousal seems, thus, to delay both responses in the lexical decision task and the EPN effect.

The absence of significant valence effects at high levels of arousal in our data is in contrast with the idea of a negativity bias in the processing of high arousal stimuli, observed in studies using emotional images and faces (e.g., Norris et al., 2010). The reduced affective reactivity in the autonomous nervous system for words relative to affective images or face-stimuli (Bayer et al., 2011) might explain the lack of a negativity bias within high-arousing words in our data. Hence, the symbolic nature of words representing concepts might reduce the specific negativity bias observed with other stimuli. This bias, that clearly serves a purpose in the context of natural environments, might disappear in conditions of visual word recognition where meaning is no longer directly grounded in physical stimulus proprieties.

4.2.2. Arousal effects under controlled valence

When valence was controlled for, arousal effects – as a processing advantage for high arousal – were present for the neutral ($\eta p^2 = .11$) and negative conditions ($\eta p^2 = .15$), but absent for positive words. The lack of arousal effects within positive valence conforms to data suggesting that the processing advantage for positive words is independent from arousal (Bayer et al., 2011).

The arousal effects observed for negative words in the EPN, further extended previous findings in very early components (Hofmann et al., 2009), demonstrating enhanced visual processing for negative words of high arousal. Note that concerning all single comparisons of arousal effects, the highest effects size ($\eta p^2 = .31$) was obtained when comparing negative high arousal to negative medium arousal words between 275 and 425 ms. These results are in line with the view that high arousal of negative concepts indicates a potential danger (e.g., Scott, O'Donnell, Leuthold, & Sereno, 2009). Again, low arousal negative words showed a somewhat delayed EPN in relation to medium arousal, indicating that they represent a special case within the two-dimensional emotion space, as they attract attention but do not trigger approach or speed up responses (e.g., Hofmann et al., 2009; Robinson et al., 2004).

Most importantly, and contradicting the view of arousal as a dimension that only modulates the intensity of valence, we also found arousal effects within neutral words evident in the larger EPN amplitudes for high-arousal relative to medium- and low-arousal words between 275 and 425 ms. This result reflects increased visual processing due to high arousal within neutral words, where emotional valence is not present.

4.2.3. Combination of arousal and valence: the U-shaped distribution

Behavioral results showed that the gain in visual processing for emotional as compared to neutral words was greater when valence was accompanied by increased arousal and that this processing advantage also held true for negative words. As shown in Fig. 4, differences in ERP amplitudes also increased notably when using these more extreme combinations of valence and arousal. ERPs were larger for both positive and negative words of high arousal when compared to neutral ones with low arousal in both EPN and LPC intervals, indicating additive effects of the two dimensions.

It should be noted, however, that the present design used variable stimulus presentation times as words disappeared from the screen with the response, overlapping with the LPC effects (typically between 450 and 600 ms). We therefore used a relatively small interval (425–500 ms) to address these effects in order to avoid potential confounds due to visual offset potentials. But since 25% of responses still fell into our selected time window, respective results should be interpreted with caution.

In our stimulus material, we did not control for age of acquisition of words, and future investigation regarding how this variable might contribute to a positivity bias in visual word recognition seems a useful enterprise (e.g., Citron et al., 2013; Kousta et al., 2009).

5. Conclusions

We observed a general preference to attend to positive words over negative and neutral ones regardless of their arousal, and to attend to high arousal words over medium and low arousal words regardless of their valence, evident in both RTs and ERPs. Our data further demonstrate that emotion effects are strongest when positive or negative valence combined with high values of arousal are compared to neutral valence combined with low arousal.

Regarding the time course of these effects, our results show that arousal effects starting as early as 200 ms after stimulus onset, preceding valence effects beginning 75 ms later. While reading words, arousal seems to prepare processing resources and attention for a subsequent evaluation in terms of valence. Arousal and valence effects were interactive between 275 and 400 ms, where processing of both dimensions appears then to be integrated.

Our results for negative words display an interesting pattern. We could not replicate a general processing advantage for negative over neutral words as suggested by previous reports (e.g. Citron et al., 2013; Conrad et al., 2011; Kousta et al., 2009). However, once we controlled for arousal, our results show faster responses and enhanced visual processing as shown in the EPN for words of negative valence and high arousal (compared to negative/medium- or neutral/ low-arousal words), presumably due to the potential danger represented by this combination. ERPs, interestingly show enhanced visual processing also for words of negative valence and low arousal, though accompanied by slower RTs.

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