Emotionally positive stimuli facilitate lexical decisions—An ERP study

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The influence of briefly presented positive and negative emotional pictures on lexical decisions on positive, negative and neutral words or pseudowords was investigated. Behavioural reactions were the fastest following all positive stimuli and most accurate for positive words. Stimulus-locked ERPs revealed enhanced early posterior and late parietal attention effects following positive pictures. A small neural affective priming effect was reflected by P3 modulation, indicating more attention allocation to affectively incongruent prime-target pairs. N400 was insensitive to emotion. Response-locked ERPs revealed an early fronto-central negativity from 480 ms before reactions to positive words. It was generated in both fronto-central and extra-striate visual areas, demonstrating a contribution of perceptual and, notably, motor preparation processes. Thus, no behavioural and little neural evidence for congruency-driven affective priming with emotional pictures was found, but positive stimuli generally facilitated lexical decisions, not only enhancing perception, but also acting rapidly on response preparation and by-passing full semantic analysis.

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1. Introduction

Emotions prepare the organism to react rapidly to the environment via two motivational systems, an appetitive system that responds to positive valence and a defensive system responding to negative valence. Arousal indicates the degree to which either system is activated. Each system interconnects appropriate episodic and semantic memory contents, physiological reactions, and action programs (Lang et al., 1998). Thus, emotions will affect different stages of information processing, ranging from attentional engagement to action preparation and execution.

Many electrophysiological studies confirm enhanced implicit attention allocation to various kinds of emotional stimuli reflected in modulations of early and late attention-related ERPs (Kissler et al., 2009; Pourtois and Vuilleumier, 2006; Schupp et al., 2006). Facilitated behavioural responses to emotional stimuli have also been described in detection (Anderson and Phelps, 2001; Brosch et al., 2007; Zeelenberg et al., 2006), evaluation (Estes and Verges, 2008), or choice reaction tasks (Estes and Adelman, 2008; Scott et al., 2009).

Response facilitation by emotional stimuli is uncontroversial, but it is debated, whether valence or arousal drives this advantage. Whereas some studies reveal faster reactions to arousing stimuli regardless of valence (Kousta et al., 2009; Larsen et al., 2006), other studies indicate speeded detection of negative emotional stimuli (Öhman et al., 2001) and yet others find accelerated responses to positive stimuli (Leppänen and Hietanen, 2004). Faster responses to positive stimuli are observed in linguistic tasks, such as color naming (Mckenna and Sharma, 1995; Williams et al., 1996), word naming (Algom et al., 2004; Estes and Adelman, 2008), and lexical decision (Estes and Adelman, 2008; Wentura et al., 2000). In general, faster responses to positive stimuli appear to occur primarily on tasks, where valence is not task-relevant (Estes and Verges, 2008). This has been attributed to slower attentional disengagement from negative stimuli, leading to motor response suppression (e.g. Estes and Adelman, 2008).

Emotional relevance affects responses not only to current, but also to subsequent emotional information. This phenomenon is called affective priming (Fazio et al., 1986): People are generally faster to judge the affective connotation of a target word (e.g. “APPEALING”) when it is preceded by a same-valence prime (e.g. “PARTY”) than by an affectively incongruent prime (e.g. “GUN”). The affective priming paradigm is well-established with evaluative decision, lexical decision, or naming as target tasks (see Klauer and Musch, 2003 for an overview). Both spreading activation in semantic networks and priming of response tendencies have been suggested as underlying mechanisms. Response tendencies are supposed to be primed mainly in evaluative decisions and semantic memory is thought to be pre-activated in lexical decisions. However, more recent reports suggest an interaction...
of these processes (Spruyt et al., 2007a,b), response tendencies also affecting the lexical decision task (see Wentura, 2000). Word stimuli are most common, but affective priming has also been reported for emotional faces (Haneda et al., 2003; Murphy and Zajonc, 1993; Rotteveel et al., 2001; Spruyt et al., 2004), real-life situations (Spruyt et al., 2007b), black-and-white line drawings (Giner–Sorolla et al., 1999) or voice–face pairings (Paulmann and Pell, 2010). Generally, affective priming is most clearly seen with SOAs shorter than 300 ms, longer SOAs abolish or reverse the effect (Klauer and Musch, 2003).

Several ERP studies have investigated affective priming, and in line with a spreading activation account many of them focused on the N400, a sensitive and reliable indicator of semantic relatedness (Holcomb, 1993; see Kutas and Federmeier, 2000 for an overview; Rösler and Hahne, 1992); N400 amplitude increases with semantic distance and reflects difficulty of semantic integration and search processes in the mental lexicon (Kutas and Federmeier, 2000; Rösler and Hahne, 1992; Supp et al., 2004). It is particularly large for phonotactically legal pseudowords (e.g. Federmeier et al., 2000; Holcomb, 1993; Supp et al., 2004; Ziegler et al., 1997). The N400 can be elicited cross-modally, reflecting the degree to which primes and targets access similar underlying semantic networks, independent of their physical similarity (for review, see Kutas and Federmeier, 2009). N400 effects have been obtained with pictorial primes and targets (McPherson and Holcomb, 1999), written primes and pictorial targets (Federmeier and Kutas, 2002; Wicha et al., 2003), or picture primes and word targets (Connolly et al., 1995). N400 is a more sensitive indicator of semantic priming than reaction time (Heil et al., 2004).

N400 also appears to index affective priming. Schirmer et al. (2002) reported that at least in females the N400 amplitude elicited by emotional words in lexical decision is influenced by the prosody of a preceding sentence. Paulmann and Pell (2010) found N400 modulation by voice prime prosody in a facial affect decision task. Bostanov and Kotchoubey (2004), presented emotional exclamations (e.g. “Yeah!” and “Oooh!”) after emotion words. This elicited a larger N400 for contextually inappropriate than to appropriate emotional exclamations. Affectively congruent music also primes lexical decisions and modulates the N400 (Steinbeis and Koelsch, 2009). These data indicate a wide replicability of affective priming and imply spreading activation as an important mechanism.

However, other studies report more variable patterns: investigating how emotional faces prime decisions on subsequent emotional facial expressions, Werheid and colleagues found ERP priming effects on early and late attention and emotion ERPs, but not on the N400 (Werheid et al., 2005a,b). This presumably reflects perceptual and attentional facilitation, but not spreading activation. Subliminally priming facial affect ratings, Li et al. (2008) also found effects on the P1 and P3a components, early (Pourtotis and Vuilleumier, 2006) and late (Cuthbert et al., 2000) indicators of attentional orienting.

Finally, studies examining the effects of pictures from the International Affective Picture System (IAPS, Lang et al., 1999) on the cortical processing of subsequent emotional information found no evidence at all for affective priming: Flaisch and colleagues, paired picture primes with picture targets and found interference of emotional primes with processing of subsequent pictures. This was evidenced in reduced target-related early posterior negativities (EPNs) and late positive potentials (LPs), but not in congruency effects (Flaisch et al., 2008a,b). Zhang et al. (2006) compared affective priming of emotionally congruent and incongruent word–word and picture–word pairs in an evaluative decision task. Neural congruency effects were observed only for the word–word and not for the picture–word pairings. For the word–word, but not for the picture–word pairs, N400 modulations in the affectively congruent condition were found. Since in the evaluation task spreading activation as reflected in N400 modulations is theoretically not the most prevalent account, the stimulus-locked analysis may have missed electrophysiological indices of response preparation that could have occurred in this design. On the other hand, two other studies using emotional pictures as primes also fail to find ERP evidence of affective priming. Given that these emotional pictures otherwise very reliably modulate brain responses (e.g. Cutather et al., 2000; for review Schupp et al., 2006), the affective priming phenomenon may not be as domain general as sometimes assumed. Thus, many studies find affective priming effects on the N400 and some report effects on other ERP components, but yet others using the otherwise so potent IAPS pictures report no priming effects at all.

Here, we investigate affective priming of lexical decisions by emotional IAPS pictures, analyzing both stimulus- and response-related ERPs. Thus, we address the domain generality of affective priming and test response facilitation by affective stimuli. ERP studies of affective priming often focus on the N400 impact as assumed spreading activation as the underlying mechanism. However, other ERP effects have also been found and the behavioural literature implies that affective priming impacts also response preparation (Spruyt et al., 2007a,b). Therefore, we analyze response- as well as target-related ERPs. By examining response preparation preceding emotional stimuli, facilitation of motor responses by emotional stimuli can be investigated regardless of affective priming.

Motor preparation is more prominent in the response-locked than in the stimulus-locked ERP (Nieuwenhuis et al., 2003). Response-locked analysis has been used to investigate volitional motor preparation (Kornhuber and Deecke, 1965), mechanisms of visual search (Luck and Hillyard, 1990), and action monitoring (for review see Taylor et al., 2007). Early studies suggest that attention and motivation can affect response reparation (Elbert et al., 1984, 1985; Kornhuber and Deecke, 1965). More recently, an emotion effect on action monitoring has been demonstrated in response locked ERPs (Simon-Thomas and Knight, 2005). Thus, response facilitation by emotional stimuli in general and in affective priming in particular would suggest that effects may be evident in pre-response ERPs.

Positive or negative pictures from the International Affective Picture System (IAPS) are used as primes, and positive, negative, and neutral adjectives or ‘pseudo-adjectives’ serve as targets in a lexical decision task. Primes and targets were chosen such that prime–target pairs matched in emotional, conduct, but differed semantically to avoid covert semantic priming as a potential source of effects. For instance, a crime scene could be followed by the German word for ‘narrow-minded’, or a mutilated body was followed by the word ‘greedy’. Similarly, a sports scene could be followed by the word ‘erotic’, and a happy family scene by the word ‘successful’.

Reaction time, response accuracy, and stimulus- and response-related ERPs are assessed. If affective priming is a domain-general phenomenon on behavioural and ERP congruency effects should occur. ERP effects may become apparent on the N400, if affective priming uses similar mechanisms as semantic priming. If affective priming affects response preparation, ERP effects should occur in response-locked ERPs. However, affective priming may also modulate perception- and attention-related ERPs. Finally, IAPS pictures might not prime lexical decisions after all, in which case emotional stimuli should still affect behavioural reactions and cortical processing in the absence of congruency effects. Given the evidence for facilitated reactions to positive stimuli in lexical decisions, accelerated responses to positive stimuli can be expected. Such effects should be reflected in response-locked ERPs. To address the above possibilities fully, a data-driven approach to EEG analysis is used to identify relevant time windows and regions of interest.
Table 1  
Mean pleasure and arousal ratings of picture and word stimuli. Additionally, word length and word frequency (based on counts for written German language from the CELEX database) are given for adjectives. The range and direction of the SAM ratings are as follows: pleasure = 9 (extremely positive) to 1 (extremely negative), arousal = 9 (extremely arousing) to 1 (not at all arousing). Standard errors are given in parentheses.

<table>
<thead>
<tr>
<th>Adjectives</th>
<th>Positive</th>
<th>Negative</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valence</td>
<td>6.70 (0.11)</td>
<td>2.80 (0.07)</td>
<td>4.94 (0.08)</td>
</tr>
<tr>
<td>Arousal</td>
<td>5.34 (0.11)</td>
<td>5.41 (0.13)</td>
<td>3.68 (0.10)</td>
</tr>
<tr>
<td>Word length (letters)</td>
<td>8.21 (0.29)</td>
<td>8.14 (0.28)</td>
<td>7.88 (0.27)</td>
</tr>
<tr>
<td>Word frequency (per million)</td>
<td>31.50 (7.63)</td>
<td>18.83 (4.19)</td>
<td>24.86 (4.59)</td>
</tr>
</tbody>
</table>

2. Methods

2.1. Participants

Sixteen native German students (8 women) from the University of Konstanz, Germany, took part in the experiment. Mean age was 23.56 (SE = .62) years and all were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). They had no history of neurological or psychiatric disease and their vision was normal or corrected to normal. Subjects signed written informed consent forms and received either a financial bonus of 12 € (≈18 $) or course credit for their participation.

2.2. Material

Primes consisted of 58 positive and 58 negative pictures from the International Affective Picture System (IAPS, Lang et al., 1999). The pictures were selected on the basis of their normative Self-Assessment Manikin (SAM, Bradley and Lang, 1994) ratings of arousal and pleasantness (valence). Selected pictures did not differ in terms of arousal (F(1,114) = 1) or complexity as measured by JPG size (F(1,114) = 1), but differed in terms of valence (F(1,114) = 2062.51; p < .0001). Mean SAM ratings of the selected positive and negative pictures are given in Table 1.

For the lexical decision task 58 positive, 58 negative, and 58 neutral adjectives were chosen from a pool of 500 German adjectives that had also been rated on the dimensions of arousal and valence using a computerized version of SAM (Bradley and Lang, 1994) by 45 students. Different subsets from this material have been used in previous studies (Herbert et al., 2006, 2008; Kissler et al., 2007, 2009). Positive, negative, and neutral adjectives differed significantly from each other with respect to valence (F(2,171) = 496.25; p < .001; negative vs. positive: F(1,114) = 908.18; p < .001; positive vs. neutral: F(1,114) = 176.39; p < .001; negative vs. neutral: F(1,114) = 383.32; p < .001). Positive and negative adjectives were matched for arousal (F(1,114) = 1), but both differed from neutral adjectives on that dimension (F(2,171) = 77.09; p < .001; negative vs. neutral: F(1,114) = 115.12; p < .001; positive vs. neutral: F(1,114) = 128.38; p < .001).

Further, adjectives were chosen to be comparable in word length (F(2,171) < 1), number of syllables (F(2,171) < 1) and word frequency (F(2,171) = 1.24; p = .29). Word frequency data were obtained from the standardized word-database CELEX (Baayen et al., 1995). See Table 1 for a summary of stimulus characteristics.

Pseudowords were based on the 174 original adjectives and were generated by letter permutations within and between words to preclude perceptual repair and at the same time maintain pronounceability. Original word length was never altered.

2.3. Procedure

Participants were familiarized with the laboratory and given general information about the study. Handedness was assessed (Oldfield, 1971) and subjects were asked about their past and current health using a standardized questionnaire.

Participants were seated in an electrically shielded room and 64 EEG electrodes were attached to their head. They were informed that they were taking part in a word processing study and that their task was to indicate by mouse click as quickly and as accurately as possible if a presented word was a legal German word or a pseudoword. They were told that pictures would briefly appear before each word (pseudoword), which they should disregard. Additionally, a written instruction was presented on the monitor. Assignment of response buttons to the index or middle finger of the right hand was counter-balanced.

696 picture–word pairs were presented on a computer monitor at a distance of 1.25 m. Presentation was divided into two blocks of 348 trials with a break between the blocks. In a 2 (pictures: valence: positive, negative) × 4 (word type: positive, neutral, negative, pseudoword) design, positive and negative pictures were followed by words of each valence or pseudowords. Picture–word pairs had been generated randomly, but pairings and order of presentation were fixed for all participants. Immediate repetitions of pictures or words (pseudowords) in two successive trials and semantic relatedness between picture and word were avoided.

Every trial started with a fixation cross shown for a random interval of 1500–2000 ms, a picture followed for 100 ms and was replaced by a word or pseudoword for another 300 ms. Then, a question mark was shown for 1000 ms which cued participants to react to the words (pseudowords) as quickly and as accurately as possible. The experimental setup is depicted in Fig. 1.

2.4. EEG recording

EEG was recorded from 64 channels referenced to Cz, using an EasyCap and NEU-ROSCAN Synamps amplifiers and software. Recording bandwidth was DC to 70Hz and sampling rate was 250 Hz. Recording impedance was held beneath 5 kΩ. Offline, data were re-referenced to an average reference and low-pass filtered at 30 Hz. For artifact control horizontal and vertical electrooculograms were recorded. Eye movement artifacts and blinks were corrected using the ocular correction algorithm implemented in BESA (Brain Electrical Source Analysis, MEGIS Software GmbH). Gross remaining artifacts were reduced by individual channel-interpolation, individual epochs containing smaller artifacts were rejected (max. 10%).

2.5. Stimulus locked data

For stimulus-locked averaging, filtered data were segmented from 100 ms before picture onset until 800 ms after target (word/pseudoword) onset and baseline corrected using 100 ms prime picture onset as baseline.

2.6. Response locked data

For response-locked averaging, filtered data were analyzed from 800 ms before the motor-response (word–nonword button press decision) to 200 ms after the response. An epoch of 1600–1500 ms before the response served as the baseline.

3. Data analysis

3.1. Behavioural data – lexical decision performance and response correctness

Reaction times and correctness of lexical decisions were analyzed with repeated measures ANOVAs with picture type (positive, negative) and word type (positive, negative, neutral, pseudoword)
as factors. For post-hoc analysis Fisher’s Least Significant Difference Test was used.

3.2. ERPs

In order to statistically test for priming and response facilitation effects, a two-stage analysis procedure was applied: First, a point-wise ANOVA including all experimental factors (picture type, word type), time-points, and EEG sensors was computed. Based on the results, regions and time-intervals of interest were identified in which experimental effects could be expected. For the point-wise ANOVA, a significance criterion of \( p < .01 \) was used. Furthermore, to avoid spurious results, only effects in regions consisting of at least 8 neighboring electrodes and within time-intervals of at least 28 ms were considered meaningful. In the second step, based on the results of this exploratory analysis, electrodes belonging to one region and time window were grouped together and submitted to repeated measure ANOVAs containing the factors picture type (positive, negative) and word type (positive, negative, neutral, pseudowords). Significant main effects and interactions in the identified regions of interest were followed up with Fisher’s Least Significant Difference tests. Statistical analysis of ERPs was carried out with the MatLab-based open source software EMEGS (ElectroMagnetic-EncephaloGraphy; www.emegs.org). Because in total three times as many pseudowords as proper words were presented during the experiment, for each subject only the first 58 pseudowords were averaged and entered into the analysis to obtain an equal number of averages for each stimulus type. The order of pseudoword presentations was random for each subject.

4. Results

4.1. Reaction times

Reaction times for the lexical decisions are shown in Figs. 2 and 3. Subjects responded significantly faster when positive pictures than when negative pictures preceded the words or pseudo-words (prime picture, \( F(1,15) = 8.15; p < .05 \), see Fig. 2). Also, participants reached their lexical decision soonest, when positive adjectives were presented and reacted slowest to pseudowords (target word, \( F(3,45) = 9.21; p < .0001 \), see Fig. 3). Post-hoc tests showed that reaction times to positive words were in tendency faster than reactions to negative words (\( p = .06 \)) and significantly faster than reactions to neutral words (\( p < .01 \)) and pseudowords (\( p < .01 \)). Further, negative words were classified faster than pseudowords (\( p < .01 \)), but not neutral words. The interaction between picture type and word type was far from significant (prime \( \times \) target, \( F(3,45) < 1 \)).
4.2. Response accuracy

Regarding response accuracy, a main effect of word type (target word, $F(3,45) = 4.72; p < .01$) was found. Prime picture type ($F(1,15) < 1$) and the interaction between prime and target ($F(3,45) < 1$) did not reach significance. Fewer errors were made when responding to positive adjectives in comparison with neutral adjectives ($p < .001$), pseudowords ($p < .05$) and in tendency also negative adjectives ($p < .08$). Most errors were made to neutral adjectives.

5. ERP results

5.1. Stimulus-locked analysis

Fig. 4 displays the temporal evolution and spatial distribution of significant effects of prime, target and the prime × target interaction in the stimulus-locked analysis. These effects are described and analyzed in more detail in the following.

5.2. Prime type

Two time-windows where prime valence affected the target-evoked ERP were identified: between 216 and 248 ms after target on-set an effect of prime type emerged at frontal and left occipito-parietal electrodes corresponding to the often described EPN effect.

At an occipito-parietal group of 8 electrodes (Oz, O1, O2, O7, O9, O10, PO9, and PO10), ERPs associated with positive primes were more negative-going than ERPs associated with negative primes ($F(1,15) = 22.2; p < .001$). A complimentary effect was found at 8 frontal sensors (AF3, AF4, AF7, AF8, FP1, FP2, and Fp1), revealing a larger positivity following positive than following negative pictures ($F(1,15) = 13.65$). Between 324 and 428 ms, a further effect of prime type was found at centro-parietal sites, corresponding to an LPP effect (see Fig. 5). This effect was further analyzed at a group of 8 parietal electrodes (PO1, PO2, P1, P2, P3, P4, Pz, and CPz), yielding a larger positivity following positive primes ($F(1,15) = 21.89, p < .001$). The prime-related ERP effects are visualized in the top row of Fig. 5.

5.3. Target type

As evident from Fig. 4 and the bottom row of Fig. 5, a target-related fronto-central effect emerged, starting at 320 ms. This effect was further analyzed in an early fronto-central and a later centro-parietal time window. It corresponded to the frontal and parietal portions of the N400 effect. Between 320 and 444 ms after word (pseudoword) onset, the target-evoked early fronto-central N400 effect was analyzed at a cluster of eight fronto-central electrodes (FZ, FCz, F1, F2, FC3, FC4, F5, and F6). This analysis yielded a significant main effect of Target ($F(3,45) = 9.68; p < .001$) which was due to the fact that pseudowords were associated with a larger negativity.
Fig. 5. Difference topographies and ERP waveforms at individual sensors illustrating follow-ups of significant effects in the stimulus-locked analysis. Top left shows the early effect due to positive prime pictures which led to a relatively more negative waveform and scalp topography between 218 and 248 ms after word on-set. Top right is the late positivity effect due to positive prime pictures. The bottom row depicts the earlier frontal and later centro-parietal portions of the N400 effect which showed differentiation between words and pseudowords, but no modulation by emotion. Target on-set is at 0 ms.

than all real words, regardless of word valence (all \( p < .001 \)). Word ERPs did not differ according to valence (all \( p > .2 \)).

Between 384 and 572 ms after word (pseudoword) onset, the later, parietal portions of this process were analyzed at a cluster of eight centro-parietal electrodes (C1, C2, CPz, CP3, CP4, P1, P2, and Pz). Again, this analysis yielded a main effect of Target (\( F(3,45) = 15.42; p < .001 \)) which was due to the fact that pseudowords were associated with a larger negativity than all words, regardless of word valence (all \( p < .001 \)). Words did not differ from each other according to valence (all \( p > .2 \)).

5.4. Prime \( \times \) target interaction

A spatially and temporally restricted prime \( \times \) target interaction emerged in a centro-parietal region between 320 and 352 ms after target on-set. It was further analyzed at a group of eight centro-parietal electrodes (CP3, CP4, CP5, CP6, CP1, P1, P2, and Pz). The prime \( \times \) target interaction (\( F(3,45) = 6.04; p < .01 \)) was due to less positive ERPs to affectively congruent, than affectively incongruent prime-target pairs. Positive–positive pairings differed from positive–negative ones (\( p < .01 \)) as well as from negative–positive ones (\( p < .05 \)). Negative–negative pairings were associated with a smaller positive potential than positive–negative pairings (\( p < .01 \)) and in tendency also smaller than negative–positive pairings (\( p < .06 \)). This effect is visualized in Fig. 6.

5.5. Response-locked analysis

Fig. 7 displays the temporal evolution and spatial distribution of significant effects of prime, target and the prime \( \times \) target interaction in the response-locked analysis. No clear spatially or temporally stable prime \( \times \) target interactions were found in the response-locked analysis. However, as evident from Fig. 7, an effect of prime emerged between 320 and 292 ms before the response. Target-related effects emerged in the response locked data between 480 and 388 ms before the response and from 288 to 68 ms pre-response. These effects were further analyzed as detailed in the following.

5.6. Prime

Between 320 and 290 ms pre-response a main effect of prime valence (\( F(1,15) = 8.56; p = .01 \)) was identified at a group of nine parietal sensors (PO1, PO2, P1, P2, P3, P4, P7, P8, and Pz). The effect was due to the fact that in parietal regions positive primes were associated with more positive going ERPs than negative primes. This effect likely resembles the above described prime-related parietal positivity.

5.7. Target

Between 480 and 388 ms before the response a main effect of target type was identified (\( F(3,45) = 6.72, p < .01 \)), which was veri-
Stimulus-Locked Analysis

Prime X Target
320 - 352 ms

Incongruent Words – Congruent Words

Fig. 6. Interaction of prime and target valence between 320 and 352 ms after target on-set at parietal scalp sites. The difference topography is shown on the left, the time course of the activity is illustrated at centro-parietal sensor CPz.

Effied at a group of eight fronto-central electrodes (F1, F2, FC3, FC4, FCz, C1, C2, and Cz). It turned out to be due to the fact that positive targets were associated with more negative brain potentials than pseudoword targets \((p < .01)\) and in tendency also negative targets \((p < .1)\).

Finally, between 288 and 96 ms pre-response a last effect of target type emerged. The nature of this effect was evaluated at a slightly left-lateralized group of eight parietal electrodes (CP3, CP5, P1, P2, P3, Pz, PO1, and PO2). Pre-response ERPs differed depending on the target type (target, \(F(3,45) = 10.33; p < .001\)). This was due to more positivity preceding responses to words, regardless of their valence, than to pseudowords (all \(p < .05\)). The effect of Prime \((F(1,15) = .16; p = .7)\) and the target \(\times\) prime interaction \((F(3,45) = .65; p = .59)\) were not significant.

In order to facilitate interpretation of these response-locked effects as due to response preparation or perceptual target processing, the sources of the effects were approximated using the L2-Minimum-Norm-Pseudoinverse method (L2-MNP, Hamalainen and Ilmoniemi, 1994). L2-MNP is an inverse modeling technique applied to reconstruct the topography of the primary current underlying the electric current distribution. The L2-MNP allows the estimation of distributed neural network activity without a priori assumptions regarding the location and/or number of current sources (Hamalainen and Ilmoniemi, 1994). In addition, of all possible generator sources only those exclusively determined by the measured electric current are considered. Four concentric spherical shells with evenly distributed 3 (azimuthal, polar, and radial direction) \(\times\) 360 dipoles were used as source model. A Tikhonov regularization parameter \(k\) of 0.02 was applied. For visualization purposes, the estimated sources were projected onto the surface of an averaged brain (Montreal Brain, Montreal Neurological Institute) as implemented in EMEGS.

Fig. 8 shows the ERP time course at selected sensors, the topographical differences, and the source localizations for the early \((480–388 \text{ ms pre-response, top row})\) and the later pre-response target effect \((288–96 \text{ ms pre-response, bottom row})\). The results suggest that both effects are attributable to enhanced activity in perception and attention, but notably also motor systems, contributing to motor-response preparation.

6. Discussion

This study investigated accuracy, reaction times, and stimulus and response-locked ERPs in a picture-word affective priming experiment using the lexical decision task. Behaviourally, we observed no congruency effects indicative of affective priming. Instead, facilitation for positive stimuli was found. First, presentation of positive pictures accelerated subjects’ reactions in the subsequent lexical decision. Second, subjects’ lexical decisions were fastest in response to positive words. Both positive and negative emotional adjectives were responded to faster than pseudowords, but the advantage was largest for positive adjectives.
Positive, but not negative adjectives, were responded to faster than neutral ones and in tendency positive adjectives were also responded to faster than negative ones. Third, participants made fewest errors when responding to positive adjectives. In lexical decision, a number of previous studies found faster reactions to positive words (Estes and Adelman, 2008; Kiehl et al., 1999; Wentura et al., 2000), which has been theoretically ascribed to delayed disengagement from and motor suppression by negative stimuli. While the present results confirm fastest lexical decisions following positive stimuli, they are not in line with a motor suppression account. Motor suppression suggests a ‘freezing-like’ response which would predict slowed reactions to negative in comparison to neutral stimuli. While the present pattern of results suggests specific facilitation for positive stimuli compared to neutral ones. Responses to negative and neutral words did not differ significantly, but numerically responses to negative words were faster.

Accelerated responses to positive stimuli may be contributed to by the response movement required. Neumann and Strack (2000) investigated the interaction between emotional content and approach or avoidance movements across several tasks including lexical decision and found response facilitation in particular when subjects had the impression of approaching a positive word. Button-press as an approach-movement may thus promote response facilitation for positive stimuli. The independent effect of prime picture valence may likewise be due to accelerated responses to positive stimuli on tasks where valence is not task relevant. Outside lexical decision, a response advantage for positive stimuli has for instance been found in face or picture recognition (Kissler and Hauswald, 2008; Leppänen and Hietanen, 2004)

The neurophysiological data largely parallel the behavioural pattern. In the stimulus-locked data, enhanced processing of positive stimuli was found, but only little evidence for congruency effects indicative of affective priming emerged. Positive prime pictures had numerically relatively small, but quite consistent and significant effects on the processing of all types of target stimuli around 220 ms and between about 320 and 420 after target on-set. Regarding timing and topography the effects resemble the previously described early posterior negativity and the late positive potential, respectively. In passive picture viewing, both these components are usually considerably larger for emotionally arousing in comparison to neutral stimuli, regardless of valence. However, the advantage is somewhat greater for positive than for negative pictures, even when these are matched for arousal (Cuthbert et al., 2000; Flaisch et al., 2008b; Kissler and Hauswald, 2008; Palomba et al., 1997; Schupp et al., 2003). The current task may have accentuated this advantage for positive stimuli. This is open to future research.

ERPs have been shown to be more sensitive measures of priming than reaction times (Heil et al., 2004) and indeed, a small congruency effect was found over parietal brain areas. However, this effect was not reflected in overt behaviour. Based on the timing,
Response-Locked Analysis

Target Effects

Fig. 8. Top row: early pre-response effect of target valence. A more pronounced fronto-central pre-target negativity is illustrated at representative sensor Cz (left). The difference topography is shown in the mid-panel and the source localization of the difference potential is shown on the right. The bottom row shows a late pre-response effect of target type (words vs. pseudowords). It is illustrated at a left centro-parietal sensor (far left) and the spatial extent of the difference is shown in the middle. The right panel depicts the source localization of the difference potential.

topography and direction of ERP amplitudes, it seems that in a small and restricted time window, processing of affectively congruent prime-target pairs consumed less attentional resources than affectively incongruent prime-target pairs as reflected in a smaller parietal positivity perhaps resembling the P3a. For facial expressions, a P3a priming effect has been reported by Li et al. (2008).

On the N400, which under a spreading activation account should have been particularly sensitive to affective priming, the well-known pseudoword effect was predominant. Although the N400 could be clearly identified in the data (see Figs. 4 and 5), no modulation by either prime or target valence, or an interaction thereof, appeared. Two different sub-processes of N400 were identified, a frontal and a centro-parietal one, which did not differ functionally. Although early studies characterized the N400 as having primarily a centro-parietal distribution, later studies showed that, although the distribution is generally broad, it is often more frontal for concrete words and pictures (Ganis and Kutas, 2003; Kounios and Holcomb, 1994) as well as in single word presentations (Herbert et al., 2008). This pattern has been only recently validated directly (Voss and Federmeier, 2010). Whereas some authors suggest that frontal N400 potentials specifically reflect familiarity effects in recognition memory rather than priming (Nyhus and Curran, 2009), in line with the present data, Voss and Federmeier (2010) in a direct comparison found no functional differences between the frontal and the centro-parietal N400.

The response-locked ERPs also revealed specific effects for positive stimuli. A small effect of positive primes, based on its timing and topography, probably mirrored the prime-induced late positive potential already evident in the stimulus-locked data. Of note, in the pre-response data, a fronto-central negativity was larger preceding reactions to positive words than to pseudowords, and in tendency also negative words. This effect occurred between 480 and 380 ms before the response was made (i.e. starting about 150 ms after target onset) and was later followed by a general response facilitation effect for words compared to pseudowords which activated similar brain areas. The topography and generator distribution of the earlier effect suggest that it reflects perceptual and attentional enhancement, but, notably also response facilitation. Early perceptual and attentional enhancement effects of emotional content in word processing have been reported (Hofmann et al., 2009; Kissler et al., 2007, 2009; Ortigue et al., 2004; Scott et al., 2009). They have been found from about 100 ms after word presentation, mostly over bilateral occipito-temporal areas, and the current source analysis indicates that the present effects are partly due to such early perceptual processing. However, superior parietal and fronto-central sources contribute to the effect, implying that
mechanisms of response preparation act already very early in the processing stream. This would suggest that initial response facilitation by affective targets can pre-cede full semantic analysis, a notion also implied by behavioural literature on affective priming (Klauer and Musch, 2003). Such effects may be mediated at least in part by a fast subcortical visual pathway (LeDoux, 2000) which also appears to rapidly modulate the reflexive behavioural response system (Lang and Davis, 2006) and early visual processes (Liddell et al., 2005). Whereas very rapid activations have been reported more often for negative stimuli, invasive recordings in humans show that they in principle also exist for positive stimuli (Kawasaki et al., 2005). Regarding emotional words, a recent study showed particularly pronounced amygdala responses to positive adjectives similar to the ones used in the present study (Herbert et al., 2009). Together with the above described observations, this supports the possibility of rapid activation of motor-related regions via a subcortical visual pathway. Lexical decisions may be especially conducive to facilitation for positive stimuli.

While still tentative, this present observation is interesting and important and calls for future ERP research into response preparation in choice reaction tasks with emotional stimuli as well as in affective priming. The results support stronger response facilitation for positive stimuli, but not as a consequence of motor suppression by negative stimuli. If this had been the case, the event-related potentials preceding negative targets should have been reduced in comparison to neutral targets. This was not the case.

A number of factors may be responsible for our failure to obtain affective priming in a picture–word lexical decision task. Since three other previous studies also failed to observe clear neural effects of affective priming using IAPS picture stimuli (Faisal et al., 2008a,b; Zhang et al., 2006) the present pattern may be specific to this particular prime-target combination and point to a limit in affective priming. In line with this, de Gelder et al. (2002) found more immediate electrocortical priming effects for face–voice, than for picture–voice pairs. Cross-modal affective priming has been reported for voice–face pairs (Paulmann and Pell), and music–word pairs (Steinbeis and Koelsch, 2009), perhaps rendering pictures special in this respect. N400 semantic priming effects have been obtained with pictures and words as well as other stimulus combinations (Kutas and Federmeier, 2009), but specifically creating picture prime and word target pairs that were not semantically related may have counteracted spreading activation processes and affective priming. In this respect, the present finding may only reflect the tip of the iceberg of a more general problem in affective priming research: Conceivably, some of the previous studies reporting ‘affective priming’ partly measured semantic priming. Storbeck and Robinson (2004) directly compared semantic and affective priming across a variety of experimental situations: They found that semantic priming was a much more robust phenomenon than affective priming, particularly in lexical decision tasks. It is difficult to completely orthogonalize semantic and affective relatedness, especially with word stimuli (see Storbeck and Robinson, 2004, for a discussion). Even if semantic relatedness has been successfully controlled in previous studies, many studies of affective priming used comparatively small prime-target sets (about 10 pairs) that were repeated numerous times in the exact same pairing. Thus, it is possible that previously reported affective priming effects were at least partly due to the effect of covert associative learning. Under the label of ‘affective’ priming subjects may have acquired semantic relatedness plus the appropriate response. The affective nature of the prime may have facilitated associative learning for congruent pairs, causing them to have a net advantage over incongruent pairs. Such a mechanism could not have come into play in our experiment since we used a large variety of complex slides as primes and adjectives as targets, which were not repeated within a particular condition (say positive–positive). Indeed, at least with the naming task which, just like the lexical decision task, is thought to rely heavily on spreading activation processes, affective priming has only been obtained in studies that used multiple stimulus repetitions and not with single presentation sets (so-called ‘infinite sets’, see Spruyt et al., 2007a,b).

In sum, using a typical affective priming set-up in a lexical decision task with emotional pictures as primes and emotional adjectives as targets, we found facilitation effects of positive primes and targets, both on a behavioural and a cortical level, but no behavioural and only very small neural congruency effects indicative of affective priming. We also found effects of positive emotional content on stimulus processing and in particular a surprisingly early impact of positive content on response preparation. The latter effect may be indicative of a direct, pre-lexical, influence of affective word content on behaviour preparation which may by-pass semantic analysis. This phenomenon, in particular, merits further examination.

References


