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Visual noise effects on emotion perception: brain potentials and stimulus identification

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Event-related potential (ERP) studies revealed an early posterior negativity (EPN) for emotionally arousing pictures. Two studies explored how this effect relates to perceptual stimulus characteristics and stimulus identification. Adding various amounts of visual noise varied stimulus perceptibility of high and low arousing picture contents, which were presented as rapid and continuous stream. Measuring dense sensor event-related potentials, study I determined that noise level was linearly related to the P1 peak. Subsequently, enlarged EPNs to emotionally arousing contents were observed, however, only for pictures containing low amounts of noise, which also enabled stimulus identification as shown by study II. These data support the notion that the EPN may serve as a measure of affective stimulus evaluation at an early transitory processing period.

Keywords: attention, early posterior negativity, emotion, event-related potential, perception

Introduction

Research in affective neuroscience accumulates evidence for the preferential processing of emotional visual stimuli [1–3]. Event-related brain potential studies are particularly informative with regard to the temporal dynamics of emotion processing in the visual brain. A consistent finding is that the processing of emotional compared with neutral pictures is associated with a negative difference potential over temporo-occipital sites within a time window between 200 and 300 ms. This early posterior negativity (EPN) is most apparent for pleasant and unpleasant pictures high in emotional arousal [4–6]. These findings have been considered from the perspective of 'natural selective attention' proposing that stimulus perception and evaluation are in part directed by underlying motivational systems of avoidance and approach [7].

From a theoretical perspective, crucial issues regarding the interpretation of the emotion arousal modulation indexed by the EPN are unresolved. For instance, it is currently unclear how the EPN emotion effect relates to stimulus identification. Early functional MRI studies observed increased activity in the amygdala to fearful faces when stimuli were not consciously perceived, possibly increasing visual processing of emotional cues by reentrant processing [8–10]. Challenging these findings, a recent study observed increased activity in fusiform gyrus and amygdala to emotional stimuli only for recognized faces [11]. Extending this research issue to event-related potential (ERP) measures, it was explored whether the early attention capture of emotionally arousing stimuli is linked to stimulus identification.

It is furthermore currently unresolved to what extent the EPN may serve as measure of high-level affective stimulus evaluation, distinct from low-level perceptual stimulus characteristics. On the one hand, research with rapid picture presentations show that stimulus identification is a fast process with a distinct neural response emerging 150 ms after presentation of complex natural scenes [12–15]. On the other hand, perceptual differences in figure/ground composition and manipulations of image size affect the ERP wave and emotional arousal modulation in the 150–300 ms time window [16,17]. One interpretation to reconcile these findings is that low-level perceptual stimulus characteristics have secondary effects on the (high-level) EPN emotional arousal effect by impeding stimulus identification. To pursue this hypothesis, this study attempted to separate processes of stimulus identification and perceptual characteristics.

In two rapid serial visual presentation studies, visual noise was overlaid on high-arousing and low-arousing emotional pictures to manipulate perceptual stimulus characteristics and stimulus identification across a wide range (see Fig. 1). In studies I and II, dense sensor EEG and behavioral measure of stimulus identification were assessed respectively. With regard to low-level perceptual characteristics, it was predicted that the amount of visual noise linearly affects early (<200 ms) ERP components irrespective of picture emotionality. With regard to the EPN, it was assumed that emotional arousal effect is linked to stimulus identification, that is, it appears at noise levels where stimuli were recognized.

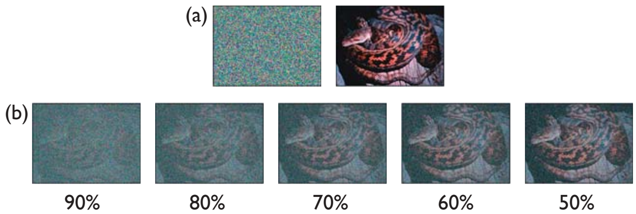

Fig. 1 (a) Original international affective picture system pictures were modified by overlaying a specified percentage of pixels from a visual noise picture. (b) Selected examples of the resulting images for selected noise conditions. Please note, recognition of the pictures is dependent on visual angle, and was much more difficult than in this illustration.

Materials and methods

Study I

Participants

Participants were 16 introductory psychology students from the University of Greifswald (7 women; 19–28 years, mean age=23.9 years) receiving either a monetary reward or course credits toward their research requirements.

Stimulus materials and procedure

Pleasant, neutral, and unpleasant pictures (N=60) from the International Affective Picture System (IAPS) complemented by additional pictures from our lab served as stimulus materials [18]. Based on previous studies reporting most pronounced functional MRI-blood oxygen level dependant signal and ERP differences in visual-associative brain region [4,5,19], statistical analysis contrasted emotional pictures high in emotional arousal with low-arousing stimulus materials.

To manipulate picture perceptibility across a wide range of conditions, color noise pixels were systematically overlaid on the IAPS pictures. As illustrated in Fig. 1, in different experimental conditions, 95, 90, 85, 80, 75, 70, 65, 60 or 50% of the pixels were taken from the random visual noise picture replacing original pixel information from the IAPS picture.

Pictures were shown in 10 separate blocks of presentation, interrupted by a short break of approximately 3 min, using a fixed order of decreasing noise level, that is, beginning with the highest noise condition (95%) and ending with the original, unmodified pictures. In each block, pictures were presented as a continuous stream without perceivable interstimulus interval for 330 ms [4,6]. For each level of visual noise, stimulus materials were shown in random order with no more than two repetitions of each valence category.

Apparatus and data analysis

Electrophysiological data were collected from the scalp using a 129-channel system (EGI; Electrical Geodesics, Inc., Eugene, Oregon, USA). Scalp impedance for each sensor was kept below 30 kΩ, as recommended by EGI systems guidelines. The EEG was collected continuously in the 0.1–100 Hz frequency range with a sampling rate of 250 Hz. Continuous EEG data were low-pass-filtered at 35 Hz before stimulus-synchronized epochs were extracted from 48 ms before until 330 ms after picture onset. A statistical approach was applied for artifact correction including the transformation of the ERP data to an average reference [20]. Separate ERPs were calculated as a function of emotional arousal and visual noise.

A two-step procedure was used to analyze the modulation of the ERP waveform as a function of affect and stimulus exposure. First, repeated measurement analyses of variance including the factor Emotional Arousal (high vs. low) and Visual Noise (10 levels) were calculated for each time point after picture onset separately for each individual sensor to identify the temporal and spatial modulation of the ERP as a function of emotional arousal and perceptibility. These waveform analyses were conducted using a significance criterion of $P<0.01$. To avoid false positives, significant effects were only considered meaningful, when the effects were observed for at least eight continuous data points (32 ms) and two neighboring sensors revealing significant affective modulation.

Second, based on the outcome of the waveform analyses, the P1 and EPN components were analyzed in conventional ERP analysis. The P1 amplitude was scored as mean activity over a time interval from 128 to 156 ms in a posterior sensor cluster comprising the following EGI sensors: 59, 60, 61, 65, 66, 67, 70, 71, 72, 74, 75 (left hemisphere), and 77, 78, 79, 83, 84, 85, 86, 89, 90, 91, 92 (right hemisphere). The EPN amplitude was scored as mean activity over a time interval from 200 to 300 ms in a posterior sensor cluster comprising the following EGI sensors: 58, 59, 60, 63, 64, 65, 66, 67, 69, 70, 71, 72, 74, 75 (left hemisphere), and 77, 78, 83, 84, 85, 86, 89, 90, 91, 92, 95, 96, 97, 100 (right hemisphere). Separate repeated-measures analyses of variance including the factor emotional arousal, visual noise (10 levels), and laterality (left vs. right) were conducted for the P1 and EPN component. For effects involving repeated measures, the Greenhouse Geisser procedure was used to correct for violations of sphericity.

Study II

Behavioral data of identification of the stimulus materials were obtained from 16 participants from the University of Konstanz (8 women; 19–33 years, mean age=25.5 years).

Picture materials and presentation were identical to study I. Participants were asked to indicate the identification of the stimulus materials by a left mouse button press. Participants were told to press the right mouse button when they reached the level at which visual noise was no longer comprising stimulus identification. For each noise condition, stimulus identification was assessed as the number of pictures recognized. In an additional test, participants verbally described the content of images that were presented at various noise levels and at the same speed. While not reported for brevity, this measure provided similar results as the first measure of stimulus identification.

Results

Study I: event-related potentials

Effects of visual noise (10 levels), emotional arousal (high vs. low), and their interaction indicated by the single sensor waveform analyses are summarized in Fig. 2a. A pronounced main effect of visual noise was observed for the P1 component most pronounced between 100 and 200 ms after stimulus onset. Collapsing across each three selected noise-level conditions and emotional arousal, Fig. 2b displays a right occipital sensor showing that the P1 peak linearly

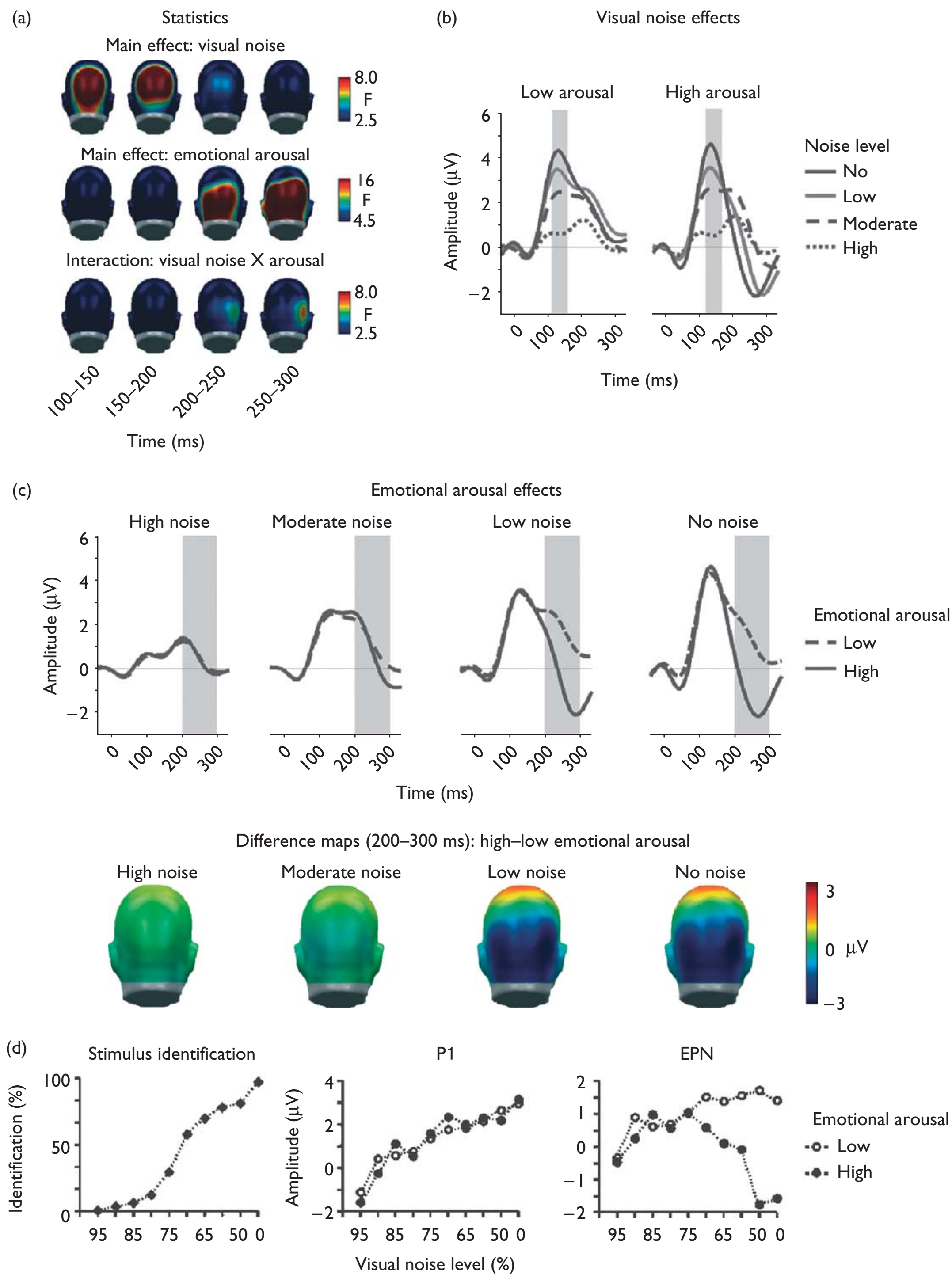

Fig. 2 Effects of emotion and visual noise. (a) Illustration of F-values (lower boundaries correspond to $P<0.01$) observed in repeated-measure analyses of variance calculated for each sensor and time point shown for time window of interest (96–300 ms). (b) Event-related potential waveforms for a selected right occipital sensor (#84) as a function of visual noise. High (95, 90, 85%), medium (80, 75, and 70%) and low (65, 60, and 50%) visual noise conditions were averaged together for the purpose of illustration. (c) Event-related potential waveforms (occipital sensor #84) and difference brain maps (200–300 ms poststimulus) as a function of emotional arousal and visual noise. All maps display a back view. (d) P1 and early posterior negativity amplitude (study I) and stimulus identification (study II) as a function of visual noise condition separately for high-arousing and low-arousing pictures.

increased with decreasing levels of visual noise. As in previous studies, emotional arousal effects were most pronounced in a time interval from 200 to 300 ms after stimulus onset. Of most interest, a significant interaction of emotional arousal and visual noise was observed. Collapsing across noise-level conditions, Fig. 2c shows enhanced EPN amplitudes to high-arousing images in the control condition with fully visible picture materials (no noise), and low-noise conditions (50, 60, and 65% conditions), while being absent in conditions with moderate and high noise levels hampering stimulus perceptibility. To further detail these effects, conventional repeated-measures analysis of variance were calculated for the P1 and EPN components.

Analysis of the P1 component revealed a highly significant main effect of visual noise, $F(9,135)=18.9$, $P<0.0001$. As shown in Fig. 2d, a linear increase of the P1 amplitude was observed with decreasing levels of visual noise, $F_{lin}(1,19)=62.9$, $P<0.0001$. Furthermore, the effect of visual noise on P1 was not qualified by any interaction involving either emotional arousal or laterality, Fs <1, ns.

Analysis of the EPN component revealed that the main effects of emotional arousal, $F(1,15)=46.8$, $P<0.0001$, and visual noise, $F(9,135)=3.9$, $P<0.01$, were qualified by a significant interaction, emotional arousal $\times$ visual noise $F(9,135)=5.5$, $P<0.001$. Separate tests for each level of noise replicated previous findings of enhanced EPN amplitudes for high-arousing compared with low-arousing images when pictures were fully visible, $t(15)=4.4$, $P<0.001$. Emotional modulation of the EPN as a function of noise level manipulation is shown in Fig. 2d. Differences between high-arousing and low-arousing pictures were limited to conditions with noise levels of 50, 60, and 65%, ts(15)=4.7, 3.6, and 2.7, $P<0.05$, respectively, while absent in conditions with higher noise levels. Furthermore, no main effect or higher-order interaction involving laterality was observed, Fs <1.0, ns.

It was further examined whether visual noise modulates the onset latency at which affective modulation reaches significance. The control and 50% condition showed highly significant modulation already in the time window from 200 to 220 ms, Fs(1,15)=14.5 and 19.5, $P<0.01$, respectively. Onset of the affective modulation was delayed in the 60 and 65% conditions, developing in the 220–240 ms window, Fs(1,15)=5.2 and 3.6, $P>0.05$ and $P=0.07$, and highly significant in the 240–260 ms time window, Fs(1,15)=24.1 and 12.3, $P<0.01$, respectively. Finally, analysis of the 70% condition indicated a significant modulation in a time window from 260 to 300 ms, $F(1,15)=5.1$, $P<0.05$.

Study II: behavioral data

As expected, stimulus identification varied across visual noise conditions $F(9,117)=51.4$, $P<0.0001$. A linear increase in stimulus identification was observed with decreasing amounts of visual noise, $F_{lin}(1,13)=221.9$, $P<0.0001$. As shown in Fig. 2d, a marked increase in stimulus identification emerged with the 70% visual noise condition at which the modulation of the EPN by emotional arousal began to emerge.

Discussion

Previous studies revealed that emotionally arousing pictures elicit an enhanced early posterior negativity [4–6]. These results were replicated when the images were presented in their original unmodified form. Building upon this replication, the present data provide novel insights into the relation of the emotional arousal EPN effect to perceptual characteristics and stimulus identification. Results are discussed with regard to the hypothesis that the EPN reflects a transitory processing period at which motivationally significant stimuli are being ‘tagged’ for preferential processing in later processing stages.

Both, perceptual stimulus characteristics and emotional significance modulated the ERP waveform. Importantly, these effects appeared in distinct subprocesses [21]. The P1 wave linearly increased with decreasing amount of visual noise, with no difference for high-arousing and low-arousing stimuli. Emotional arousal modulation appeared in the typical EPN time window between 200 and 300 ms, specifically in visual noise conditions in which the stimulus materials were recognized. Thus, the low-level visual feature manipulation utilized in this study was successful in separating effects owing to perceptual stimulus characteristics from the process of affective stimulus evaluation [22]. Moreover, the findings provide further support for the notion that selective stimulus processing indexed by posterior negativities is consequent upon stimulus identification (cf. [23]). Specifically, preventing stimulus identification abolished the modulation of the EPN as a function of emotional arousal. In addition, noise conditions posing difficulties for stimulus identification were associated with a delayed appearance of the affective EPN modulation. Overall, these findings appear consistent with the notion that the EPN reveals the attention capture of emotionally significant stimuli with low-level perceptual characteristics primarily affecting stimulus identification.

Regarding the relation of selective emotion processing and stimulus recognition, the present ERP findings seem to parallel recent functional MRI data showing that fearful faces selectively activated the amygdala and fusiform gyrus when participants were aware of the facial expressions [11]. Studies using rapid serial visual presentations, however, demonstrated that pictures can be identified whereas the representations of the stimuli rapidly fade or are overwritten leading to the subjective impression that all stimuli are seen while the stream cannot be explicitly recalled when probed later [12,13]. As the EPN is linked to the process of stimulus identification rather than consolidation [23], study II asked participants to indicate when pictures could be identified. Assessment of stimulus identification served not to determine individual thresholds of conscious stimulus recognition precisely, but to reveal the dynamic change of stimulus identification across noise levels (cf. [24]). In that respect, results appear clear in suggesting that the EPN effect is observed in conditions in which participants are able to extract stimulus meaning (cf. [25]). Future studies focusing specifically on the threshold region of stimulus identification, rather than a broad range of perceptibility, may be informative in pursuing this issue. Overall, these data are in line with the notion that the EPN reflects an early attentional selection mechanism at which stimulus meaning is already extracted whereas more sustained processing is needed to produce awareness and conscious recognition [7].

Conclusion

The EPN has been suggested to reveal the attention capture of emotional cues. This present study determined the affective EPN modulation in relation to visual stimulus characteristics and stimulus identification. It was shown that low-level visual stimulus characteristics primarily modulate the P1 wave preceding the emotion-sensitive EPN component. Furthermore, emotional modulation of the EPN was seen for conditions in which noise levels allowed stimulus identification. These data are consistent with the notion that the EPN reflects a transitory processing period at which motivationally significant stimuli are ‘tagged’ for preferential processing in higher-order visual-associative brain areas.

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