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Event-related beta oscillations are affected by emotional eliciting stimuli

Bahar Güntekin, Erol Başar*

Istanbul Kultur University, Brain Dynamics, Cognition and Complex Systems Research Center, Istanbul, Turkey

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ABSTRACT

According to previous results, negative emotional facial expressions elicit oscillatory beta responses. The present study analyzes event-related beta oscillations upon presentation of International Affective Picture System (IAPS) and aims to show whether behavior of beta in response to negative IAPS pictures also have similar dynamics. IAPS pictures (unpleasant, pleasant, and neutral) were presented as a block and random passive viewing to 14 healthy subjects (8 male). Only with pictures with similar luminance level were selected as stimuli. Event-Related Potentials (ERPs) were recorded from 30 different scalp locations, and adaptive digital filtering was used for analysis in different frequency windows. The maximum peak-to-peak amplitudes were measured for each subject's averaged beta responses (15–30 Hz) in the 0 and 300 ms time window. Beta responses were significantly higher for unpleasant pictures than for pleasant and neutral pictures (average 50%). Beta responses were significantly higher for unpleasant than for pleasant pictures over frontal, central and parietal electrode sides ($p < 0.05$). Furthermore, beta responses were significantly higher for unpleasant than for neutral pictures over parietal and occipital electrodes ($p < 0.04$). In addition, the pleasant pictures elicited higher beta responses than neutral pictures over occipital electrode sites ($p < 0.04$). The results of the present study indicate that negative emotions are related to increased beta responses in humans, independent of stimulus types (facial expression or IAPS pictures). Accordingly, beta responses to negative emotions are possibly a common phenomenon. The standardization of luminance in pictures may reduce divergences between results from different laboratories.

One of the emerging trends in neuroscience is the analysis of the emotional states. In our previous publications, we reported on brain oscillations upon various emotional stimulations. The present study applied the International Affective Picture System (IAPS) to examine brain oscillatory responses to different types of stimuli. We consider the beta frequency window as an important frequency response for possible refined description of negative emotional inputs. According to Solms and Turnbull [30], emotion is akin to a sensory modality that provides information about the current state of body self, as opposed to the state of the object world. "Emotion" is the aspect of consciousness that remains if all externally derived contents are removed. Furthermore, the emotion that one perceives is also subjective and "Emotion is a perception of the state of the subject, not the object world" [30]. Le Doux [23] proposed that emotions or feelings are conscious indications of unconscious processes.

A number of studies have analyzed the emotional states by means of human electrophysiology, mostly by means of spontaneous EEG or conventional Event-Related Potentials. However, few studies have analyzed the emotional states by means of Event-Related Oscillations (EROs) [17,19,20,28]. In a series of publications on face recognition and emotion, our group has reported differentiations of "known" and "unknown" faces using several oscillatory components [7]. Results were also published of the analyses of "loved" versus "familiar" and "unfamiliar" faces by oscillatory components [8]. Furthermore, EROs of facial expressions yielded relevant differentiation between responses to angry and happy facial expressions in the alpha and beta frequency ranges [13,14]. In the present report, IAPS pictures were used as a next step in the analysis of emotion by means of brain oscillations.

Previous reports that analyzed event-related oscillations upon application of IAPS paradigm have shown contradictory results [1,2,4,5]. Aftanas et al. [1] reported that valence discrimination is associated with the time-locked synchronized theta activity as well as hemispheric asymmetries in anterior–posterior direction. Müller et al. [24] reported increased gamma (30–50 Hz) power for negative valence over left temporal region. Balconi et al. [4] found increased theta power upon negative emotions compared with positive emotions; Furthermore, these authors also reported increased delta power in response to high-arousal than low-arousal stimuli. Klados et al. [18] analyzed delta response power upon application of IAPS pictures and reported synchronized delta power after the stimulus onset. None of these groups indicated an emotional effect on event-related beta oscillations. In a previous study [13],

* Corresponding author. Tel.: +90 212 498 43 92; fax: +90 212 498 45 46.
E-mail address: e.basar@iku.edu.tr (E. Başar).

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increased beta in response to angry faces was reported in frontal and central electrodes. Beta oscillatory response was also found to be high during periods of anxiety [27] or in response to anxious rumination [3]. The aim of the present study is therefore to compare beta response oscillations upon stimulations eliciting negative versus neutral and positive emotion. Our hypothesis is that if the increased beta in response to negative emotions is a common phenomenon, the negative IAPS images will also elicit higher beta responses.

Fourteen subjects (8 males) volunteered to participate in the study; most were university students and university staff and faculty members. Participants' ages ranged from 19 to 32 years. The mean age of subjects was 23.78 ± 4.61 years. All of the subjects were right handed. All subjects had completed at least 10 years of education. All subjects were interviewed with a questionnaire on their family history, demographic and medical profiles and drinking habits. None of the subjects reported any current or past neurological or psychiatric illness and all participants had normal or corrected to normal vision. All subjects signed an approved consent form.

Thirty pictures were selected from the International Affective Picture System (IAPS [22]). Ten "unpleasant" pictures showed mutilation, attack scenes and wild animals; 10 "neutral" pictures showed persons and household objects; and 10 "pleasant" pictures depicted babies and engaging animal scenes. The luminance of the pictures was measured by Delta OHM HD 2302.0 light meter. The distance between the screen and the subjects' eyes was 1 m, accordingly the luminance was measured by placing the light meter 1 m away from the screen. Only pictures with similar luminance level were selected. The mean luminance for all thirty pictures was 23.4 ± 5.2 cd/m^2. The IAPS references of the stimuli are given in Appendix A. All pictures were presented on a 19-in. computer monitor with a refresh rate of 60 Hz. Pictures subtended a visual angle of 8° horizontally. Pictures were presented for 1000 ms, with an interstimulus interval that varied randomly between 3 and 7 s. Two different stimuli designs were applied, (1) passive block design; (2) passive random design.

(1) *Passive block design*: 40 (10×4) unpleasant pictures, 40 pleasant (10×4) and 40 neutral (10×4) were presented.
(2) *Passive random design*: The same set of pictures (10 unpleasant, 10 pleasant and 10 neutral) were presented in a pseudo-random design and, in total, 120 pictures were presented.

As Olofsson et al. [25] reported in their review, in IAPS research there are number of studies, which used different paradigms. Since emotional processes are complex processes different paradigms may cause different results in electrophysiology. Passive block design and passive random design were included in the study in order to see if the effects of these stimuli will be different on event-related oscillations.

Subjects were first presented with two examples of the affective stimuli for each affective category, respectively, that were not part of the experimental series. They were also instructed to maintain gaze on the fixation point and to avoid exploratory eye movements and eye blinks during picture presentation.

After the recording session, the subjects were asked to rate the respective picture based on two categories, affective valence and arousal, using a paper and pencil version of the self-assessment manikin (SAM [21]).

EEG was recorded with 30 Ag–AgCl electrodes mounted in an elastic cap (Easy-cap) according to the international 10–20 system. Additionally, two linked earlobe electrodes (A1 + A2) served as references. The EOG from the medial upper and lateral orbital rim of the right eye was also registered. For the reference electrodes and EOG recordings, Ag–AgCl electrodes were used. All electrode impedances were less than 10 kΩ. The EEG was amplified by means of a BrainAmp 32-channel DC amplifier with band limits of 0.01–250 Hz. The EEG was digitized on-line with a sampling rate of 500 Hz.

The sweep numbers were equalized randomly between the pleasant, unpleasant and neutral stimulation conditions. Before the averaging procedure, the epochs containing artifacts were rejected by an off-line technique, i.e. single sweep EOG recordings were examined visually and trials with eye movement or blink artifacts were rejected. Subject averages and grand averages were calculated for each electrode site and experimental condition. The data were digitally filtered in the beta (15–30 Hz) frequency range.

Subsequently, for each task condition (pleasant, unpleasant and neutral pictures), we measured the maximum peak-to-peak amplitudes for each subject's averaged beta response – that is, the largest peak-to-peak value in beta frequency range in terms of μV s found in the time window between 0 and 300 ms.

SPSS was used for statistical analysis. Maximum peak-to-peak amplitude beta responses in 0–300 ms time window were analyzed by means of repeated measures ANOVA including the within subject factors 3 coronal (left medial, medial, right medial) × 4 anterior-to-posterior (frontal, central, parietal, occipital) × 3 emotion (unpleasant, pleasant, neutral). Furthermore, temporal locations (T_7, T_8, TP_7, TP_8) were analyzed separately by means of repeated measures ANOVA including the within subjects factors 2 location × 2 hemisphere × 3 emotion. In order to control if there is difference between two stimuli designs we have also included the design (Block versus Random) as a within subject factor in the ANOVA analysis. We have found that there were no statistically significant differences between two designs. Furthermore, it was found that in the block design there were significant differences between emotion and emotion × antpost. On the contrary, there were no significant differences in the random design paradigm for emotion. The mentioned results for block design were not seen clearly when two stimuli designs were included in the same ANOVA analysis. Accordingly, we have preferred to analyze block and random designs separately. Greenhouse–Geisser corrected *p*-values are reported. Post hoc comparisons were performed by Tukey's test. Subjective ratings of arousal and valence were compared between pleasant, unpleasant and neutral pictures using the Wilcoxon paired sample test. Luminance values of pictures were also compared between pleasant, unpleasant and neutral pictures with ANOVA test.

The subjects' mean valence scores for the *unpleasant pictures* were 6.71 ± 1.39, thus being significantly higher than for the *neutral* (5.2 ± 0.50; $p < 0.007$) and *pleasant pictures* (2.77 ± 0.67; $p < 0.002$). The mean arousal scores for the *unpleasant pictures* (4.32 ± 1.82) were significantly lower than for the *pleasant pictures* (6.44 ± 1.83; $p < 0.004$) and for the *neutral* pictures (7.22 ± 1.47; $p < 0.002$). There was no significant difference between the *pleasant* and the *neutral* pictures for the arousal rating scale.

The mean luminance value for the *unpleasant pictures* was 23.90 ± 4.48; the mean luminance value for the *pleasant pictures* was 22.50 ± 4.42; the mean luminance value for the *neutral pictures* was 24.00 ± 6.79. Furthermore, there were no statistically significant results between luminance levels of different types of stimuli ($F(2,18) = 0.239$; $p > 0.05$).

Fig. 1 illustrates the grand averages of beta responses in frontal-central and parietal electrode sites upon presentation of unpleasant and pleasant pictures. Grand averages of beta responses to unpleasant pictures are represented by a red line and grand averages of beta responses to pleasant pictures are represented by a blue line. As shown in Fig. 1, the grand averages of beta responses to unpleasant pictures are at least 50% higher than the grand averages of beta responses to pleasant pictures.

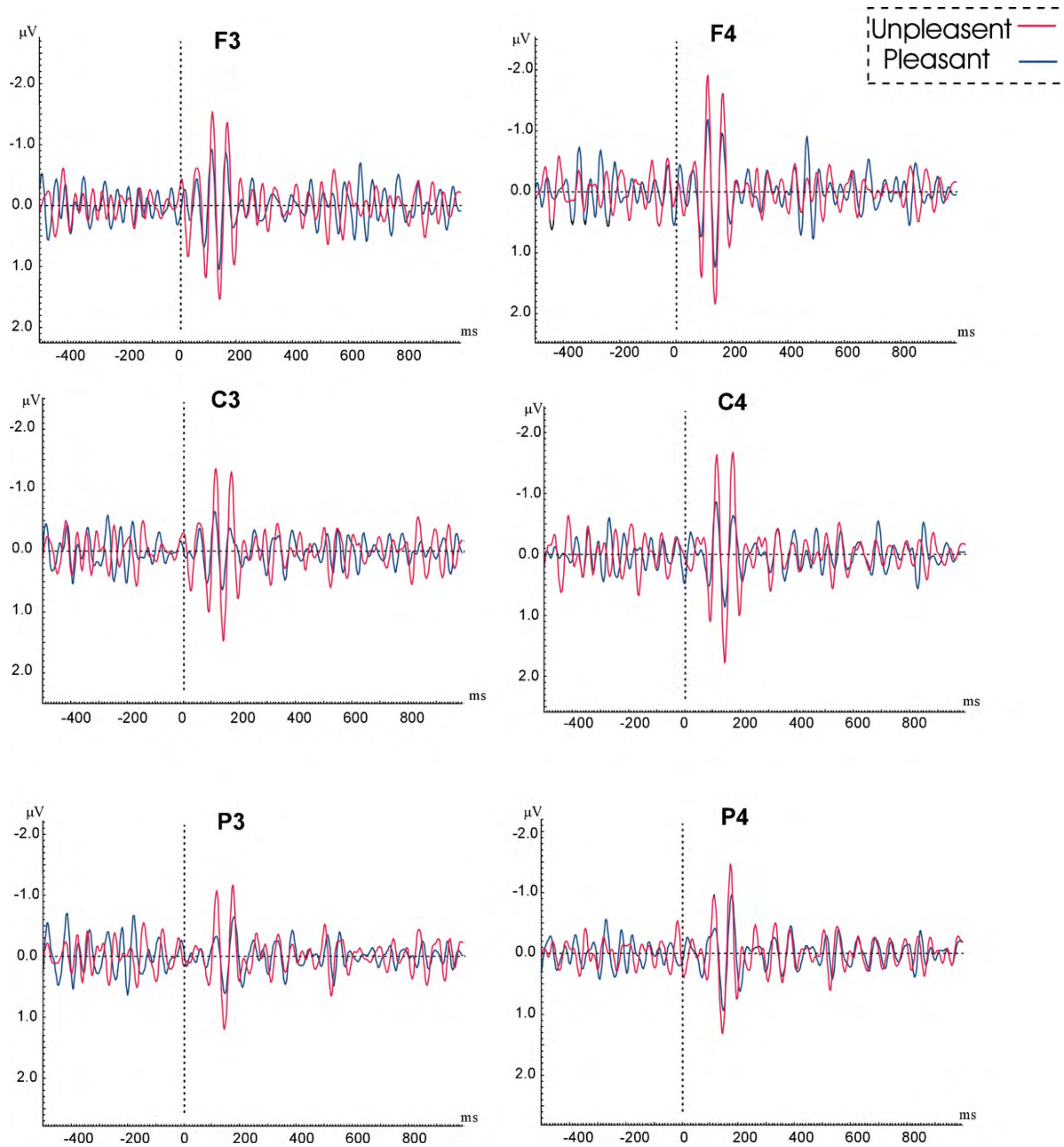

Fig. 1. Grand averages of beta responses in frontal–central–parietal (F_3; F_4; C_3; C_4; P_3; P_4) electrode sites upon presentation of unpleasant and pleasant pictures. Grand averages of beta responses to unpleasant pictures are represented by a red line and grand averages of beta responses to pleasant pictures are represented by a blue line. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Fig. 2 represents the mean amplitudes of averaged maximum peak-to-peak beta responses in 0–300 ms time window over frontal (F_3, F_z, F_4), central (C_3, C_z, C_4), parietal (P_3, P_z, P_4) and occipital (O_1, O_z, O_2) areas upon presentation of "unpleasant" and "pleasant" pictures. As it is seen in the figure for all electrodes the unpleasant pictures elicited higher beta response than the pleasant pictures. The statistical findings described below are in good accordance with Figs. 1 and 2.

ANOVA on beta responses revealed significant results for emotion ($F(2,26) = 4.33$; $p < 0.03$). Post hoc analysis confirmed that the negative pictures elicited higher beta responses than the positive and neutral pictures ($p < 0.05$). Furthermore, the ANOVA on beta responses revealed significant results for anterior–posterior ($F(3,39) = 4.03$; $p < 0.04$). Post hoc analysis confirmed that the beta responses elicited over the frontal electrode sites were larger than central, parietal and occipital recording sites ($p < 0.0001$; $p < 0.0001$; $p < 0.05$). ANOVA on beta responses revealed significant results for emotion × anterior–posterior ($F(6,78) = 4.08$; $p < 0.02$). Post hoc comparisons revealed that beta responses upon negative pictures were significantly higher than positive pictures over frontal ($p < 0.05$), central ($p < 0.005$), parietal ($p < 0.02$) recording sides (Figs. 1 and 2). Post hoc comparisons revealed that beta responses upon negative pictures were significantly higher than neutral pictures over parietal ($p < 0.04$) and occipital ($p < 0.0001$) recording sites (Fig. 2). Furthermore, beta responses upon positive pictures were significantly higher than neutral pictures over occipital ($p < 0.04$) recording sites.

ANOVA performed for temporal locations on beta responses also revealed significant results for emotion ($F(2,26) = 4.14$; $p < 0.04$). Post hoc analysis confirmed that the negative pictures elicited higher beta responses than the positive and neutral pictures ($p < 0.05$). Furthermore, the ANOVA on beta responses revealed significant results for emotion × location × hemisphere ($F(2,26) = 3.89$; $p < 0.05$). Post hoc comparisons revealed that beta

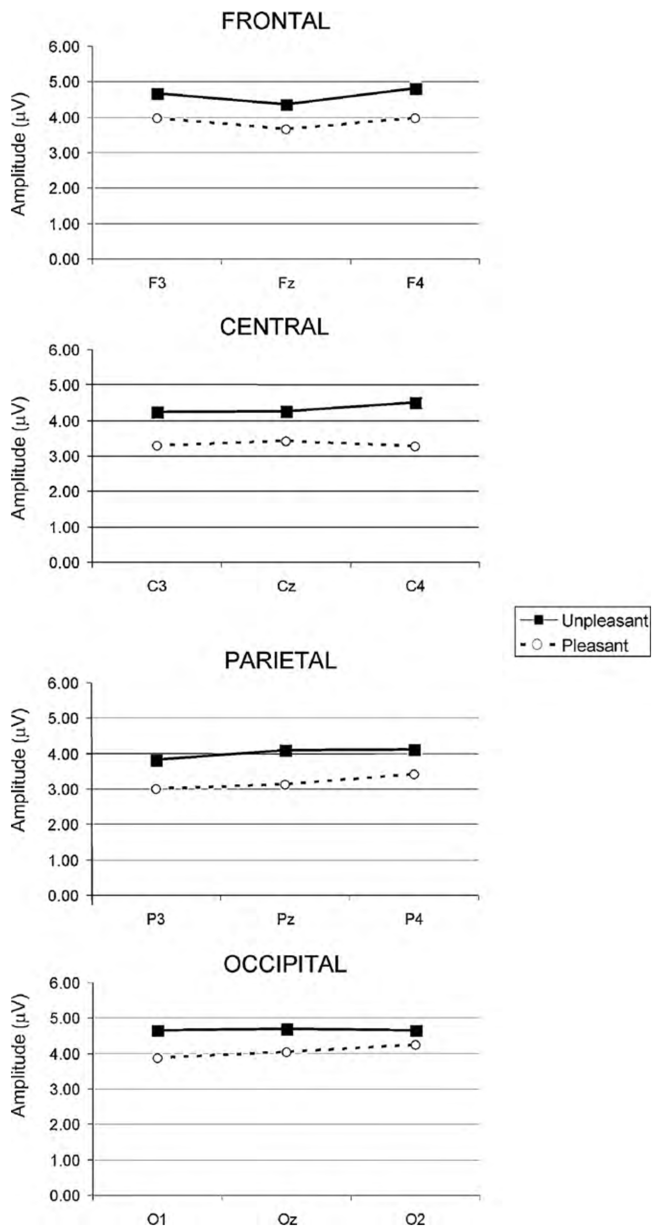

Fig. 2. Mean amplitudes of averaged maximum peak-to-peak beta responses in 0–300 ms time window over frontal (F_3, F_z, F_4), central (C_3, C_z, C_4), parietal (P_3, P_z, P_4) and occipital (O_1, O_z, O_2) areas upon presentation of "unpleasant" and "pleasant" pictures. Open circles represents mean amplitudes for pleasant pictures and filled squares represent mean amplitudes for unpleasant pictures.

responses upon negative pictures were significantly higher than neutral pictures over TP_8 electrode ($p < 0.05$).

ANOVA on beta responses did not reveal significant results for emotion. ANOVA on beta responses revealed significant results for anterior–posterior ($F(3,39) = 4.65$; $p < 0.03$). Post hoc analysis confirmed that the beta responses elicited over the frontal electrode sites were larger than central, parietal and occipital recording sites ($p < 0.0001$; $p < 0.0001$; $p < 0.003$). ANOVA performed for temporal locations on beta responses did not revealed any significant results.

The present study indicated that the beta response oscillations were increased upon emotional stimuli. In frontal, central and parietal electrodes, the beta responses were higher upon stimulation by unpleasant pictures in comparison to pleasant pictures. Furthermore, beta responses were significantly higher for unpleasant than for neutral pictures over parietal and occipital electrodes. In addition, the pleasant pictures elicited higher beta responses than neutral pictures over occipital electrode sites. These results indicated that the beta response oscillations are enhanced and selectively distributed especially upon unpleasant pictures. Only at the occipital recording sites did the pleasant stimuli elicit higher beta responses compared to neutral stimuli. In an earlier study, Ray and Cole [29], who used a different picture set reported that beta oscillations reflect emotional processes. These authors reported increased beta activity at temporal and parietal areas upon presentation of pleasant stimuli. The results of Ray and Cole [29] and present study have some contradictory results. In both studies the increased beta response upon emotional stimuli is a common and important finding.

In our previous study, increased left frontal and central beta responses to "angry" face expression stimuli in comparison to "happy" face expression stimuli were reported [13]. The results of the present study and the results of Güntekin and Başar [13] merit additional attention, since these studies indicate that, independent of stimulus type (face expression or IAPS pictures), pictures with negative emotions trigger increased beta responses in humans. One of the important differences between the results of Güntekin and Başar [13] and the present study is that the negative pictures of IAPS showed a distributed topographically from fronto-central to parieto-occipital areas, while Güntekin and Başar [13] reported that only frontal and central areas showed higher beta responses upon presentation of angry faces. Thus, the present results in Figs. 1 and 2 suggest that affective stimuli induce an enhancement and extension in the distributed activation of beta oscillatory response.

Özgören et al. [26] reported increased frontal event-related beta amplitudes in response to unknown faces in comparison to known faces (comparison of semantic and episodic stimuli). Further, these authors recorded *prolonged beta oscillations* to known faces in frontal areas. All these results indicate that the different types of pictures (semantic, episodic, emotional, affective, etc.) may have different effects on beta responses. Gender differences are also important in the analysis of event-related oscillations. Female subjects showed increased delta and beta responses to simple light [12] and increased occipital beta responses to face expressions [15]. Accordingly, in future studies, the effects of gender on event-related oscillations upon presentation of IAPS pictures should also be analyzed with a larger sample group.

In the present study both pleasant and unpleasant pictures elicitied higher beta response in occipital region. Occipital region seem to have an important role in rapid and automatic identification of emotional pictures. Affective ERPs have been linked theoretically to attention orientation for unpleasant pictures during earlier components (<300 ms) [25]. IAPS pictures are thought to modulate brain activities related to primary and early visual processing [11]. Results related to unpleasant and pleasant picture stimulations indicate that the occipital areas are also involved in fine functional adjustments related to emotional and selective attention processes [25]. It is also possible that the occipital cortex, which is involved in phyletic memory, could have additional properties to link emotional memory with phyletic memory [14].

IAPS pictures belong to the standard picture group, which is used to analyze the emotional states. However, it should be noted that it remains difficult to reach a precise standardization, since the pictures have different categories, different colors and different spatial frequencies as well as different luminance values. There are several studies in the literature that analyzed the effects of different properties of IAPS pictures, such as category, color and spatial frequency [9–11]. However, luminance is one of the most basic and important properties that must be checked before beginning the experiments. Therefore, in the present study, we paid particular attention to luminance and chose pictures with similar luminance levels (mean

23.4 ± 5.2 cd/m^2). There was a particularly large difference between pictures with a white background and those with a black background. Further research is required to establish new standards for experiments performed using IAPS pictures. The color, luminance or spatial frequency of the pictures are some of the most basic and important properties that should be standardized in order to avoid divergent results.

One of the important findings of the present study is that the significant results were recorded only for the "block" design but not for the "random" design. Further research is needed to compare two different designs and various other designs and their effects on event-related oscillations. Accordingly, not only standardization of IAPS pictures but also standardization of different stimuli designs seems to be important features in IAPS research.

The present study indicated that the emotional processes were represented by distributed beta oscillatory response. Recent publications favor the idea that attention, perception, learning and memory are inseparable, as described by Hayek [16]. The discussed data obtained by various techniques in our laboratory and others indicate that the exact localization of "single" sources underlying the measured electrical activity related to emotional stimuli processing is not possible. We therefore emphasize the notion of a "Whole BrainWork" for all types of functional processing in the brain [6,23]. Accordingly, it is assumed that, if methodologically possible, we should see involvement of, e.g., the amygdala, the frontal, temporal, parietal and occipital lobes in processing of IAPS pictures. Thus, the brain oscillatory responses distributed over the scalp should be considered as a template and ensemble of features, including various degrees of amplitudes, phases and prolongations. We emphasize the analysis of several parameters of electrical activity to reach a more reliable description of distinct brain functions [6].

(1) The results of the present study and those of Güntekin and Başar [13] indicate that negative emotions trigger increased beta responses in humans, independent of stimulus types (facial expression or IAPS pictures). Accordingly, beta responses to negative emotions are possibly a common phenomenon.
(2) Although the increased beta responses seem to be a common phenomenon for identification of negative emotions, the topology changes according to the stimulation. The responses to negative IAPS pictures showed a distributed increase of beta responses, while in the study by Güntekin and Başar [13] only frontal and central areas showed higher beta responses upon presentation of angry faces.
(3) Further, the present report shows that not only the quality of the picture causing emotion but also their luminosity level is important in making comparisons and in achieving a standardized analytical framework and more dependable results. This standardization, in turn, may reduce methodologically related variations between the results from different laboratories.
(4) The results of the present study support the hypothesis that affective picture processing should be described as an automatic feature of perception [23]. The results also indicate that the exact localization of "single" sources underlying the measured electrical activity related to emotional stimuli processing is not possible. Rather, the notion of a "Whole BrainWork" for all types of functional processing in the brain [6,23] is emphasized.

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Appendix A.

Unpleasant pictures: 2353.2; 6350; 2205; 6540; 3400; 1930; 1052; 1274; 1932; 1114. *Pleasant pictures*: 2050; 2332; 2340; 2080; 1460; 1500; 1610; 1722; 1710. *Neutral pictures:* 2190; 2210; 2214; 2480; 2495; 7020; 7030; 7041; 7080; 7150.

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