Psychophysiology, 48 (2011), 1397–1404. Wiley Periodicals, Inc. Printed in the USA.

DOI: 10.1111/j.1469-8986.2011.01204.x

Affective modulation of the LPP and α-ERD during picture viewing

ANDREA DE CESAREI AND MAURIZIO CODISPOTI
Department of Psychology, University of Bologna, Bologna, Italy

Abstract

Brain responses to engaging stimuli may be reflected both in event-related potentials (ERPs) and in electroencephalogram (EEG) oscillations. Previous studies investigating the effects of top-down factors on stimulus encoding revealed similar modulation of late ERPs and alpha-band desynchronization (α-ERD) by relevant target stimuli. Focusing on the bottom-up effects of emotional content and picture size, the present study aimed to investigate the relationship of the late positive potential (LPP) and α-ERD during the viewing of emotional pictures. Results showed similar affective modulation by picture arousal of the LPP and α-ERD. Moreover, picture size reduction diminished overall magnitude of both responses, but did not dampen affective modulation of either response. These results suggest that, during affective picture viewing, these two brain responses similarly reflect the engagement of motivational systems in order to facilitate perception.

Descriptors: Emotion, Orienting, Oscillations, Alpha, ERPs

Brain responses to emotional scenes have been investigated using a variety of measures, including the event-related potentials (ERPs). Perhaps the most well-established finding in ERP literature on emotional processing is that emotionally arousing (pleasant and unpleasant) pictures elicit a larger late positive potential (LPP) than neutral pictures (Codispoti, Mazzetti, & Bradley, 2009; Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Johnston, Miller, & Burleson, 1986; Radilova, 1982; Schupp, Flaisch, Stockburger, & Junghöfer, 2006). This effect has been interpreted as a reflection of motivational significance, in which emotional stimuli reflexively engage corticolimbic appetitive and defensive systems in order to facilitate perception and ultimately promote adaptive behavior (Bradley, 2009; Codispoti, Ferrari, & Bradley, 2007; Ferrari, Bradley, Codispoti, & Lang, 2011).

Cortical responses, recorded by electroencephalography, can be characterized not only in the time domain for the study of ERPs, but also in the time-frequency domain in order to study oscillatory activity. The alpha wave is a rhythmic oscillation of the electroencephalogram (EEG) in the frequency range from 8 to 12 Hz. The onset of a visual stimulus results in a desynchronization of the EEG alpha band (α-ERD) over occipital areas (Berger effect; Berger, 1929). In tasks requiring categorization of task-relevant events, targets result in a more pronounced desynchronization of the EEG alpha band compared to non-target stimuli (Klimesch, Doppelmayr, Russegger, Pachinger, & Schwaiger, 1998). Target stimuli are also associated with a larger late positivity (P300) in the ERP (Azizian, Freitas, Parvaz, & Squires, 2006; Donchin, 1981; Johnson, 1986; Kok, 2001; Luck & Hillyard, 2000; Roth, 1983), and previous studies observed that these two brain responses are similarly affected by several factors in oddball tasks (Bastiaansen, Böcker, Brunia, de Munck, & Spekreijse, 2001; Herrmann & Knight, 2001; Mazaheri & Picton, 2005; Polich, 2007; Sergeant, Geuze, & van Winsum, 1987; Spencer & Polich, 1999; Yordanova & Kolev, 1998). Altogether these results suggest that, although the P300 and α-ERD reflect different processes, they may be regulated by similar attentional mechanisms.

While previous studies examined the effects of directed attention, where "top-down" signals derived from task demands, less is known about the effects of the intrinsic relevance of the stimulus (bottom-up signals) on α-ERD. Moreover, previous research did not evaluate the relationship between α-ERD and LPP during the perception of emotional pictures. The present study will examine the effects of pleasant and unpleasant stimuli, varying in emotional arousal, on the α-ERD and LPP. If these brain responses reflect similar processes, then it can be expected that, in a picture-viewing paradigm, presentation of motivationally relevant pictures will result in a similar modulation of both late ERPs and of the α-ERD, even in the absence of specific task instruction.

Brain responses to emotional stimuli have been widely investigated via the presentation of affective pictures evoking a broad range of emotional reactions, varying in intensity and involving both pleasant and unpleasant picture contents (Bradley & Lang,

The authors want to thank Dr. Brian Roach for his kind help in data analysis. The authors are also grateful to all participants who took part in the study.

Address correspondence to: Maurizio Codispoti, Department of Psychology, University of Bologna, Viale Berti Pichat, 5, 40128 Bologna (BO), Italy. E-mail: maurizio.codispoti@unibo.it

PSYCHOPHYSIOLOGY

2007). Following a dimensional approach, emotional behavior can be defined by a first dimension of affective valence, which controls the direction of emotional engagement (approach or withdrawal), and a second dimension of arousal, which dictates the intensity of affective response. Since the magnitude of the late positive potential clearly varies with emotional arousal, with the largest LPP elicited when viewing the most arousing emotional contents (Cuthbert et al., 2000; Schupp et al., 2004), we presented different pleasant and unpleasant picture contents varying in the arousal dimension to further evaluate the relationship between the α-ERD and the LPP.[1]

The retinal size that an object subtends reveals information about its distance from the observer, which might modulate its motivational relevance. Building on the direct relationship between distance and retinal size, a number of studies have suggested that stimulus size may also play a role in modulating emotional responses (Codispoti & De Cesarei, 2007; De Cesarei & Codispoti, 2006, 2008, 2010; Detenber & Reeves, 1996; Teghtsoonian, & Frost, 1982). Affective ratings, as well as sympathetic responses reflecting action preparation, indicated more pronounced emotional responses to larger compared to smaller stimuli. On the other hand, a previous study that investigated the effects of picture size on electrocortical indexes of emotional processing indicated that picture size did not affect the affective modulation of the late positive potential (De Cesarei & Codispoti, 2006). However, this previous study used only specific highly arousing picture contents such as mutilated bodies and erotic scenes. It could well be that, while highly arousing stimuli elicit affective responses with little modulation caused by stimulus imminence, the relevance of specific less arousing picture contents, such as threatening people or attacking animals, critically depends on their imminence. If this is true, then affective modulation of the LPP in reaction to these pictures will vary with picture size, being maximal for large pictures and minimal for small ones. The present study will test this possibility, by presenting emotional and neutral pictures varying in arousing value and in picture size, and examining the affective modulation of the LPP. Moreover, as alpha desynchronization is thought to index activation of visual areas (Pfurtscheller, Stancák, & Neuper, 1996), it is possible that changes in picture size that decrease the number of details that are visible in a picture will also result in a less pronounced affective modulation of the α-ERD.

Method

Participants

A total of 20 participants (10 females) with no diagnosed psychological or neurological disorders took part in the study. Age ranged from 21 to 30 ($M = 24.1$, $SD = 2.59$), and 90% were right-handed. On arrival at the laboratory, participants signed an informed consent form, which included the information that arousing scenes would be presented.

[1]As compared to the investigation of emotional reactions to highly arousing (pleasant and unpleasant) and neutral pictures only, a wider range of categories allows for a more specific examination of the relationship between arousal and cortical responses, for instance, excluding the possibility that the observed effects are due to confounds (e.g., color, spatial frequency, or familiarity), which may be present for some categories (Pernet, Schyns, & Demonet, 2007).

Stimuli and Equipment

Images were selected from various sources including the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008), the Internet, and document scanning. Based on arousal rating data from previous studies, which investigated affective reactions to comparable picture contents (Bradley, Codispoti, Cuthbert, & Lang, 2001; Bradley & Lang, 2007), ten picture categories were selected (each $N = 20$): erotic couples, male nudes, female nudes, babies, animals in neutral contexts, neutral faces, people in neutral contexts, attacking animals, attacking humans, and mutilated bodies, for a total of 200 pictures. Pictures of same-sex nudes (pictures of nudes that were the same sex as the viewer) were not shown to participants; therefore, each participant viewed a total of 180 different images.

A total of 4 versions of each picture were created by resizing to 100%, 50%, 25%, or 12.5% of the original size. All pictures were equated in brightness and contrast (155 and 25 on a scale ranging from 0 to 255) and pasted on a gray background of the same brightness (De Cesarei & Codispoti, 2006). Horizontal and vertical visual angles subtended by pictures were $21.23^\circ \times 16.22^\circ$ (100%), $10.71^\circ \times 8.2^\circ$ (50%), $5.36^\circ \times 4.1^\circ$ (25%), and $2.68^\circ \times 2.05^\circ$ (12.5%).

Pictures were presented on a 19″ CRT monitor at 1 m from the observer. A chinrest assured that the distance between participant and the monitor remained constant within and across participants. The experiment was run using E-Prime (Schneider, Eschman, & Zuccolotto, 2002).

Procedure

On arrival, the laboratory was shown to the participants. After the sensors were applied, the instructions were read out to the participants, who were asked to look at the images while avoiding eye and body movements. To keep participants engaged in the picture-viewing task, they were told that, at the end of the experiment, they would be asked to recall as many images as possible. Data from the recall task are not reported.

The experimental session was divided into 8 blocks, lasting about 10 min each. In each block, the same 180 stimuli were presented in a different order. During each block, the same number of stimuli from each category and size condition was presented. For each single participant, each picture was always presented in the same size, in order to prevent an influence on recognition of the picture in the smallest size when the same image had already been viewed in the 100% size. Across all participants, all pictures were assigned to all size conditions.

During each trial, a fixation cross was presented for 500 ms. After this time, an image was displayed and remained visible for 1 s. After image offset, a blank screen was displayed for an amount of time ranging from 700 to 1300 ms (intertrial interval, ITI).

EEG Recording and Processing

EEG was recorded at a sampling rate of 500 Hz and a resolution of 0.12 μV from 59 active sites referenced to Cz using an SA Instrumentation Co. (San Diego, CA) UF-64/72BA amplifier and in-house developed acquisition software. Impedance of each sensor was kept below 10 kΩ. EEG was on-line filtered from 0.01 to 100 Hz. Eye movements were recorded from two bipolar pairs of electrodes, placed, respectively, 1 cm above and below the right eye and 1 cm to the left and right sides of the eyes. Ocular signal was recorded with a resolution of 0.24 μV, and was on-line filtered from 0.01 to 100 Hz. Off-line analysis was performed using EMEGS (Junghöfer & Peyk, 2004), and included removal of eye movements from the EEG signal (Gratton, Coles, & Donchin, 1983), artifact detection and sensor interpolation (Junghöfer, Elbert, Tucker, & Rockstroh, 2000), and average reference. On average, 87.5% clean trials entered analysis.

Wavelet Analysis

A time-frequency analysis was conducted on single trial data, using complex Morlet wavelets varying in time and frequency with a Gaussian shape. The time-frequency analysis was performed using the FieldTrip software (http://fieldtrip.fcdonders.nl/) through EMEGS (Peyk, De Cesarei, & Junghöfer, 2011). The f/SD(f) ratio was set to 3 and the number of wavelet cycles was set to 5 (Tallon-Baudry, Bertrand, Delpuech, & Pernier, 1997). The range of analysis was from 8 to 80 Hz, and analysis was performed in time windows from -500 ms before picture onset to 1 s after picture onset, in steps of 10 ms. As frequency resolution is maximal for low frequencies and minimal for high frequencies (Roach & Mathalon, 2008), the step between successive frequencies varied linearly from 0.5 Hz for the lowest frequencies to 5 Hz for the highest frequencies. The power spectrum was converted in dB (Delorme & Makeig, 2004), and the -200 to -50 ms baseline period preceding picture onset was subtracted from the resulting power spectrum.

Data Analysis

Averaged ERP waveforms were calculated for each participant and experimental condition. LPP was scored as the average ERP amplitude at centroparietal sensor sites (CP3, CP1, CPz, CP2, CP4, P3, P1, Pz, P2, P4). LPP was scored in the 300–700 ms time interval. A baseline correction based on the 100 ms prior to stimulus onset was performed.

Alpha desynchronization was scored at bilateral parieto-occipital sensor sites (P7, P5, P3, P1, P2, P4, P6, P8, PO7, PO5, PO3, PO2, PO4, PO6, O3, O1, O2, O4), in the same time interval as the LPP (300–700 ms). Data from two participants, who did not exhibit a high prestimulus alpha power and consequently did not show any alpha reduction after picture presentation, were discarded from this analysis.

Separately for each dependent variable, a repeated measures analysis of variance (ANOVA) was conducted with picture category (9 levels) and picture size (4 levels) as factors. In order to deal with sphericity violations that increase the probability of type I error, a Huynh-Feldt correction (Huynh & Feldt, 1970) was applied to the degrees of freedom. The partial eta squared statistic, indicating the proportion between the variance explained by one experimental condition and the total variance, has been calculated and is reported as a measure of effect size. Additionally, an analysis of contrast was carried out to describe significant trends in the data (Loftus, 1996). As picture category comprised several levels, this approach was chosen because it allows for the identification of predictable trends in the data, which can be interpreted according to previous literature and research hypotheses. Following previous results (Bradley et al., 2001; Bradley & Lang, 2007), the order of levels for the picture category was: erotic couples, opposite sex nudes, babies, animals, faces, neutral people, animal attack, human attack, and mutilated bodies. In this way, a quadratic effect described patterns which were more (or less) pronounced for arousing compared to neutral stimuli. For picture size, the order of levels was: 100%, 50%, 25%, 12.5%. In this way, a linear effect indicated patterns that either increased or declined with picture size.

As the aim of the study was to compare affective modulation of the LPP and of α-ERD, additional analyses were conducted. First, the average of responses for both the LPP and α-ERD was calculated for each picture category. These responses were then compared to each other by means of a linear fit, to test the association between the affective modulation of these responses. Moreover, the quadratic coefficient of the category effect was calculated for each participant and response. The quadratic coefficient describes the fit between observed data and the data predicted by picture arousal and allows us to determine the extent to which each participant exhibited a modulation by arousal of the LPP, of the α-ERD, or both. Quadratic coefficients that exceeded the $0 \pm 95\%$ confidence interval threshold were regarded as statistically significant. The correlation of the quadratic coefficients for the LPP and the α-ERD was also examined, to investigate the within-participant association between affective modulation of these two electrocortical responses.

Results

Late Positive Potential[2]

A significant main effect of Category was observed on the LPP window, $F(8,152) = 19.59$, $p < .001$, $\eta^2_p = .51$. This effect was further characterized by a significant quadratic contrast, $F(1,19) = 58.61$, $p < .001$, $\eta^2_p = .76$, indicating a more positive LPP for arousing compared to neutral pictures (see Figures 1 and 2). Pairwise comparisons are reported in Table 1. A significant effect of picture size was observed, $F(3,57) = 16.56$, $p < .001$, $\eta^2_p = .47$, indicating less positivity in the LPP window for smaller compared to larger pictures. However, statistical analysis failed to reveal any significant interaction between Category and Size, $F(24,456) < 1$, ns.

Alpha Band (9–12 Hz)

Alpha-ERDs are reported in Figure 2. A significant effect of picture category was observed on α-ERD, $F(8,136) = 9.38$,

[2]A previous study (De Cesarei & Codispoti, 2006) reported that affective picture content modulated occipital ERPs in the 150–300 ms time window, and that this effect was dampened by picture size reduction. Therefore, a preliminary analysis was carried out to investigate the effects of picture content and size on this early ERP modulation. ERPs in the temporo-occipital scalp region (sensors TP7, TP8, P7/T5, P5, P6, P8/T6, PO7, PO5, PO3, POz, PO4, PO6, PO8) were averaged in the 150–300 ms time interval. A main effect of picture category was observed, $F(8,152) = 18.73$, $p < .001$, $\eta^2_p = .5$, and qualified by a significant quadratic contrast, $F(1,19) = 40.65$, $p < .001$, $\eta^2_p = .68$, indicating less pronounced positivity for arousing compared to neutral images. Consistent with previous results (De Cesarei & Codispoti, 2006), this effect was dampened by picture size reduction, as revealed by the significant size × category interaction, $F(24,456) = 2.21$, $p < .01$, $\eta^2_p = .1$. Additionally, a main effect of picture size was also observed, $F(3,57) = 23.74$, $p < .001$, $\eta^2_p = .56$, indicating less pronounced positivity for smaller as compared to larger pictures.

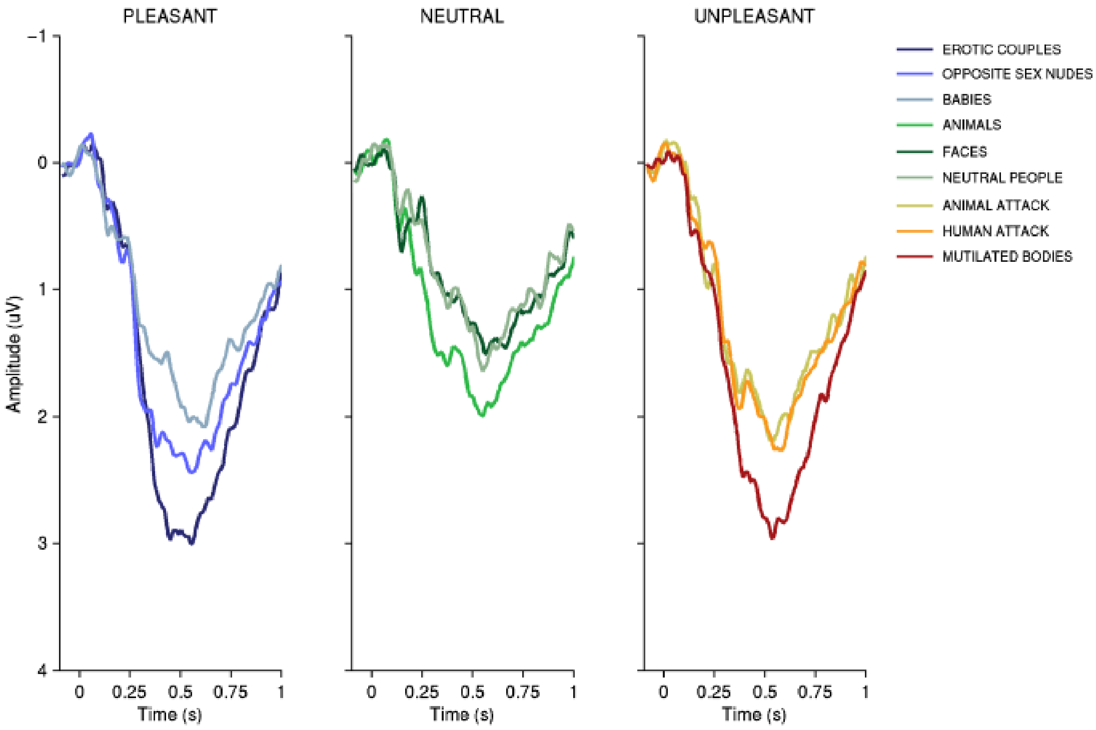

Figure 1. The effects of picture content on LPP at centroparietal sensor sites. Data from separate picture sizes were averaged together.

$p < .001$, $\eta^2_p = .36$. Alpha-ERD was more pronounced in reaction to more arousing stimuli compared to less arousing and neutral contents, and this effect was well described by a quadratic trend, $F(1,17) = 40.42$, $p < .001$, $\eta^2_p = .7$. Pairwise comparisons are reported in Table 1. Picture size significantly modulated α-ERD, with less pronounced desynchronization in reaction to smaller compared to larger pictures, $F(3,51) = 19.35$, $p < .001$, $\eta^2_p = .53$. However, no interaction of picture content and size was observed, $F(24,408) = 1.34$, ns.

Affective Modulation of the LPP and α-ERD

As both the α-ERD and the LPP were modulated by picture content in a similar time window, and this affective modulation was similarly unaffected by picture size reduction, an additional analysis directly examined the relationship between affective modulation of the LPP and of the α-ERD. The α-ERD–LPP relationship was described almost perfectly by a linear fit, $R^2 = .93$. Consistently, affective modulation of these measures was markedly similar (see Figure 2).

To examine the association between affective modulation of the α-ERD and the LPP at the individual level, an additional analysis was carried out. In this analysis, the quadratic trend coefficient of the category effect, indicating the fit between observed data and the data predicted by picture arousal, was calculated for each participant. Significant quadratic modulations of LPP and α-ERD band were observed for 17 (94%) and 15 (83%) participants, respectively. Notably, 14 out of the 17 participants who showed a quadratic modulation of LPP also showed a quadratic modulation of α-ERD. However, no significant correlation was observed between the quadratic modulation of LPP and α-ERD, Pearson $r = -.29$, ns.

Discussion

In this study, we assessed the effects of natural scenes, varying in emotional picture content and size, on α-ERD and the LPP. We observed a clear relationship between affective modulation of the LPP and of the α-ERD. The pattern of affective modulation of these two brain responses was remarkably similar, and both measures were modulated by emotional picture content and by picture size in the same time window. In addition to these positive findings, no interaction of picture size and category was observed on either response. Finally, most participants who exhibited an LPP affective modulation also showed α-ERD emotional modulation.

In terms of functional significance, the LPP and the α-ERD have been suggested to reflect different processes. On the one hand, the LPP has been interpreted to reflect both attentional allocation toward significant stimuli and motivational significance—the activation of appetitive and defensive motivational systems (Codispoti et al., 2007; Ferrari et al., 2011). On the other hand, decreased alpha-band activity has been interpreted as representing an electrophysiological correlate of cortical activation or enhanced cortical excitability and engagement in stimulus processing (Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003; Klimesch, 1999; Klimesch, Sauseng, & Hanslmayr, 2007; Pfurtscheller, 2001; Pfurtscheller et al., 1996; Sauseng & Klimesch, 2008). In the present results, when arousing compared to neutral pictures were presented, alpha power over occipital scalp regions decreased, suggesting a higher activation of visual processing areas possibly associated with perceptual enhancement.[3]

[3]While the present study clearly demonstrated that picture size reduction did not dampen affective modulation of the LPP and α-ERD, the present results are also of interest regarding the processing of pictures

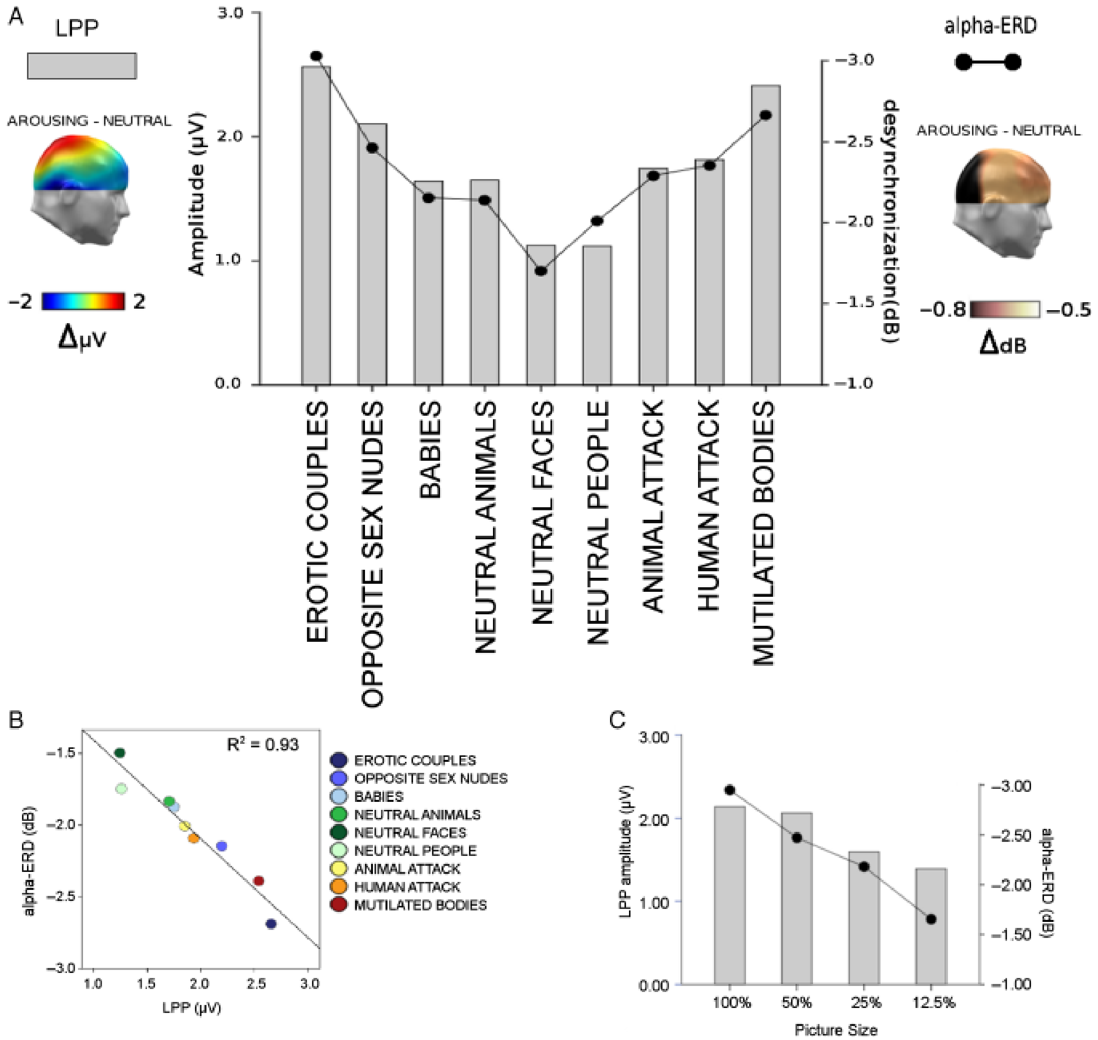

Figure 2. The effects of picture content and size on the LPP and on the α-ERD. A: The effects of picture category on the LPP (bars) and on the α-ERD (lines and dots). Scalp topography of the LPP and on the α-ERD are represented on the left and right side of the graph, next to the corresponding y axis of the bar graph. B: Linear correlation between the effects of picture category on the LPP and on the α-ERD. C: The effects of picture size on the LPP (bars) and on the α-ERD (lines and dots).

Consistent with these findings, neuroimaging studies indicate that during affective picture perception both unpleasant and pleasant pictures prompt significantly greater activation across the extrastriate occipital, parietal, and inferior temporal visual cortex, compared to neutral pictures (Bradley et al., 2003; Vuilleumier & Driver, 2007). One interpretation of these findings is that this larger activation of visual processing areas for emotional stimuli, compared to neutral stimuli, is attributable to re-entrant projections to the sensory system from the brain's motivational circuits (Amaral & Price, 1984; Amaral, Price, Pitkanen, & Carmichael, 1992; Spiegler & Mishkin, 1981). The present results suggest that, in addition to the enhanced metabolic request revealed by fMRI, these re-entrant projections may also modulate the EEG alpha rhythm as reflected by α-ERD, when motivational circuits signal the presence of a relevant stimulus.

varying in size and complexity. While overall brightness was kept constant in all four sizes (De Cesarei & Codispoti, 2006), the complexity of pictures varied with picture size, with smaller pictures containing less finely grained details compared to larger pictures (De Cesarei & Codispoti, 2008, 2010; Loftus & Harley, 2005). It may be that different levels of complexity, rather than the different picture sizes, caused the overall reduction in ERP positivity and in alpha desynchronization for smaller compared to larger images. While future studies might further investigate this topic, it is interesting to note that neither factor—picture size or complexity—affected emotional modulation of the LPP or of the α-ERD.

Table 1. *Pairwise Comparisons of the LPP and Alpha-ERD*

Category	LPP	Alpha-ERD
Erotic couples	ab	ab
Opposite sex nudes	bcd	bcde
Babies	de	cdefg
Neutral animals	de	cdefg
Neutral faces	f	efg
Neutral people	f	defg
Animal attack	de	bcdef
Human attack	cde	bcde
Mutilated bodies	ab	bcd

Note: Categories which share at least one letter do not significantly differ.

Previous research on alpha oscillations during emotional picture processing has reported inconsistent findings: some studies observed no effects of picture arousal on alpha activity (Keil et al., 2001; Müller, Keil, Gruber, & Elbert, 1999), whereas other studies observed larger event-related synchronization during high arousal pictures, over the frontal area only, compared to low arousal ones (Aftanas, Reva, Varlamov, Pavlov, & Makhnev, 2004; Aftanas, Varlamov, Pavlov, Makhnev, & Reva, 2002); or alpha suppression as a function of emotional arousal over the parietal area (Simons, Detenber, Cuthbert, Schwartz, & Reiss, 2003). However, these studies varied remarkably in terms of critical aspects such as picture exposure duration of the stimuli, central or lateralized presentation of the stimuli, dissimilar baseline measures, data analysis technique to calculate alpha oscillations, or limited numbers of sensors and reference-dependent characterization of field potential. It may well be that one of these aspects is critical for elicitation of affective modulation of the α-ERD, and future studies might systematically explore the role of stimulus parameters and of data acquisition and analysis on event-related desynchronization of the alpha rhythm.

While previous studies focused on the effects of top-down or contextual manipulations such as directed attention or stimulus repetition, the present study focused on a bottom-up manipulation, namely size reduction, which is expected to reduce the imminence of an emotional stimulus (Codispoti & De Cesarei, 2007; De Cesarei & Codispoti, 2008; Detenber & Reeves, 1996). Affective modulation of the LPP was similar across picture sizes ranging from $21 \times 16^\circ$ to $3 \times 2^\circ$, as was previously observed for highly arousing contents (De Cesarei & Codispoti, 2006). In addition, the present study examined less arousing picture categories, the relevance of which may be more directly related to the distance from the observer (e.g., a threatening animal); in contrast with this hypothesis, it was observed that affective modulation to these pictures was similar across all picture sizes, suggesting that affective modulation of the LPP is related to the detection of relevant contents, with little modulation caused by their imminence. Alpha desynchronization closely replicated this pattern of results, with similar affective modulation for large and small stimuli. Altogether, these results suggest that affective modulation of both LPP and α-ERD may be driven by the symbolic meaning of a visual scene, rather than by its visual imminence (De Cesarei & Codispoti, 2006).

The present results integrate well with the results of previous studies in describing the emotional response to stimuli varying in content and size. In particular, it has been repeatedly observed that affective modulation of sympathetic activation varies with picture size, possibly reflecting a gradient of action preparation to relevant contents varying in imminence (Codispoti & De Cesarei, 2007; De Cesarei & Codispoti, 2010; Teghtsoonian & Frost, 1982). On the other hand, physiological as well as behavioral responses related to attention allocation and engagement of motivational systems were similarly modulated by emotional pictures varying in size (Codispoti & De Cesarei, 2007; De Cesarei & Codispoti, 2006, 2008, 2010). In addition, the results of the present study suggest that perceptual enhancement as a reaction to relevant contents, indexed by the α-ERD, is modulated by the presence but not by the imminence of arousing pictures.

As the present data suggest a strong functional association between the LPP and the α-ERD, it is tempting to conclude that these two responses might index the same brain processes. However, there are several reasons to be cautious regarding this possibility. Although the pattern of modulation by category and by size, but not by their interaction, was similar for the two responses, the effect sizes revealed that the LPP was more systematically related to affective picture content compared to α-ERD, suggesting a greater interindividual variability in alpha modulation compared to the LPP. Along the same lines, a linear relationship between the affective modulation of LPP and α-ERD was not found. An additional difference was that the topographic distribution of the affective modulation differed, and in particular was observed at occipital sites for the α-ERD and at centroparietal sites for the LPP. In order to determine a strong functional association between two responses, future studies should evaluate if these cortical responses are similarly modulated by other top-down and bottom-up factors.

In this direction, the present study provided two important results: first, a common modulatory factor of the LPP and α-ERD was identified in the arousing value of affective pictures; second, it was shown that picture size reduction modulated overall magnitudes but did not dampen emotional modulation of either response. Future studies could examine the extent to which other perceptual (e.g., color or composition) or contextual (e.g., directed attention or repetition) manipulations might exert similar effects on these two responses, highlighting functional similarities or dissociations.

References

Aftanas, L. I., Reva, N. V., Varlamov, A. A., Pavlov, S. V., & Makhnev, V. P. (2004). Analysis of evoked EEG synchronization and desynchronization in conditions of emotional activation in humans: Temporal and topographic characteristics. *Neuroscience and Behavioral Physiology*, *34*, 859–867.

Aftanas, L. I., Varlamov, A. A., Pavlov, S. V., Makhnev, V. P., & Reva, N. V. (2002). Time-dependent cortical asymmetries induced by emotional arousal: EEG analysis of event-related synchronization and desynchronization in individually defined frequency bands. *International Journal of Psychophysiology*, *44*, 67–82.

Amaral, D. G., & Price, J. L. (1984). Amygdalo-cortical projections in the monkey (Macaca fascicularis). *Journal of Comparative Neurology*, *230*, 465–496.

Amaral, D. G., Price, J. L., Pitkanen, A., & Carmichael, T. (1992). Anatomical organization of the primate amygdaloid complex. In J. Aggleton (Ed.), *The amygdala: Neurobiological aspects of emotion, memory, and mental dysfunction* (pp. 1–66). New York, NY: Wiley-Liss.

Azizian, A., Freitas, A. L., Parvaz, M. A., & Squires, N. K. (2006). Beware misleading cues: Perceptual similarity modulates the N2/P3 complex. *Psychophysiology*, *43*, 253–260.

Bastiaansen, M. C., Böcker, K. B., Brunia, C. H., de Munck, J. C., & Spekreijse, H. (2001). Event-related desynchronization during anticipatory attention for an upcoming stimulus: A comparative EEG/MEG study. *Clinical Neurophysiology*, *112*, 393–403.

Berger, H. (1929). Über das Elektrenkephalogramm des Menschen. *Archiv für Psychiatrie und Nervenkrankheiten*, *87*, 527–570.

Bradley, M. M. (2009). Natural selective attention: Orienting and emotion. *Psychophysiology*, *46*, 1–11.

Bradley, M. M., Codispoti, M., Cuthbert, B. N., & Lang, P. J. (2001). Emotion and motivation I: Defensive and appetitive reactions in picture processing. *Emotion*, *1*, 276–298.

Bradley, M. M., & Lang, P. J. (2007). Emotion and motivation. In J. T. Cacioppo, L. G. Tassinary, & G. Berntson (Eds.) *Handbook of Psychophysiology* (3rd ed, pp. 581–607). New York, NY: Cambridge University Press.

Bradley, M. M., Sabatinelli, D., Lang, P. J., Fitzsimmons, J. R., King, W., & Desai, P. (2003). Activation of the visual cortex in motivated attention. *Behavioral Neuroscience*, *117*, 369–380.
Codispoti, M., & De Cesarei, A. (2007). Arousal and attention: Picture size and emotional reactions. *Psychophysiology*, *44*, 680–686.
Codispoti, M., Ferrari, V., & Bradley, M. M. (2007). Repetition and event-related potentials: Distinguishing early and late processes in affective picture perception. *Journal of Cognitive Neuroscience*, *19*, 577–586.
Codispoti, M., Mazzetti, M., & Bradley, M. M. (2009). Unmasking emotion: Exposure duration and emotional engagement. *Psychophysiology*, *46*, 731–738.
Cooper, N. R., Croft, R. J., Dominey, S. J., Burgess, A. P., & Gruzelier, J. H. (2003). Paradox lost? Exploring the role of alpha oscillations during externally vs. internally directed attention and the implications for idling and inhibition hypotheses. *International Journal of Psychophysiology*, *47*, 65–74.
Cuthbert, B. N., Schupp, H. T., Bradley, M. M., Birbaumer, N., & Lang, P. J. (2000). Brain potentials in affective picture processing: Covariation with autonomic arousal and affective report. *Biological Psychology*, *52*, 95–111.
De Cesarei, A., & Codispoti, M. (2006). When does size not matter? Effects of stimulus size on affective modulation. *Psychophysiology*, *43*, 207–215.
De Cesarei, A., & Codispoti, M. (2008). Fuzzy picture processing: Effects of size reduction and blurring on emotional processing. *Emotion*, *8*, 352–363.
De Cesarei, A., & Codispoti, M. (2010). Effects of picture size reduction and blurring on emotional engagement. *PLoS ONE*, *5*, e13399.
Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics. *Journal of Neuroscience Methods*, *134*, 9–21.
Detenber, B. H., & Reeves, B. (1996). A bio-informational theory of emotion: Motion and image size effects on viewers. *Journal of Communication*, *46*, 66–84.
Donchin, E. (1981). Presidential address, 1980. Surprise!...Surprise? *Psychophysiology*, *18*, 493–513.
Ferrari, V., Bradley, M. M., Codispoti, M., & Lang, P. J. (2011). Repetitive exposure: Brain and reflex measures of emotion and attention. *Psychophysiology*, *48*, 515–522.
Gratton, G., Coles, M. G., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology*, *55*, 468–484.
Herrmann, C. S., & Knight, R. T. (2001). Mechanisms of human attention: Event related potentials and oscillations. *Neuroscience & Biobehavioral Reviews*, *25*, 465–476.
Huynh, H., & Feldt, L. S. (1970). Conditions under which mean square ratios in repeated measurements design have exact F-distributions. *Journal of the American Statistical Association*, *65*, 1582–1589.
Johnson, R. Jr. (1986). A triarchic model of P300 amplitude. *Psychophysiology*, *23*, 367–384.
Johnston, V. S., Miller, D. R., & Burleson, M. H. (1986). Multiple P3s to emotional stimuli and their theoretical significance. *Psychophysiology*, *23*, 684–694.
Junghöfer, M., & Peyk, P. (2004). Analyzing electrical activity and magnetic fields in the brain. *Matlab News & Notes*, *2/04*, 14–15.
Junghöfer, M., Elbert, T., Tucker, D. M., & Rockstroh, B. (2000). Statistical control of artifacts in dense array EEG/MEG studies. *Psychophysiology*, *37*, 523–532.
Keil, A., Müller, M. M., Gruber, T., Wienbruch, C., Stolarova, M., & Elbert, T. (2001). Effects of emotional arousal in the cerebral hemispheres: A study of oscillatory brain activity and event-related potentials. *Clinical Neurophysiology*, *112*, 2057–2068.
Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. *Brain Research Reviews*, *29*, 169–195.
Klimesch, W., Doppelmayr, M., Russegger, H., Pachinger, T., & Schwaiger, J. (1998). Induced alpha band power changes in the human EEG and attention. *Neuroscience Letters*, *244*, 73–76.
Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: The inhibition-timing hypothesis. *Brain Research Reviews*, *53*, 63–88.
Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology*, *38*, 557–577.
Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). *International affective picture system (IAPS): Affective ratings of pictures and instruction manual*. Technical Report A-8 Gainesville, FL: University of Florida.
Loftus, G. R. (1996). Psychology will be a much better science when we change the way we analyze data. *Current Directions in Psychological Science*, *5*, 161–171.
Loftus, G. R., & Harley, E. M. (2005). Why is it easier to identify someone close than far away? *Psychonomic Bulletin & Review*, *12*, 43–65.
Luck, S. J., & Hillyard, S. A. (2000). The operation of selective attention at multiple stages of processing: Evidence from human and monkey electrophysiology. In M. S. Gazzaniga (Ed.), *The new cognitive neurosciences*. Cambridge, MA: MIT Press.
Mazaheri, A., & Picton, T. W. (2005). EEG spectral dynamics during discrimination of auditory and visual targets. *Cognitive Brain Research*, *24*, 81–96.
Müller, M. M., Keil, A., Gruber, T., & Elbert, T. (1999). Processing of affective pictures modulates right-hemispheric gamma band EEG activity. *Clinical Neurophysiology*, *110*, 1913–1920.
Pernet, C., Schyns, P. G., & Demonet, J. F. (2007). Specific, selective or preferential: Comments on category specificity in neuroimaging. *Neuroimage*, *35*, 991–997.
Peyk, P., De Cesarei, A., & Junghöfer, M. (2011). Electromagnetic encephalography software: Overview and integration with other EEG/MEG toolboxes. *Computational Intelligence and Neuroscience*, Article ID 861705. doi: 10.1155/2011/861705
Pfurtscheller, G. (2001). Functional brain imaging based on ERD/ERS. *Vision Research*, *41*, 1257–1260.
Pfurtscheller, G., Stancák, A. Jr., & Neuper, C. (1996). Event-related synchronization (ERS) in the alpha band—an electrophysiological correlate of cortical idling: A review. *International Journal of Psychophysiology*, *24*, 39–46.
Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, *118*, 2128–2148.
Radilova, J. (1982). The late positive component of visual evoked response sensitive to emotional factors. *Activitas Nervosa Superior, Suppl.*, *3*, 334–337.
Roach, B. J., & Mathalon, D. H. (2008). Event-related EEG time-frequency analysis: An overview of measures and an analysis of early gamma band phase locking in schizophrenia. *Schizophrenia Bulletin*, *34*, 1–20.
Roth, W. T. (1983). A comparison of P300 and skin conductance response. In A. W. K. Gaillard & W. Ritter (Eds.), *Tutorials in event related potentials: Endogenous components* (pp. 177–199). Amsterdam, The Netherlands: North-Holland.
Sauseng, P., & Klimesch, W. (2008). What does phase information of oscillatory brain activity tell us about cognitive processes? *Neuroscience & Biobehavioral Reviews*, *32*, 1001–1013.
Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-prime user's guide*. Pittsburgh, PA: Psychology Software Tools Inc.
Schupp, H. T., Cuthbert, B. N., Bradley, M. M., Hillman, C. H., Hamm, A. O., & Lang, P. J. (2004). Brain processes in emotional perception: Motivated attention. *Cognition and Emotion*, *18*, 593–611.
Schupp, H. T., Flaisch, T., Stockburger, J., & Junghöfer, M. (2006). Emotion and attention: Event-related brain potential studies. *Progress in Brain Research*, *156*, 31–51.
Sergeant, J., Geuze, R., & van Winsum, W. (1987). Event-related desynchronization and P300. *Psychophysiology*, *24*, 272–277.
Simons, R. F., Detenber, B. H., Cuthbert, B. N., Schwartz, D. D., & Reiss, J. E. (2003). Attention to television: Alpha power and its relationship to image motion and emotional content. *Media Psychology*, *5*, 283–301.
Spencer, K. M., & Polich, J. (1999). Poststimulus EEG spectral analysis and P300: Attention, task, and probability. *Psychophysiology*, *36*, 220–232.
Spiegler, B. J., & Mishkin, M. (1981). Evidence for the sequential participation of inferior temporal cortex and amygdala in the acquisition of stimulus-reward associations. *Behavioural Brain Research*, *3*, 303–317.
Tallon-Baudry, C., Bertrand, O., Delpuech, C., & Pernier, J. (1997). Oscillatory gamma-band (30–70 Hz) activity induced by a visual search task in humans. *Journal of Neuroscience*, *17*, 722–734.

Teghtsoonian, R., & Frost, R. O. (1982). The effect of viewing distance on fear of snakes. *Journal of Behavior Therapy and Experimental Psychiatry*, *13*, 181–190.

Vuilleumier, P., & Driver, J. (2007). Modulation of visual processing by attention and emotion: Windows on causal interactions between human brain regions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *362*, 837–855.

Yordanova, J., & Kolev, V. (1998). Event-related alpha oscillations are functionally associated with P300 during information processing. *NeuroReport*, *9*, 3159–3164.

(Received November 25, 2010; Accepted February 20, 2011)