Behavioral Neuroscience
2007, Vol. 121, No. 6, 1156–1162

0735-7044/07/$12.00 DOI: 10.1037/0735-7044.121.6.1156

Neural Response to Emotional Pictures Is Unaffected by Concurrent Task Difficulty: An Event-Related Potential Study

Greg Hajcak, Jonathan P. Dunning, and Dan Foti
Stony Brook University

The late positive potential (LPP) is an event-related potential that is enhanced when viewing arousing (pleasant and unpleasant) pictures compared to neutral pictures. The affective modulation of the LPP is believed to reflect the increased attention to, and perceptual processing of, emotional stimuli. The present study examined whether concurrent task difficulty (performing mathematics) would modulate the LPP while participants viewed emotionally arousing stimuli. Results indicated that the LPP was larger following pleasant and unpleasant stimuli than it was following neutral stimuli; moreover, the magnitude of this increase was not influenced by concurrent task difficulty. This finding suggests that the affective modulation of neural activity during picture viewing is relatively automatic and is insusceptible to competing task demands. Results are further discussed in terms of the LPP's role in motivated attention and implications for research on emotion regulation.

Keywords: emotion, late positive potential, event-related potential, International Affective Picture System, emotion regulation

Emotional stimuli, in comparison with neutral stimuli, elicit greater activation in the visual cortex during passive viewing (Bradley et al., 2003; Breiter et al., 1996; Lane, Chua, & Dolan, 1999; Lane et al., 1997; Sabatinelli, Flaisch, Bradley, Fitzsimmons, & Lang, 2004). Enhanced activity in the visual cortex has also been observed for attended relative to unattended stimuli (Gandhi, Heeger, & Boynton, 1999; Lane et al., 1999), suggesting that both attention and emotion similarly modulate neural activity related to visual processing (Lane et al., 1999; Vuilleumier, 2005). The notion that emotion directs attention and thereby facilitates perception has been described as "motivated attention" and may result from projections from the amygdala to the visual cortex (Bradley et al., 2003; Lang et al., 1998; Morris et al., 1998; Sabatinelli, Bradley, Fitzsimmons, & Lang, 2005).

A number of studies have begun to examine whether the facilitated processing of emotional stimuli depends on attentional resources. For instance, Vuilleumier, Armony, Driver, and Dolan (2001) manipulated spatial attention and found that the response of the amygdala to fearful faces was unaffected by whether emotional stimuli were presented in attended or unattended locations. Another study found that reducing attention to emotional stimuli did not decrease amygdala response to facial displays of fear (Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003).

The automaticity of facilitated emotional processing has also been examined by manipulating concurrent task demands. Erk, Abler, and Walter (2006) reported that a distracting and demanding task reduced neural activity related to emotional anticipation but did not influence neural activity related to the actual processing of emotional stimuli. Lane et al. (1999) also examined functional activity related to emotional processing under conditions of distraction and found that although emotional images (both pleasant and unpleasant) elicited increased activity in areas of the visual cortex, this activation was not influenced by concurrent task difficulty and level of distraction (Lane et al., 1999). Along similar lines, Fichtenholtz et al. (2004) found that activation of the amygdala to emotional scenes was invariant with respect to whether emotional scenes were task relevant or not. By manipulating spatial attention, task relevance, and concurrent task difficulty, these data collectively indicate that the facilitated processing of motivationally salient stimuli is relatively automatic and does not depend on the availability of attentional resources (however, see Pessoa, McKenna, Gutierrez, & Ungerleider, 2002).

As pointed out by Compton (2003), measures of emotional response using functional MRI (fMRI) are integrated over a rather long window, and the impact of attentional load on emotional processing might best be studied at earlier stages of processing. In fact, early neural response to emotional pictures and its modulation by task demands can be studied using event-related potentials (ERPs). For instance, two studies have found that an ERP index of enhanced processing of facial expressions of emotion is eliminated when spatial attention is allocated elsewhere (Eimer, Holmes, & McGlone, 2003; Holmes, Vuilleumier, & Eimer, 2003). However, it has been suggested that faces elicit relatively weak emotional responses (Ochsner, Bunge, Gross, & Gabrieli, 2002), and faces might therefore be more susceptible than more emotionally evocative stimuli to competing demands.

In the present study, we sought to investigate whether the electrocortical response to complex emotional stimuli is modulated by concurrent task difficulty. Specifically, we focused on the positive deflection in the ERP, referred to as the late positive potential (LPP), that is larger following the presentation of emotional pictures than following the presentation of neutral ones

Greg Hajcak, Jonathan P. Dunning, and Dan Foti, Department of Psychology, Stony Brook University.

Correspondence concerning this article should be addressed to Greg Hajcak, Department of Psychology, Stony Brook University, Stony Brook, NY 11794-2500. E-mail: greg.hajcak@stonybrook.edu

(Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Keil et al., 2002; Lang, Bradley, & Cuthbert, 1997b; Schupp et al., 2000). The enhancement of the LPP begins approximately 300 ms after stimulus onset and is maintained throughout the duration of stimulus presentation. Functionally, the affective modulation of the LPP is thought to reflect the increased attention to, and facilitated perceptual processing of, emotional stimuli. In fact, a recent study that combined ERP and fMRI methods indicated that the increased LPP elicited by emotional stimuli correlated with increased blood flow in occipital, parietal, and inferotemporal regions in the brain (Sabatinelli, Lang, Keil, & Bradley, 2007).

A number of recent studies from our lab have indicated that the increased LPP elicited by emotional stimuli can be modulated by emotion regulation instructions (Hajcak, Moser, & Simons, 2006; Hajcak & Nieuwenhuis, 2006; Moser, Hajcak, Bukay, & Simons, 2006). In conjunction with previous studies that report modulation of increased ERP responses to emotional facial displays as a function of spatial attention (Eimer et al., 2003; Holmes et al., 2003), it seems feasible that difficulty associated with concurrent task demands might modulate the magnitude of the LPP.

To examine the specific influence of concurrent task difficulty on electrocortical measures of emotional processing, we measured the LPP elicited by pleasant, neutral, and unpleasant pictures first in a passive viewing block, and then while participants concurrently performed either easy or more difficult mathematics. If the LPP is modulated by concurrent task difficulty, the affective modulation of the LPP (i.e., unpleasant and pleasant compared with neutral) should be reduced during a difficult concurrent task compared with during an easy concurrent task. On the other hand, the affective modulation of the LPP might be comparable across easy and difficult blocks, which would suggest that the early neural activity related to emotional processing reflected in the LPP is unaffected by concurrent task difficulty.

Method

Subjects

Twenty-three undergraduate students (10 men, 13 women) participated in the current study. Two subjects were excluded from analysis due to recordings of poor quality, leaving 21 subjects (8 men, 13 women) for the final sample. No subjects discontinued their participation in the experiment once the procedures had begun. Seven subjects were awarded $40 for their participation, and the remaining 16 subjects received course credit.

Stimulus Materials

A total of 120 pictures were selected from the International Affective Picture System (IAPS; Lang et al., 1997a); of these, 40 depicted pleasant scenes (e.g., smiling faces, nudes), 40 depicted neutral scenes (e.g., neutral faces, household objects), and 40 depicted unpleasant scenes (e.g., sad faces, violent images).[1] The three categories differed on normative ratings of valence (M = 7.07, SD = 1.68, for pleasant picture content; M = 5.07, SD = 1.24, for neutral picture content; and M = 2.42, SD = 1.58, for unpleasant picture content); in addition, the emotional pictures were reliably higher on normative arousal ratings (M = 5.42, SD = 2.23, for pleasant picture content; M = 6.19, SD = 2.21, for unpleasant picture content; and M = 2.80, SD = 1.99, for neutral picture content).

The task was administered on a Pentium D class computer using Presentation software (Neurobehavioral Systems, Inc.; Albany, CA) to control the presentation and timing of all stimuli. Each picture was displayed in color and occupied the entirety of a 19-in. (48.26-cm) monitor. At a viewing distance of approximately 24 in. (60.96 cm), each picture occupied approximately 40° of visual angle horizontally and vertically.

Procedure

After giving a brief description of the experiment, we attached electroencephalograph (EEG) sensors and gave detailed task instructions to the subjects. In the first portion of the task, subjects viewed a series of pictures as they were displayed on the screen. Twenty pictures were randomly selected for each block, with a total of six blocks. Each of the 120 pictures was displayed exactly once during this portion of the task. At the beginning of each block, an instruction was presented for 2,000 ms ("Simply view these pictures"). Each picture was presented for 2,000 ms, and a fixation mark (+) was presented for 500 ms between pictures.

In the second portion of the task, subjects performed mental arithmetic while viewing pictures. In each block, subjects were asked to subtract either 2 (easy condition) or 4 (difficult condition) from a running total and to say the new total out loud at the onset of the appearance of each picture. Ten randomly selected IAPS pictures were presented in each block, with a total of 24 blocks. Each of the 120 pictures was displayed twice for this portion of the task–once during an easy block and once during a difficult block. At the beginning of each block, difficulty level was randomly selected, and an instruction indicating the chosen level was displayed for 4,500 ms ("At the onset of each picture, continue to subtract ___ [*2* or *4*] from. . ."). A random integer between 50 and 100 was then selected as the starting number for that block and displayed on the screen for 2,000 ms. Otherwise, the timing of stimuli presentation was identical to that in the passive viewing condition. For every block, the difficulty level and the number of errors were recorded; however, accuracy was not assessed as a function of picture type, because within each block, picture type was random.

Psychophysiological Recording, Data Reduction, and Analysis

The continuous EEG was recorded using an ActiveTwo head cap and the ActiveTwo BioSemi system (BioSemi, Amsterdam,

[1] The numbers of the IAPS pictures used were the following: pleasant (1463, 1601, 1710, 1811, 2000, 2070, 2080, 2091, 2092, 2165, 2340, 2345, 4002, 4290, 4532, 4572, 4608, 4658, 4659, 4660, 4664, 4810, 5470, 5621, 5626, 5628, 7325, 8021, 8032, 8080, 8200, 8210, 8280, 8320, 8370, 8400, 8461, 8465, 8490, 8540), neutral (2190, 2320, 2570, 2840, 2880, 5390, 5532, 5534, 5731, 5740, 5800, 5900, 7000, 7002, 7004, 7006, 7009, 7010, 7025, 7034, 7035, 7040, 7041, 7060, 7080, 7090, 7100, 7130, 7140, 7150, 7175, 7190, 7217, 7224, 7233, 7235, 7491, 7550, 7595, 7950), and unpleasant (1050, 1200, 1300, 2730, 2800, 3010, 3160, 3170, 3230, 3261, 3300, 3350, 6200, 6210, 6230, 6244, 6250, 6312, 6313, 6370, 6550, 6560, 6571, 6821, 9040, 9042, 9050, 9253, 9300, 9400, 9405, 9410, 9433, 9520, 9600, 9611, 9810, 9910, 9920, 9921).

Netherlands). Recordings were taken from 64 scalp electrodes based on the 10/20 system, as well as 2 electrodes placed on the left and right mastoids. The electrooculogram generated from blinks and eye movements was recorded from 4 facial electrodes: 2 approximately 1 cm above and below the subject's left eye, 1 approximately 1 cm to the left of the left eye, and 1 approximately 1 cm to the right of the right eye. As per BioSemi's design, the ground electrode during acquisition was formed by the Common Mode Sense active electrode and the Driven Right Leg passive electrode.

All bioelectric signals were digitized on a laboratory microcomputer using ActiView software (BioSemi). The EEG was sampled at 500 Hz. Off-line analysis was performed using Brain Vision Analyzer software (Brain Products, Gilching, Germany). All data were re-referenced to the numeric mean of the mastoids and filtered (band-pass 0.1 to 30 Hz). The EEG was segmented for each trial, beginning 500 ms before each picture onset and continuing for 2,500 ms. The EEG was corrected for blinks and eye movements using the method developed by Gratton, Coles, and Donchin (1983). Specific intervals for individual channels were rejected in each trial by use of a semiautomated procedure, with physiological artifacts identified by the following criteria: a voltage step of more than 50.0 μV between sample points, a voltage difference of 300.0 μV within a trial, and a maximum voltage difference of less than 0.50 μV within 100-ms intervals.

ERPs were constructed by separately averaging trials in the nine conditions, representing all combinations of difficulty (view, easy, difficult) and valence (pleasant, neutral, unpleasant). For each ERP average, the average activity in the 200-ms window prior to picture onset served as the baseline. To reduce the spatial dimensions of the data set, we created eight clusters of electrodes with five electrodes in each. Per Dien and Santuzzi's (2005) suggestion, we employed three 2-level regional clusters: left versus right hemisphere, anterior versus posterior, and inferior versus superior. The left–right anterior–superior clusters included electrodes AF3/4, F1/2, F3/4, FC1/2, and FC3/4; the left–right anterior–inferior clusters were defined by electrodes AF7/8, F5/6, F7/8, FC5/6, and FT7/8; the left–right posterior–superior clusters included CP1/2, CP3/4, P1/2, P3/4, and PO3/4; and the left–right posterior–inferior clusters included CP5/6, P5/6, P7/8, PO7/8, and TP7/8.

The LPP was defined as the average activity in two time windows following stimulus onset: 400–1,000 ms (early window) and 1,000–2,000 ms (late window). The LPP was first evaluated in the view condition to identify electrode clusters and time windows in which emotional stimuli differed from neutral stimuli. Next, the LPP was compared across easy and difficult conditions as a function of picture type (pleasant, neutral, and unpleasant) at locations (i.e., spatial clusters) where picture type influenced the LPP.

In all cases, the LPP was statistically evaluated using SPSS (Version 14.0) General Linear Model software, with Greenhouse-Geisser correction applied to probability values associated with repeated measures comparisons with multiple degrees of freedom.

Results

View Condition—Early Window (400–1,000 ms)

In the early window, the LPP did not vary as a function of hemisphere, $F(1, 20) < 1$, but was larger at more posterior, $F(1, 20) = 99.60$, $p < .001$, and superior, $F(1, 20) = 25.07$, recording sites and varied as a function of stimulus type, $F(2, 40) = 6.47$, $p < .01$. The main effect of emotional stimuli on the LPP was qualified by interactions between stimulus type and the anterior–posterior, $F(2, 40) = 23.25$, $p < .001$, and inferior–superior, $F(2, 40) = 26.26$, $p < .001$, spatial dimension locations. Other two-, three-, and four-way interactions involving stimulus type did not reach significance.

To further examine the two-way interaction between stimulus type and anterior–posterior distribution, we collapsed across hemisphere and inferior–superior electrode clusters. Stimulus type influenced LPP magnitude at posterior recording sites, $F(2, 40) = 32.39$, $p < .001$, whereas the effect of stimulus type did not reach significance at anterior recording sites, $F(2, 40) = 2.82$, $p > .05$. Post hoc comparisons at the posterior recording sites indicated that the LPP was larger for pleasant and unpleasant pictures than for neutral pictures, $t(20) = 7.14$, $p < .001$, and $t(20) = 6.55$, $p < .001$, respectively; the LPP elicited by pleasant pictures did not differ from the LPP elicited by unpleasant pictures, $t(20) = 0.48$, $p > .60$. Thus, the modulation of the LPP by emotional stimuli was reliable in the early window at posterior recording sites but not anterior recording sites.

To further examine the two-way interaction between stimulus type and inferior–superior distribution, we collapsed across hemisphere and anterior–posterior electrode clusters. The LPP varied as a function of stimulus type at both inferior, $F(2, 40) = 4.10$, $p < .05$, and superior, $F(2, 20) = 10.17$, $p < .001$, electrode sites. Post hoc comparisons confirmed that pleasant pictures were associated with a larger LPP than were neutral pictures at inferior, $t(20) = 2.83$, $p < .01$, and superior, $t(20) = 5.14$, $p < .001$, recording sites. However, the LPP elicited by unpleasant images differed from that elicited by neutral images at superior, $t(20) = 3.00$, $p < .01$, but not inferior, $t(20) = 0.19$, $p > .85$, sites. Pleasant and unpleasant LPPs did not differ from one another at either superior, $t(20) = 1.09$, $p > .25$, or inferior, $t(20) = 2.48$, $p < .05$, sites after Bonferroni's correction for multiple comparisons (.05/3 = .017). In sum, then, the early LPP was larger following the presentation of emotional stimuli at superior sites; however, at inferior sites, only the LPP elicited by pleasant images differed from that elicited by neutral images.

Overall, the modulation of the LPP in the early window was reliable at superior and posterior recording sites. Figure 1 (left) presents the ERPs for pleasant, neutral, and unpleasant IAPS images in the view condition at anterior–superior and posterior–superior recording sites. Figure 2 (top left) presents the scalp distribution of both the pleasant minus neutral and unpleasant minus neutral differences in the early window. Figures 1 and 2 indicate increased positive activity at superior–posterior recording sites, consistent with previous studies on the LPP (Cuthbert et al., 2000; Hajcak & Niewwenhuis, 2006; Keil et al., 2002; Schupp et al., 2000).

View Condition—Late Window (1,000–2,000 ms)

In the late window, a similar pattern of main effects emerged. Stimulus type once again interacted with superior–inferior location, $F(2, 40) = 15.65$, $p < .001$; however, the interaction between stimulus type and anterior–posterior location did not reach significance, $F(2, 40) < 1$. Thus, emotional stimuli modulated the LPP

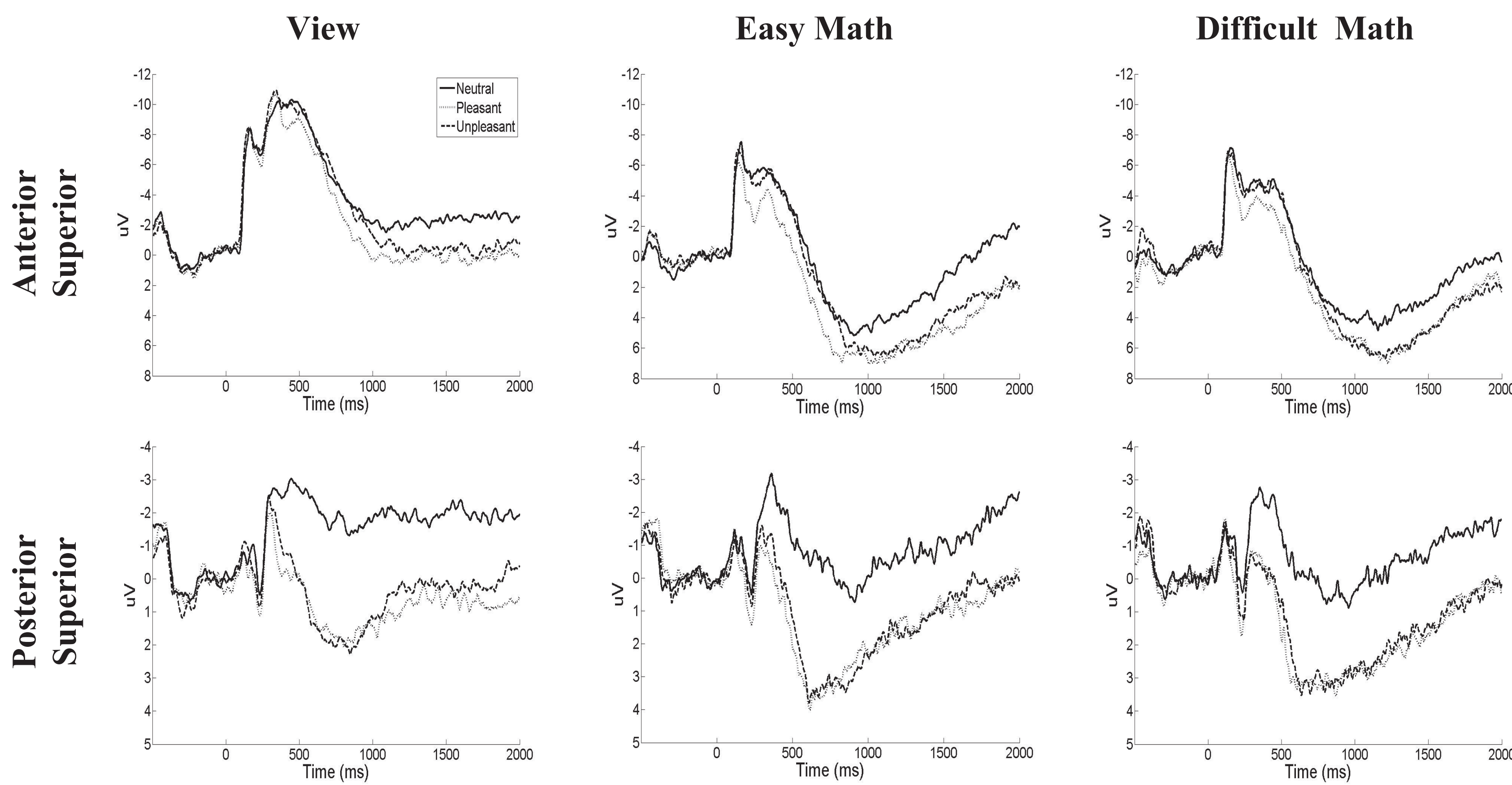

Figure 1. Event-related potentials elicited by pleasant, neutral, and unpleasant International Affective Picture System images at anterior–superior (top) and posterior–superior (bottom) electrode clusters during the view (left), easy mathematics (middle), and difficult mathematics (right) conditions. Note that the ordinate of the anterior–superior and posterior–superior graphs have different scales.

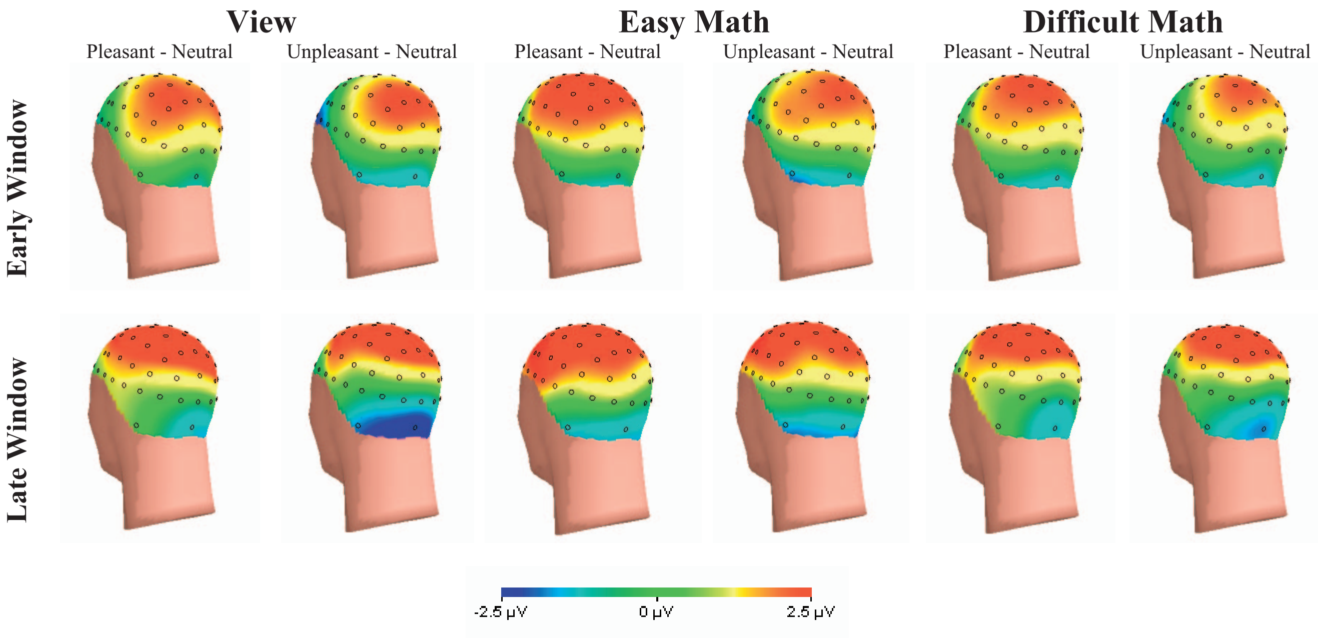

Figure 2. Scalp topography of unpleasant minus neutral and pleasant minus neutral differences in both the early (top) and late (bottom) windows during passive viewing (two columns on the left), easy mathematics (two columns in the middle), and difficult mathematics (two columns on the right) conditions.

at all superior recording sites in the late window. To further examine this interaction, we compared the LPP at superior sites, collapsing across hemisphere and anterior–posterior electrode clusters. Consistent with the impression from Figure 1, the LPP was larger for pleasant and unpleasant images than for neutral images, $t(20) = 5.28$, $p < .001$, and $t(20) = 3.12$, $p < .01$, respectively; however, the LPP for pleasant images did not differ from that for unpleasant images, $t(20) = .79$, $p > .40$. Consistent with the impressions from Figures 1 and 2, the LPP in the late window was larger following pleasant and unpleasant images than it was following neutral images at superior recording sites; however, this difference was evident at both anterior and posterior sites and was equivalent across hemispheres.

Mathematics Tasks

The LPP during easy and difficult mathematics tasks was analyzed at locations where emotion reliably modulated LPP magnitude in the passive viewing task: posterior–superior recording sites for the early window (400–1,000 ms) and superior recording sites for the late window (1,000–2,000 ms).

In the early window, a 2 (task difficulty) × 3 (stimulus type) repeated measures analysis of variance indicated that the LPP varied as a function of stimulus type, $F(2, 40) = 46.95$, $p < .001$; however, task difficulty did not influence the LPP, $F(1, 20) < 1$, and did not interact with stimulus type, $F(2, 40 < 1$. As in the viewing condition, the LPP was larger following pleasant and unpleasant pictures than it was following neutral pictures, $t(20) = 7.88$, $p < .001$, and $t(20) = 7.53$, $p < .001$, respectively. In addition, the LPP following pleasant pictures did not differ from that following unpleasant pictures, $t(20) = 1.15$, $p > .25$.

Similarly, in the late window, LPP magnitude varied as a function of stimulus type, $F(2, 40) = 15.43$, $p < .001$; however, task difficulty again did not influence the LPP, $F(2, 40) = 1.05$, $p > .30$, and did not interact with stimulus type, $F(2, 40) < 1$. Similar to the early window, the LPP was larger following pleasant and unpleasant pictures than it was following neutral pictures, $t(20) = 4.75$, $p < .001$, and $t(20) = 4.13$, $p < .001$, respectively, while the LPP following pleasant pictures did not differ from that following unpleasant pictures, $t(20) = 0.36$, $p > .70$.

Thus, the modulation of the LPP by emotional stimuli did not differ between easy and difficult tasks. In both the early and late windows, LPP magnitude elicited by emotional images differed significantly from LPP magnitude elicited by neutral images; however, unpleasant and pleasant images were associated with comparable LPPs. Consistent with the impression from Figure 1 (middle and right panels), emotional stimuli elicited a similar enhancement in both the easy and difficult conditions; this enhancement was characterized by a similar scalp topography (Figure 2, middle and right panels).

Behavioral Data

For each subject, the total number of errors committed was converted to an accuracy score for each condition, representing the percentage of correct trials. Subjects were significantly more accurate in the easy condition ($M = 96.39$, $SD = 4.90$) than in the difficult condition ($M = 84.72$, $SD = 14.20$), $t(20) = 4.89$, $p < .001$. Thus, the behavioral data confirmed that accuracy was poorer in the difficult mathematics conditions than in the easy mathematics conditions. To assess the role of differential math ability among subjects, the modulation of the LPP in the difficult condition was correlated with accuracy during difficult blocks. Accuracy in the difficult block was uncorrelated with both the unpleasant minus neutral ($r = .19$, $p > .35$) and pleasant minus neutral ($r = .10$, $p > .65$) early LPP differences at posterior sites during difficult math blocks; similarly, the unpleasant minus neutral and pleasant minus neutral late LPP differences at superior sites were uncorrelated with accuracy in the difficult blocks ($r = .28$, $p > .20$, and $r = .09$, $p > .70$, respectively).

Discussion

In line with previous studies, the LPP was reliably larger following the presentation of emotional stimuli (both pleasant and unpleasant) than following the presentation of neutral stimuli while participants passively viewed pictures. More specifically, the LPP became more positive approximately 300 ms following the onset of pleasant and unpleasant stimuli in comparison with the onset of neutral stimuli, and this difference was maintained for the duration of stimulus presentation (Cuthbert et al., 2000; Keil et al., 2002; Lang et al., 1997b; Schupp et al., 2000). This modulation of the LPP by emotional stimuli was not, however, influenced by concurrent task difficulty: The magnitude and scalp distribution of the emotion-modulated LPP was similar across passive viewing and viewing while performing easy and difficult mathematics.

Previous studies have described the emotional modulation of the LPP in terms of a parietal maximum (Keil et al., 2002; Schupp et al., 2000), whereas other studies have reported a more diffuse modulation of the LPP along midline recording sites (Cuthbert et al., 2000). In the present study, there was some degree of topographical shift in neural activity over the course of the sustained processing of emotional stimuli. Specifically, in the early window (400–1,000 ms), the modulation of the LPP was largest at bilateral superior–posterior recording sites. These results are in line with those reported by Keil and colleagues and further suggest that the parietal maximum does not depend on using the minimum norm estimate or the average reference (as employed by Keil et al., 2002). In the late window (1,000–2,000 ms), however, the larger LPP elicited by emotional stimuli was equally large across all superior recording sites. These data are more consistent with results reported by Cuthbert and colleagues (2000), who found a more diffuse influence of emotion on the LPP. Future research might utilize spatial–temporal principal component analysis to investigate the scalp topography of the LPP over the course of emotional picture processing.

In both the early (400- to 1,000-ms) and late (1,000- to 2,000-ms) poststimulus windows, pleasant and unpleasant pictures were characterized by a similar increase in LPP amplitude regardless of whether subjects were performing easy or difficult mathematics. These results appear to dovetail well with previous functional neuroimaging investigations that found distracting, demanding, or difficult tasks did not influence neural activity elicited by emotional stimuli (Erk, Abler, & Walter, 2006; Lane et al., 1999). Some positron emission tomography and fMRI studies have, however, demonstrated that concurrent attentional demands can modulate brain activity to emotional stimuli in temporal and prefrontal cortices (Pessoa et al., 2002; Vuilleumier et al., 2001), and it is worth noting that it seems unlikely that the LPP indexes activity in these regions.

The present study then indicates that relatively early electrocortical activity elicited by emotional stimuli may not be susceptible to competing task demands. These data are consistent with the suggestion that the LPP indexes the early facilitated perceptual processing of motivationally salient stimuli (Cuthbert et al., 2000; Keil et al., 2002; Lang et al., 1997b; Schupp et al., 2000) and suggest that the enhanced LPP is a relatively automatic, or bottom-up, increase in attention and perceptual processing allocated to motivationally salient stimuli (Bradley et al., 2003; Lang et al., 1997b; Keil et al., 2002).

It is interesting that several recent studies have reported a modulation of the LPP as a function of presumably top-down emotion regulation instructions. For instance, Moser et al. (2006) found that the LPP was reduced when participants were instructed to reduce their emotional response to unpleasant images. Along similar lines, Hajcak and Nieuwenhuis (2006) reported that the LPP elicited by unpleasant images was reduced after participants reinterpreted the picture in a less negative way. Thus, there is evidence that the LPP *can* be modulated by task demands, at least when the task is directly relevant to the emotional content of the stimuli. The present study might inform the interpretation of these previous LPP studies of emotion regulation. For instance, the emotion regulation condition is likely more difficult than the control condition in studies of reappraisal—and therefore differences in task difficulty might account for changes in the LPP. An alternative view is that reduced attention to the emotional stimuli—an emotion regulation strategy described as *distraction* by Gross and Thompson (2007)—might explain differences in the LPP as a function of reappraisal. However, the fact that emotional stimuli were characterized by an LPP of increased magnitude in both the easy and difficult conditions in the present study suggests that effects of emotion regulation on the LPP may not be due to distraction or differences attributable to task difficulty.

One possible limitation is that the task may not have been difficult enough to elicit differences in LPP modulation. Although it is difficult to rule out this possibility, subject performance scores confirmed that accuracy was significantly poorer in the difficult math conditions than in the easy math conditions. In addition, we did not measure the influence of emotional picture viewing on task performance. In future studies, then, it might be important to use more difficult concurrent tasks and to examine the bidirectional effects between emotional pictures and cognitive demand. Nonetheless, the present study provides initial evidence that the modulation of the LPP in the primary and secondary visual cortex by emotional stimuli is relatively automatic and is not influenced by concurrent task difficulty. These data provide support for the growing notion that emotional stimuli may automatically capture attention and receive increased processing resources in these areas.

References

Anderson, A. K., Christoff, K., Panitz, D., De Rosa, E., & Gabrieli, J. D. (2003). Neural correlates of the automatic processing of threat facial signals. *Journal of Neuroscience, 23*(13), 5627–5633.

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*(2), 369–380.

Breiter, H. C., Etcoff, N. L., Whalen, P. J., Kennedy, W. A., Rauch, S. L., Buckner, R. L., et al. (1996). Response and habituation of the human amygdala during visual processing of facial expression. *Neuron, 17*(5), 875–887.

Compton, R. J. (2003). The interface between emotion and attention: A review of evidence from psychology and neuroscience. *Behavioral and Cognitive Neuroscience Reviews, 2*(2), 115–129.

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*(2), 95–111.

Dien, J., & Santuzzi, A. M. (2005). Application of repeated measures ANOVA to high-density ERP datasets: A review and tutorial. In T. C. Handy (Ed.), *Event-related potentials: A methods handbook* (pp. 57–84). Cambridge, MA: MIT Press.

Eimer, M., Holmes, A., & McGlone, F. P. (2003). The role of spatial attention in the processing of facial expression: An ERP study of rapid brain responses to six basic emotions. *Cognitive, Affective, & Behavioral Neuroscience, 3*(2), 97–110.

Erk, S., Abler, B., & Walter, H. (2006). Cognitive modulation of emotion anticipation. *European Journal of Neuroscience, 24*(4), 1227–1236.

Fichtenholtz, H. M., Dean, H. L., Dillon, D. G., Yamasaki, H., McCarthy, G., & LaBar, K. S. (2004). Emotion-attention network interactions during a visual oddball task. *Brain Research: Cognitive Brain Research, 20*(1), 67–80.

Gandhi, S. P., Heeger, D. J., & Boynton, G. M. (1999). Spatial attention affects brain activity in human primary visual cortex. *Proceedings of the National Academy of Sciences of the United States of America, 96*(6), 3314–3319.

Gratton, G., Coles, M. G., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology, 55*(4), 468–484.

Gross, J. J., & Thompson, R. A. (Eds.). (2007). *Emotion regulation: Conceptual foundations.* New York: Guilford Press.

Hajcak, G., Moser, J. S., & Simons, R. F. (2006). Attending to affect: Appraisal strategies modulate the electrocortical response to arousing pictures. *Emotion, 6*(3), 517–522.

Hajcak, G., & Nieuwenhuis, S. T. (2006). Reappraisal modulates the electrocortical response to negative pictures. *Cognitive, Affective, and Behavioral Neuroscience, 6,* 291–297.

Holmes, A., Vuilleumier, P., & Eimer, M. (2003). The processing of emotional facial expression is gated by spatial attention: Evidence from event-related brain potentials. *Brain Research. Cognitive Brain Research, 16*(2), 174–184.

Keil, A., Bradley, M. M., Hauk, O., Rockstroh, B., Elbert, T., & Lang, P. J. (2002). Large-scale neural correlates of affective picture processing. *Psychophysiology, 39*(5), 641–649.

Lane, R. D., Chua, P. M., & Dolan, R. J. (1999). Common effects of emotional valence, arousal and attention on neural activation during visual processing of pictures. *Neuropsychologia, 37*(9), 989–997.

Lane, R. D., Reiman, E. M., Bradley, M. M., Lang, P. J., Ahern, G. L., Davidson, R. J., et al. (1997). Neuroanatomical correlates of pleasant and unpleasant emotion. *Neuropsychologia, 35*(11), 1437–1444.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997a). *International Affective Picture System: Instruction manual and affective ratings.* Gainesville, FL: University of Florida, The Center for Research in Psychophysiology.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997b). Motivated attention: Affect, activation and action. In P. J. Lang, R. F. Simons, & M. T. Balaban (Eds.), *Attention and orienting: Sensory and motivational processes* (pp. 97–135). Hillsdale, NJ: Erlbaum.

Lang, P. J., Bradley, M. M., Fitzsimmons, J. R., Cuthbert, B. N., Scott, J. D., Moulder, B., et al. (1998). Emotional arousal and activation of the visual cortex: An fMRI analysis. *Psychophysiology, 35*(2), 199–210.

Morris, J. S., Friston, K. J., Buchel, C., Frith, C. D., Young, A. W., Calder, A. J., et al. (1998). A neuromodulatory role for the human amygdala in processing emotional facial expressions. *Brain, 121,* 47–57.

Moser, J. S., Hajcak, G., Bukay, E., & Simons, R. F. (2006). Intentional modulation of emotional responding to unpleasant pictures: An ERP study. *Psychophysiology, 43*(3), 292–296.

Ochsner, K. N., Bunge, S. A., Gross, J. J., & Gabrieli, J. D. (2002). Rethinking feelings: An FMRI study of the cognitive regulation of emotion. *Journal of Cognitive Neuroscience, 14*(8), 1215–1229.

Pessoa, L., McKenna, M., Gutierrez, E., & Ungerleider, L. G. (2002). Neural processing of emotional faces requires attention. *Proceedings of the National Academy of Sciences of the United States of America, 99*(17), 11458–11463.

Sabatinelli, D., Bradley, M. M., Fitzsimmons, J. R., & Lang, P. J. (2005). Parallel amygdala and inferotemporal activation reflect emotional intensity and fear relevance. *Neuroimage, 24*(4), 1265–1270.

Sabatinelli, D., Flaisch, T., Bradley, M. M., Fitzsimmons, J. R., & Lang, P. J. (2004). Affective picture perception: Gender differences in visual cortex? *Neuroreport, 15*(7), 1109–1112.

Sabatinelli, D., Lang, P. J., Keil, A., & Bradley, M. M. (2007). Emotional perception: Correlation of functional MRI and event-related potentials. *Cerebral Cortex, 17,* 1085–1091.

Schupp, H. T., Cuthbert, B. N., Bradley, M. M., Cacioppo, J. T., Ito, T., & Lang, P. J. (2000). Affective picture processing: The late positive potential is modulated by motivational relevance. *Psychophysiology, 37*(2), 257–261.

Vuilleumier, P. (2005). How brains beware: Neural mechanisms of emotional attention. *Trends in Cognitive Sciences, 9*(12), 585–594.

Vuilleumier, P., Armony, J. L., Driver, J., & Dolan, R. J. (2001). Effects of attention and emotion on face processing in the human brain: An event-related fMRI study. *Neuron, 30*(3), 829–841.

Received April 17, 2007
Revision received July 5, 2007
Accepted July 6, 2007 ■