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The Persistence of Attention to Emotion: Brain Potentials During and After Picture Presentation

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Emotional stimuli have been shown to elicit increased perceptual processing and attentional allocation. The late positive potential (LPP) is a sustained P300-like component of the event-related potential that is enhanced after the presentation of pleasant and unpleasant pictures as compared with neutral pictures. In this study, the LPP was measured using dense array electroencephalograph both before and after pleasant, neutral, and unpleasant images to examine the time course of attentional allocation toward emotional stimuli. Results from 17 participants confirmed that the LPP was larger after emotional than neutral images and that this effect persisted for 800 ms after pleasant picture offset and at least 1,000 ms after unpleasant picture offset. The persistence of increased attention after unpleasant compared to pleasant stimuli is consistent with the existence of a negativity bias. Overall, these results indicate that attentional capture of emotion continues well beyond picture presentation and that this can be measured with the LPP. Implications and directions for future research are discussed.

Keywords: emotion, attention, late positive potential, LPP, ERP

Compared to neutral pictures, both pleasant and unpleasant pictures are viewed longer (Lang, Bradley, & Cuthbert, 1997) and elicit larger evoked potentials (Schupp, Junghofer, Weike, & Hamm, 2003). Additionally, emotional stimuli are associated with greater activation of the amygdala and visual cortex (Britton, Taylor, Sudheimer, & Liberzon, 2006). When pleasant and unpleasant images are presented simultaneously with neutral images, individuals tend initially to fixate longer on pleasant and unpleasant pictures (Calvo & Lang, 2004). These behavioral, physiological, and neural changes are thought to reflect increased attention toward motivationally salient stimuli (Lang et al., 1997; Schupp, Cuthbert et al., 2004).

Because of their excellent temporal resolution, event-related brain potentials (ERPs) can be used to assess the time course of attentional allocation to emotional stimuli. In particular, the P300 component of the ERP has been used extensively to study processes related to attention (Johnson, 1984, 1986; Magliero, Bashore, Coles, & Donchin, 1984). Consistent with the notion that emotional stimuli capture attention, both pleasant and unpleasant stimuli also elicit a slow and sustained positive ERP that has a posterior midline scalp distribution. This late positive potential (LPP) has an onset around 250 ms after stimulus presentation and is highly sensitive to the emotional nature of stimuli. The LPP generally appears larger for both pleasant and unpleasant stimuli compared with neutral stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Hajcak, Moser, & Simons, 2006; Hajcak & Nieuwenhuis, 2006; Keil et al., 2002; Lang et al., 1997; Schupp et al., 2000; Schupp, Junghofer, Weike, & Hamm, 2003).

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Given its topographical and morphological characteristics, the LPP may index similar attention and orienting processes as the classic P300 wave (Donchin & Coles, 1988). Just as the P300 is larger for attended than unattended stimuli, the enhanced LPP may index augmented attention to arousing stimuli (Schupp et al., 2003). In fact, increased attention to emotional stimuli results in the reduction of attention to competing stimuli. For example, the P300 elicited by background tones is actually attenuated when participants are viewing emotional compared with neutral pictures (Bradley, Codispoti, & Lang, 2006; Cuthbert, Schupp, Bradley, McManis, & Lang, 1998; Schupp, Cuthbert, Bradley, Birbaumer, & Lang, 1997; Schupp et al., 2004). These data suggest that increased attention to the foreground emotional stimuli results in decreased attentional allocation to the P300-eliciting tone (Bradley et al., 2006; Schupp et al., 1997).

Reduced probe P300 amplitude has also been reported in the postpicture period (Schupp et al., 1997). That is, even after the offset of an emotional picture, the P300 to an auditory probe continues to be reduced. The notion that pleasant and unpleasant stimuli result in the sustained capture of attention is consistent with behavioral data indicating impaired performance on trials after the presentation of emotional pictures (Hartikainen, Ogawa, & Knight, 2000; Mitchell, Richell, Leonard, & Blair, 2006; Verbruggen & De Houwer, 2007). No study to date, however, has directly examined ERPs both during and after picture presentation.

Although there appears to be facilitated attention to both pleasant and unpleasant stimuli, Cacciopo and colleagues (Ito, Larsen, Smith, & Cacioppo, 1998; Smith, Cacioppo, Larsen, & Chartrand, 2003) have argued that neural systems that evaluate emotional stimuli appear to be more sensitive to negative than positive information. For instance, attention is drawn more to unpleasant than pleasant stimuli (Hansen & Hansen, 1988; Ohman, Lundqvist, & Esteves, 2001; Pratto & John, 1991). Additionally, some studies have reported a larger LPP for unpleasant than pleasant stimuli

(Huang & Luo, 2006; Ito et al., 1998). These data suggest that the LPP might be used to assess the presence of a negative attentional bias both during and after the presentation of unpleasant stimuli.

In the present study, we examined the time course and scalp distribution of ERPs both during and after the presentation of pleasant, neutral, and unpleasant stimuli to determine whether the LPP might index the sustained increase in attention toward emotional stimuli. On the basis of existing ERP studies, we hypothesized that both pleasant and unpleasant compared with neutral stimuli would be associated with an increased LPP during picture presentation. Insofar as the LPP indexes increased attention toward emotional stimuli, we further predicted that the increased LPP would continue well into the postpicture period. Modulation of the LPP, then, might be used to shed light on the time course of attentional allocation to emotional stimuli even after the presentation of emotional stimuli. Furthermore, we examined whether attentional allocation was increased after the presentation of unpleasant compared with pleasant stimuli, as predicted by the negativity bias literature (Ito et al., 1998; Smith et al., 2003). If so, the LPP might be used to further examine the time course of this bias (Smith et al., 2003).

Method

Participants

Seventeen undergraduate students (9 men and 8 women) participated in the current study. No participants discontinued their participation in the experiment once the procedures had begun. All participants received course credit for their participation.

Stimulus Materials

We selected a total of 120 pictures from the International Affective Picture System (Lang et al., 1997); of these, 40 depicted pleasant scenes (e.g., smiling faces and nudes), 40 depicted neutral scenes (e.g., neutral faces and household objects), and 40 depicted unpleasant scenes (e.g., sad faces and 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 a brief description of the experiment, electroencephalograph (EEG) sensors were attached. In the first practice block, participants viewed 10 International Affective Picture System images and were simply instructed to view each picture. In the actual experiment, each of the 120 total pictures was displayed exactly once and was presented for 2,000 ms; a fixation mark (+) was presented for 1,500 ms during the intertrial interval. At the beginning of each block, an instruction was presented for 2,000 ms ("Simply view these pictures").

Psychophysiological Recording, Data Reduction, and Analysis

The continuous EEG was recorded using a custom elastic cap and the ActiveTwo BioSemi system (BioSemi, Amsterdam, The Netherlands). Recordings were taken from 64 scalp electrodes on the basis of the 10/20 system and 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 participant'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 rereferenced to the numeric mean of the mastoids and bandpass filtered with cutoffs of 0.1 and 30 Hz. The EEG was segmented for each trial, beginning 200 ms before each picture onset and continuing for 3,200 ms; thus, the ERP averages represented the full 2,000 ms of stimulus presentation and a 1,000-ms period after stimulus offset. 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, using 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 each picture type (pleasant, neutral, and unpleasant). For each ERP average, the average activity in the 200-ms window before 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 used three two-level regional clusters: left versus right hemisphere, anterior versus

[1] The numbers of the International Affective Picture System 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, and 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, and 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, and 9921.

posterior, and inferior versus superior. The left and right anterior–superior clusters included electrodes AF3/4, F1/2, F3/4, FC1/2, and FC3/4; the left and right anterior–inferior clusters were defined by electrodes AF7/8, F5/6, F7/8, FC5/6, and FT7/8; the left and right posterior–superior clusters included CP1/2, CP3/4, P1/2, P3/4, and PO3/4; and the left and right posterior–inferior clusters included CP5/6, P5/6, P7/8, PO7/8, and TP7/8.

The LPP was first evaluated as the average activity in two time windows: during stimulus presentation (400–2,000 ms) and after picture offset (2,000–3,000 ms). To better characterize the LPP after stimulus offset, the postpicture period was further analyzed in 200-ms windows (2,000–2,200, 2,200–2,400, 2,400–2,600, 2,600–2,800, and 2,800–3,000). In all cases, the LPP was statistically evaluated using SPSS (Version 14.0) General Linear Model software, with Greenhouse-Geisser correction applied to p values associated with multiple degrees of freedom, repeated measures comparisons.

Results

LPP During Picture Presentation (400–2,000 ms)

The scalp distributions of the unpleasant minus neutral difference waves and pleasant minus neutral difference waves are presented in Figure 1 (top). During picture presentation, the LPP did not vary between left and right hemispheres, $F(1, 16) < 1$, or between superior and inferior recording sites, $F(1, 16) < 1$, but was larger at more posterior sites, $F(1, 16) = 25.63$, $p < .001$, and varied as a function of stimulus type, $F(2, 32) = 7.54$, $p < .01$. The main effect of picture type on the LPP was qualified by interactions between stimulus type and the inferior–superior spatial dimension locations, $F(2, 32) = 7.25$, $p < .01$. 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 the inferior–superior distribution, we averaged hemisphere and the anterior–posterior electrode clusters; stimulus type influenced LPP magnitude at both superior, $F(2, 32) = 9.13$, $p < .01$, and inferior, $F(2, 32) = 5.02$, $p < .05$, recording sites. Post hoc comparisons at the superior recording sites indicated that the LPP was larger for pleasant and unpleasant as compared with neutral pictures, ts(16) = 3.88 and 4.23, ps < .001, respectively; the LPP elicited by pleasant pictures did not differ from the LPP elicited by unpleasant pictures, $t(16) = 1.42$, $p > .15$. At inferior recording sites, the LPP did not differ reliably for pleasant as compared with both neutral, $t(16) = 1.98$, $p > .05$, and unpleasant, $t(16) = 1.60$, $p > .10$, pictures. However, unpleasant pictures were associated with a larger LPP than neutral pictures, $t(16) = 2.84$, $p < .05$. In sum, the LPP was larger during the presentation of both pleasant and unpleasant emotional stimuli at superior sites; however, at inferior sites only the LPP elicited by unpleasant images differed from neutral. Figure 2 presents the ERPs for pleasant, neutral, and unpleasant pictures at superior recording sites, where

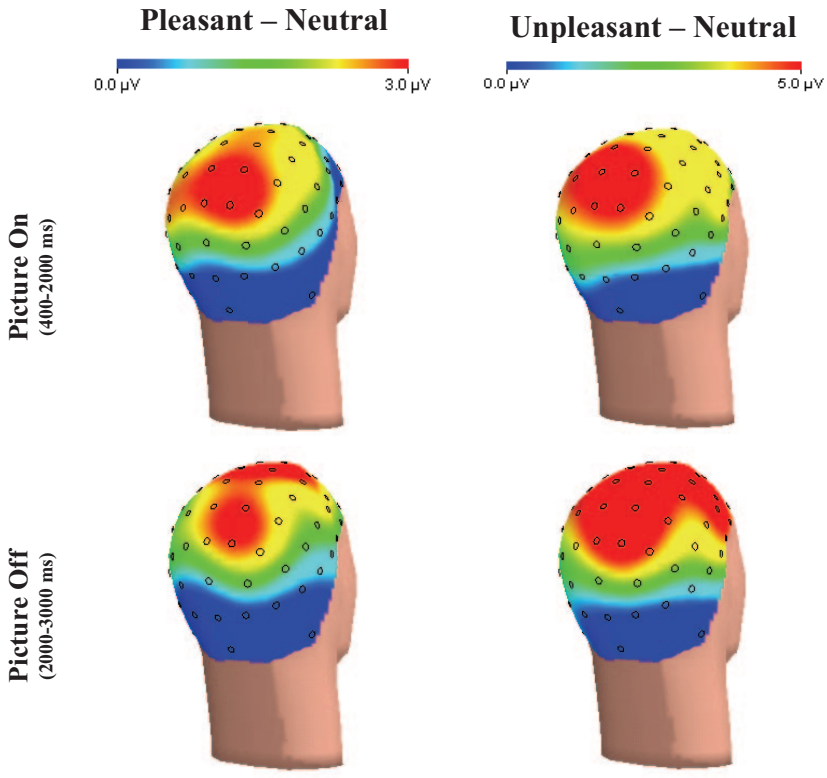

Figure 1. Scalp topography of pleasant minus neutral (left) and unpleasant minus neutral (right) event-related potential differences during (top) and after (bottom) picture presentation. Please note that the pleasant minus neutral and unpleasant minus neutral figures have different scales.

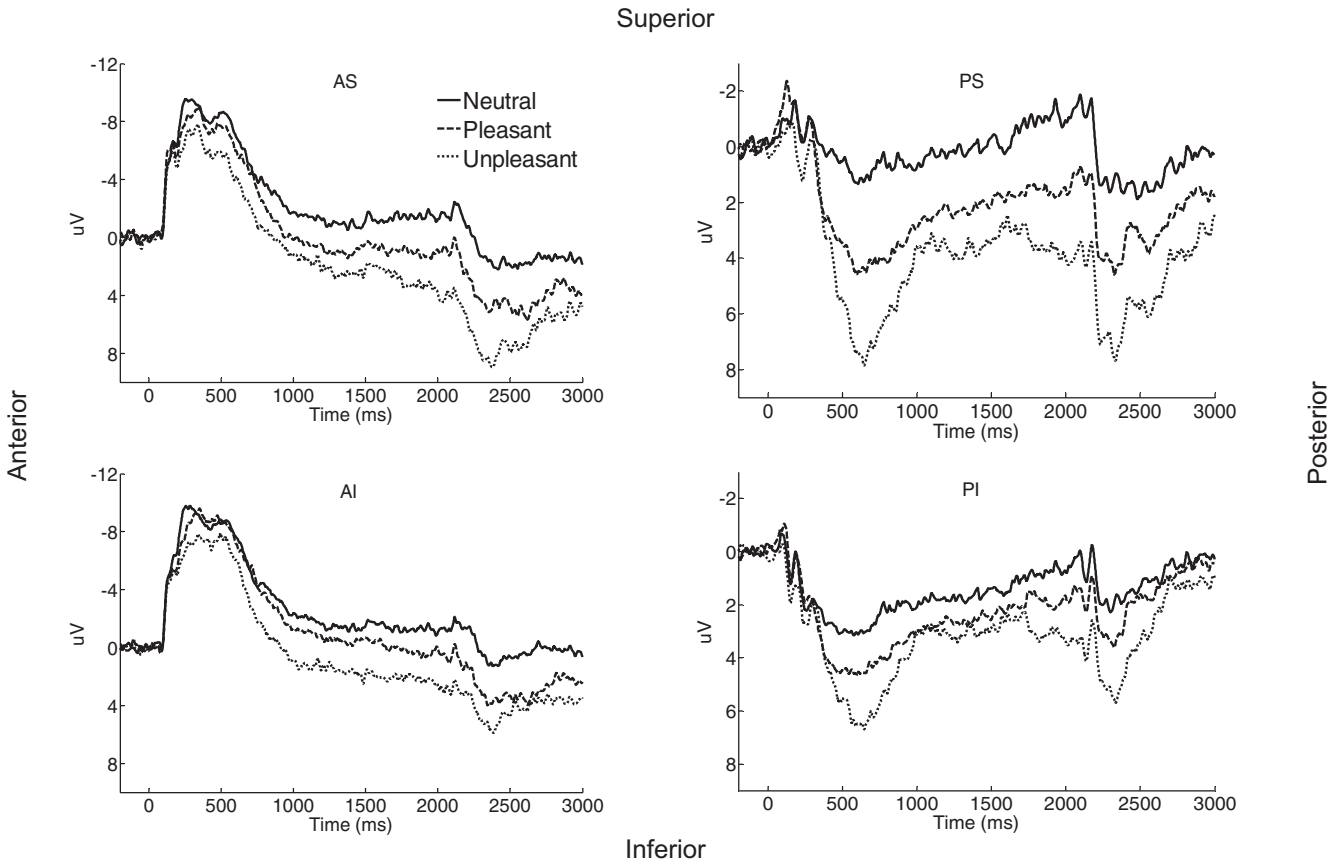

Figure 2. Event-related potentials after the presentation of pleasant, neutral, and unpleasant pictures at anterior–superior (AS; top left), anterior–inferior (AI; bottom left), posterior–superior (PS; top right), and posterior–inferior (PI; bottom right) recording sites. Please note that negative is plotted upward; the scale of the ordinate differs between anterior and posterior sites; picture onset and offset occurred at 0 and 2,000 ms, respectively.

both emotional stimuli modulated the LPP. Consistent with previous studies, the LPP diverged approximately 300 to 400 ms after picture onset and was more positive for emotional than for neutral pictures for the entire period of picture presentation (Cuthbert et al., 2000; Hajcak & Nieuwenhuis, 2006; Schupp et al., 2000).

LPP After Picture Offset (2,000–3,000 ms)

The scalp topographies of the unpleasant minus neutral and pleasant minus neutral difference waveforms are presented in Figure 1 (bottom). The analyses of the LPP magnitude after picture offset produced a pattern of results similar to what was obtained during picture presentation. In particular, the LPP continued to vary with stimulus type, $F(2, 32) = 9.59$, $p < .001$, and the magnitude of this effect differed between the superior and inferior recording sites, $F(2, 32) = 5.68$, $p < .05$. Other main effects and interactions did not reach significance.

To further examine the significant interaction involving stimulus type, we compared the LPP at inferior and superior sites, collapsing across hemisphere and anterior–posterior electrode clusters. The LPP varied as a function of stimulus type at superior recording sites, $F(2, 32) = 12.04$, $p < .001$, and post hoc paired-sample t tests confirmed that the LPP was larger for pleasant and unpleasant as compared with neutral images, ts$(16) = 3.42$ and 4.38, ps $< .001$, respectively. However, pleasant images did not differ from unpleasant images, $t(16) = 2.18$, $p < .05$, after Bonferroni's correction for multiple comparisons (.05/3 = .017). The LPP also differed as a function of stimulus type at inferior recording sites, $F(2, 32) = 5.34$, $p < .05$; however, post hoc paired-sample t tests indicated that only the LPP after unpleasant stimuli differed from neutral stimuli, $t(16) = 2.95$, $p < .01$, at inferior recording sites. The LPP after pleasant stimuli did not differ from either neutral, $t(16) = 2.09$, $p > .05$, or unpleasant pictures, $t(16) = 1.47$, $p > .15$. Thus, consistent with the impression from Figure 2, the LPP continued to be reliably larger after both pleasant and unpleasant images as compared with neutral images at superior recording sites, even after picture offset. In fact, the analyses of the LPP during and after picture offset produced nearly identical results.

To further examine the time course of the LPP after picture offset, the LPP was analyzed in successive 200-ms windows at superior recording sites, where the effect of emotion was largest and most consistent. Consistent with the overall analyses in the

2,000- to 3,000-ms window, a 5 (window: 2,000–2,200, 2,200–2,400, 2,400–2,600, 2,600–2,800, and 2,800–3,000 ms) × 3 (picture type: pleasant, neutral, and unpleasant) analysis of variance (ANOVA) revealed that the LPP varied by picture type, $F(2, 32) = 12.1$, $p < .001$. Additionally, the LPP differed over time, $F(4, 64) = 8.1$, $p < .001$, which was qualified by an interaction between window and picture type, $F(8, 28) = 4.4$, $p < .001$. An ANOVA on each window indicated significant differences of picture types in all five windows: 2,000–2,200 ms, $F(2, 32) = 17.4$, $p < .001$; 2,200–2,400 ms, $F(2, 32) = 16.7$, $p < .001$; 2,400–2,600 ms, $F(2, 32) = 10.0$, $p < .001$; 2,600–2,800 ms, $F(2, 32) = 6.7$, $p < .01$; and 2,800–3,000 ms, $F(2, 32) = 5.9$, $p < .01$. Post hoc paired-sample t tests confirmed significant differences between unpleasant and neutral pictures in all windows: 2,000–2,200 ms, $t(16) = 5.4$, $p < .001$; 2,200–2,400 ms, $t(16) = 5.0$, $p < .001$; 2,400–2,600 ms, $t(16) = 4.1$, $p = .001$; 2,600–2,800 ms, $t(16) = 3.1$, $p < .01$; and 2,800–3,000, $t(16) = 3.2$, $p < .01$. Significant differences were also found between pleasant and neutral pictures in the 2,000- to 2,200-ms, $t(16) = -4.3$, $p = .001$; 2,200- to 2,400-ms, $t(16) = -4.3$, $p = .001$; 2,400- to 2,600-ms, $t(16) = -3.0$, $p < .01$; and 2,600- to 2,800-ms windows, $t(16) = -3.1$, $p < .01$, but not in the 2,800- to 3,000-ms window, $t(16) = -2.0$, $p > .05$. Finally, there were no significant differences between unpleasant and pleasant pictures in any window after Bonferroni's correction for multiple comparisons (.05/3 = .017). Overall, these results indicate that differences in LPP between emotional and neutral pictures persist for approximately 800 ms for pleasant pictures and for at least 1,000 ms for unpleasant pictures after picture offset.

Discussion

In line with previous ERP studies of emotional picture viewing, the LPP was larger after the presentation of both pleasant and unpleasant as compared with neutral pictures—a difference that began approximately 300 to 400 ms after stimulus onset and was evident throughout the picture presentation period (Cuthbert et al., 2000; Foti & Hajcak, in press; Hajcak, Dunning, & Foti, 2007; Hajcak & Nieuwenhuis, 2006). Going beyond previous studies, results confirmed that a positivity with a similar scalp topography was also evident after stimulus offset. These data indicate that emotion-elicited attention persists after picture presentation and that the LPP can be used to study protracted attention toward emotional stimuli.

In terms of the temporal course of this effect, the LPP elicited by unpleasant as compared with neutral pictures differed for at least 1,000 ms after picture offset, whereas the LPP elicited by pleasant pictures differed from neutral pictures for 800 ms after picture offset. Thus, neural activity indexing increased attention returned to baseline faster for pleasant as compared with unpleasant emotional stimuli, suggesting that increased attention continues longer after unpleasant than pleasant stimuli. Future studies might further manipulate intertrial interval to examine the outer limits of this effect, especially with regard to attentional allocation after the presentation of unpleasant stimuli.

In the present study, the LPP during picture presentation was numerically larger for unpleasant than pleasant pictures, and at inferior recording sites, only the unpleasant pictures differed from neutral. This pattern of results is generally consistent with previous studies that have found larger LPPs to unpleasant than pleasant stimuli (Huang & Luo, 2006; Ito et al., 1998). Additionally, several previous studies have reported increases in earlier ERP measures of perception and attention in the context of viewing unpleasant stimuli (Carretie, Hinojosa, Martin-Loeches, Mercado, & Tapia, 2004; Carretie, Mercado, Tapia, & Hinojosa, 2001; Delplanque, Lavoie, Hot, Silvert, & Sequeira, 2004; Huang & Luo, 2006; Smith et al., 2003). Collectively, these data provide further support for the notion of a negativity bias in attention toward emotional stimuli and indicate that increased attentional processing of unpleasant stimuli is rather sustained. Augmented and persistent attention toward threatening stimuli may represent an evolutionarily advantageous process (Lang, Davis, & Ohman, 2000).

It is worth pointing out that other studies that have used very brief stimulus presentation durations have also suggested that the LPP does not depend on the physical presence of visual stimuli. For instance, Schupp et al. (Schupp, Junghofer et al., 2004; Schupp et al., 2007) used rapid image presentation (i.e., 120 −333 ms) and found the LPP lasts up to 300 ms after picture offset. This poststimulus effect, however, may not reflect the continued attention to emotional stimuli, but rather the delay in how long it takes for the neural generator of the LPP to develop after stimulus presentation. To our knowledge, the present study is the first to directly examine the LPP both during and after picture offset.

Jackson and colleagues (Davidson, 1998; Jackson et al., 2003) have argued that measures of emotional processing after stimulus offset can be used to index individual differences in affective style and automatic emotion regulation. For instance, a number of studies have found that the magnitude of the defensive startle reflex is larger both during and after the presentation of unpleasant pictures (Codispoti, Bradley, & Lang, 2001; Jackson, Malmstadt, Larson, & Davidson, 2000; Jackson et al., 2003; Larson, Ruffalo, Nietert, & Davidson, 2005; Schupp et al., 1997). Thus, faster startle recovery after stimulus offset may suggest increased ability to automatically "shut down" defensive emotional activity (Jackson et al., 2003). The present study raises the possibility that the LPP could also be used to quantify uninstructed attentional recovery after emotional picture offset. In fact, studies have already found that the LPP is sensitive to both explicit (Hajcak & Nieuwenhuis, 2006; Krompiner, Moser, & Simons, 2008; Moser, Hajcak, Bukay, & Simons, 2006) and implicit (Foti & Hajcak, in press; Hajcak et al., 2006) emotion regulation instructions. It will be important to determine whether postpicture LPPs might index meaningful individual differences related to affective style and automatic emotion regulation (Davidson, 1998; Jackson et al., 2003).

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