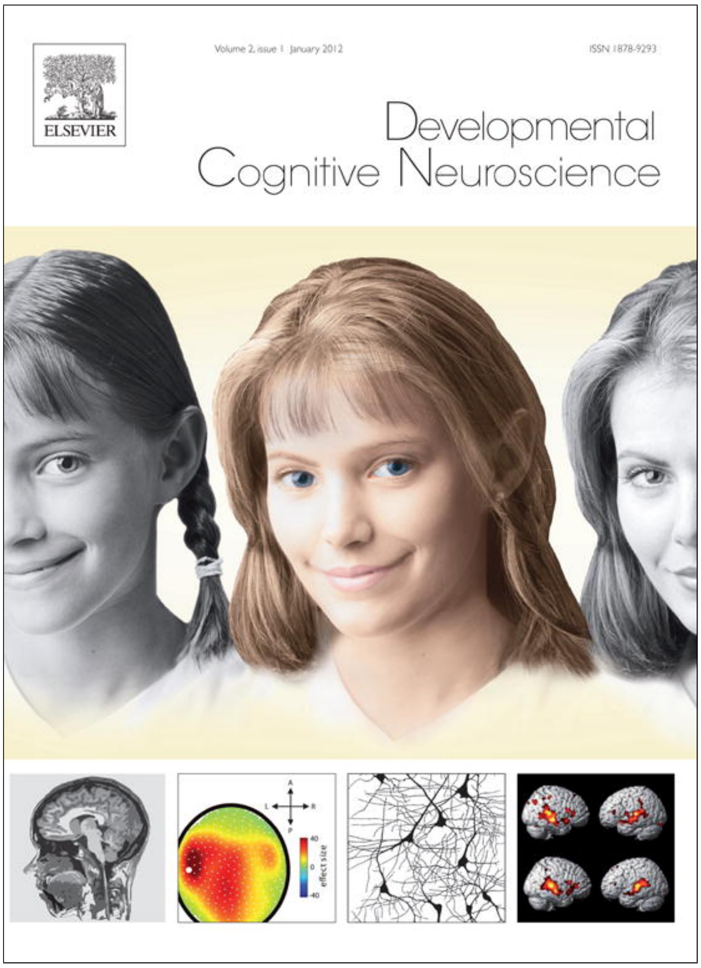
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Emotional picture processing in children: An ERP study

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ABSTRACT

The late positive potential (LPP) reflects increased attention to emotional versus neutral stimuli in adults. To date, very few studies have examined the LPP in children, and whether it can be used to measure patterns of emotional processing that are related to dispositional mood characteristics, such as temperamental fear and anxiety. To examine this question, 39 typically developing 5–7 year olds (*M* age in months = 75.27, SD = 5.83) passively viewed complex emotional and neutral pictures taken from the International Affective Picture System. Maternal report of temperamental fear and anxiety was obtained and fearful behavior during an emotional challenge was observed. As documented in adults, LPP amplitudes to pleasant and unpleasant stimuli were larger than to neutral stimuli, although some gender differences emerged. Larger LPP amplitude differences between unpleasant and neutral stimuli were associated with greater observed fear. The LPP as a measure of individual differences in emotional processing is discussed.

1. Introduction

How children process emotional information is highly relevant to the study of normative development, as well as to the study of psychopathology (Derry and Kuiper, 1981; Levin et al., 2007; MacLeod et al., 1986; Shackman et al., 2007). In non-disordered groups, unpleasant emotional stimuli are more rapidly and automatically processed than emotionally neutral stimuli (Phelps, 2006). Similarly, anxiety disorders are characterized by exaggerated attention to threat-relevant stimuli, also termed the threat bias (McNally, 1996; Mogg and Bradley, 1998). Thus, there is a continuum between normative capture of attention by emotion and dysregulated and maladaptive emotional processing. Examining the neural correlates of normal and abnormal emotional processing may help to identify biomarkers indicating who is at risk for the development of emotional problems.

There is a growing body of research on the neural correlates of emotional processing in children. Functional magnetic imaging (fMRI) studies have shown that the nature of emotional responses change over the lifespan (Mather et al., 2004). For example, compared to adults, children show greater amygdala activity in response to neutral compared to fearful faces (Thomas et al., 2001b). Moreover, research with clinical groups suggests adult-like abnormalities in emotional processing: anxious children, for instance, show an exaggerated amygdala response to threatening stimuli (McClure et al., 2007; Thomas et al., 2001a). Although such studies are clearly important, emotional processing occurs on an extremely rapid timescale, on the order of milliseconds. Functional MRI has excellent spatial resolution, but has relatively slow temporal resolution and thus cannot provide insights into emotional processing with millisecond precision. In contrast, research with scalp-recorded event-related potentials (ERPs) is ideally suited for capturing the earliest emerging emotional processing operations. For example, ERP research has documented that early adversity, such as the experience of

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child abuse and institutional rearing, alters the processing of emotional faces beginning a few hundred milliseconds after stimulus presentation (e.g., Cicchetti and Curtis, 2005; Parker and Nelson, 2005), and at later stages of processing (Pollak et al., 2001). Thus, the highly sensitive temporal resolution of ERPs has the potential to clarify specific facets of emotional processing that may characterize both normative and disrupted development.

The late positive potential (LPP) is an ideal ERP for examining emotional processing in children. The LPP is a sustained positive deflection that occurs approximately 200–300 ms following presentation of emotional (unpleasant and pleasant) versus neutral stimuli and is maximal at midline parietal recording sites (Cuthbert et al., 2000; Hajcak et al., 2006; Hajcak and Nieuwenhuis, 2006; Keil et al., 2002; Schupp et al., 2000). The LPP is also evident at more central and anterior recording sites around 1000 ms after initial stimulus presentation (Cuthbert et al., 2000; Dennis and Hajcak, 2009; Foti and Hajcak, 2008). Although similar to the P300 in terms of its initial timing, scalp topography, and sensitivity to salient and task-relevant stimuli (Johnson, 1984; Squires et al., 1977), the LPP differs from the P300 in some important ways: the LPP is sustained during the presentation of emotional stimuli (Cuthbert et al., 2000) and is also evident following initial stimulus offset (Hajcak and Olvet, 2008). In addition, other studies have shown that LPP amplitudes can be attenuated or increased if participants are asked to direct their attention to less or more arousing portions of emotional stimuli, respectively (Dunning and Hajcak, 2009; Hajcak et al., 2009), and vary independently from task difficulty (Hajcak et al., 2007). Moreover, neuroimaging research shows that the LPP corresponds to activation in neural regions associated with attention to and perceptual processing of motivationally salient stimuli (Sabatinelli et al., 2007). Thus, taken together, these studies suggest that the LPP reflects sustained attention to and perceptual processing of emotional stimuli.

To date, however, there has only been one study to our knowledge that has examined the LPP in the context of passive processing of complex emotional pictures in children (Hajcak and Dennis, 2009). This study recorded EEG while 5- to 10-year-old children viewed pleasant, unpleasant and neutral stimuli from the International Affective Picture System (IAPS; Lang et al., 2008). Hajcak and Dennis (2009) found that, like adults, children showed larger LPP amplitudes in occipital–parietal recording sites to pleasant and unpleasant compared to neutral pictures. There were no differences between the left and right hemispheres. Interestingly, when multiple time windows of the LPP were examined, only the early window (500–1000 ms) showed this expected effect of picture type; during the middle window (1000–1500 ms) only LPP amplitudes to unpleasant pictures were reliably larger than neutral pictures, and during the late window (1500–2000 ms), no significant effect of picture type emerged, suggesting that these children did not engage in ongoing evaluation of the emotional stimuli.

The current study sought to build on the findings from Hajcak and Dennis (2009) but differed in several ways. One, the current study examined the LPP in multiple regions (rather than only occipital–parietal recording sites) and time windows to examine whether the sensitivity of the LPP to emotional picture type changes over the course of processing. Second, the current study focused on children aged 5–7 in order to clearly identify the effects of picture type on the LPP in a more discrete, younger group of children. Previous studies of the LPP in children (Hajcak and Dennis, 2009; Dennis and Hajcak, 2009) targeted a broader range of ages, but did not have a sample size adequate for cross-age comparison. We also targeted this age range because the early school years are a time during which cognitive and neural changes strongly influence how children process emotional information. For example, maturation of brain regions involved in cognitive control and emotion regulation (e.g., Casey et al., 2000) influence how children process emotional information, and patterns of connectivity between limbic and frontal regions of the brain change over the course of childhood and adolescence, and strongly influence emotional capabilities (Somerville and Casey, 2010).

In addition to examining whether the LPP is sensitive to emotional versus neutral content in young children as it is in adults, a secondary goal of the current study was to examine whether the LPP varies with affective individual differences, in particular fearful and anxious behavior. Although the current sample of children was typically developing, we reasoned that since increased attention to threatening and unpleasant stimuli has been implicated in the development and maintenance of anxiety disorders (Mathews and MacLeod, 2002; Mogg and Bradley, 1998), then fearful and anxious behavioral tendencies in a normative range should also be associated with increased attention to and/or processing of unpleasant stimuli. ERP studies have examined such attentional processing tendencies using ERP components such as the error-related negativity (Weinberg et al., 2010) and the P3b (Shackman et al., 2007). A growing body of evidence suggests that the LPP can also capture increased attention to unpleasant emotional stimuli. For example, larger LPP amplitudes to unpleasant compared to neutral stimuli are associated with greater state anxiety in adults (MacNamara and Hajcak, 2009) and anxious-depressed symptoms in typically developing children (Dennis and Hajcak, 2009). We predicted that children with larger LPP amplitudes to unpleasant versus neutral pictures – reflecting increased attention to unpleasant pictures – will be associated with more fearful behavior, greater fearful temperament, and more anxiety within a typical range.

In addition, given previous studies showing gender differences in emotional processing (Bradley et al., 2001; Dennis and Hajcak, 2009; Lithari et al., 2010; Sabatinelli et al., 2004; Weinberg and Hajcak, 2010), we examined gender effects on the LPP. In particular, females may show greater attention to negative emotional stimuli since studies have shown them to have higher reactivity and greater subjective arousal to aversive stimuli than males (Hall et al., 2004). Thus, females may show larger LPP amplitudes to unpleasant pictures.

The current study had two specific hypotheses. First, we predicted that children would show greater LPP amplitudes to unpleasant and pleasant compared to neutral stimuli. Given previous findings, we expected that this effect of picture type would emerge in the earliest time window of the LPP and examined whether this effect would be sustained throughout the duration of stimulus processing (Hajcak and Dennis, 2009). Second, we explored whether the effect of picture type differed between girls and boys (Dennis and Hajcak, 2009), with one possibility being that girls would show larger LPP amplitudes to unpleasant pictures. Third, we predicted that children who show relatively larger LPP amplitudes to unpleasant compared to neutral stimuli will show greater anxious and fearful behavior in a normative range (measured via maternal report of anxious symptoms and of fearful temperament and via observed fearful behavior). We explored whether these effects were significant across multiple time windows of the LPP.

2. Methods

2.1. Participants

Fifty-nine children (32 males) and their caregivers provided informed consent to participate in the current study. Twenty participants were excluded from analyses due to excessive movement artifacts in their EEG recordings or declined to participate in the EEG portion of the assessment. Ultimately, 39 typically developing children between the ages of 5 and 6, with 2 additional children who had just turned 7 years of age (22 boys, 17 girls, *M* age in months = 75.49, SD = 5.90, range = 60–84 months) were included in the study. Maternal report of child ethnicity was as follows: 15 Caucasians, 14 African-Americans, 5 Hispanics/Latino, 2 Asians, 1 Pacific Islander, and 2 who mothers reported as being more than one race. Mothers completed questionnaires assessing child temperament and emotional behavior and reported no diagnosed developmental or attention problems. Participants spent approximately 3 h in the laboratory and at the end of the study, families were compensated with $100.00 for their time. In addition, the children were given a certificate of completion and astronaut ice cream for their involvement.

2.2. Stimulus materials

A total of 90 developmentally appropriate stimuli were selected from the International Affective Picture System (IAPS; Lang et al., 2008). All stimuli used were identical to those used in the one previous study examining the LPP in response to IAPS pictures in children (Hajcak and Dennis, 2009). Stimuli were 30 unpleasant pictures depicting scenes such as airplane crashes and snakes[1]; 30 pleasant pictures showing images such as Disneyworld and ice cream[2]; and 30 neutral pictures depicting pictures such as household objects or scenes of nature.[3] Unlike the Hajcak and Dennis (2009) study which included older children, this study was unable to obtain subjective valence and arousal ratings of the IAPS pictures because this particular sample of young children had difficulty understanding the self-assessment mannequin rating technique (Lang et al., 1993). Therefore, means and standard deviations for valence and arousal ratings were taken from the IAPS normative adult ratings (Lang et al., 2008): unpleasant, pleasant, and neutral pictures differed in terms of valence (means of 7.45 (SD = 1.50) for pleasant, 5.29 (SD = 0.74) for neutral, and 3.32 (SD = 1.74) for unpleasant). Also, emotional pictures differed from neutral in terms of arousal (means of 5.79 (SD = 2.10) for unpleasant, 4.76 (SD = 2.30) for pleasant, and 2.81 (SD = 0.65) for neutral). Both valence and arousal are rated on a 9-point scale, with higher ratings for valence corresponding to more pleasant and higher ratings for arousal corresponding to more arousing.

The task was administered using Presentation software (Version 2, Neurobehavioral Systems, Inc.; Albany, CA) and all stimuli were presented in color and occupied the entire screen. All stimuli were presented using an IBM computer and 17″ monitor. Children were seated 65 cm from the computer monitor during the task.

2.3. Procedures and measures

Children were accompanied by their mothers to the laboratory where mothers gave informed consent and children gave verbal assent. After a brief introduction to the laboratory and task, children were seated in front of a T.V. screen where they watched cartoons while electrodes were placed on their scalp to monitor electrical brain activity. After completion of the setup, the children were moved to a dark experimental booth where they were told they would be "astronauts going into space" to reduce anxiety children might feel about the experiment or equipment and passively viewed the 90 pictures from the IAPS. The task was initiated by a research assistant and all trials began automatically. Each of the 90 pictures were randomly selected once and displayed on the screen for 2000 ms with a 500 ms interstimulus interval. A video camera was placed facing the child and monitored by a research assistant outside of the experimental booth to ensure that children were attending to the stimuli. Following the passive viewing task, children went on to complete a directed reappraisal task in which EEG was recorded (DeCicco et al., in press). After a short break to clean up, they completed the behavioral portion of the study (black box task) along with other behavioral tasks not reported in the current study. During this time, mothers filled out questionnaires assessing their children's temperament and behavior.

[1] The IAPS numbers for unpleasant pictures were 1050, 1120, 1201, 1300, 1321, 1930, 2120, 2130, 2688, 2780, 2810, 2900, 3022, 3230, 3280, 5970, 6190, 6300, 6370, 7380, 9050, 9250, 9421, 9470, 9480, 9490, 9582, 9594, 9600, and 9611.

[2] The IAPS numbers for pleasant pictures were 1460, 1463, 1601, 1610, 1710, 1750, 1811, 1920, 1999, 2070, 2091, 2165, 2224, 2311, 2340, 2345, 2791, 4603, 5831, 7325, 7330, 7400, 7502, 8031, 8330, 8380, 8461, 8490, 8496, and 8620.

[3] The IAPS numbers for neutral pictures were 5220, 5711, 5740, 5750, 5800, 5820, 7000, 7002, 7004, 7006, 7009, 7010, 7025, 7031, 7035, 7041, 7050, 7080, 7090, 7100, 7140, 7150, 7175, 7190, 7224, 7233, 7235, 7236, 7595, and 7950.

2.3.1. Temperament

Mothers completed the Children's Behavior Questionnaire (CBQ; Rothbart et al., 2001) to assess child characteristics on various dimensions of temperament. The CBQ is a 195-item questionnaire designed to measure 15 dimensions of temperament in children aged 3–7 years. The CBQ scale included in this study was fear ($\alpha = .78$) consisting of items such as "Is afraid of burglars or the 'boogie' man" and "Is very frightened by nightmares".

2.3.2. Anxiety

Mothers also completed the Child Behavior Checklist for 1½–5 year olds (CBCL; Achenbach and Rescorla, 2000) a 100-item questionnaire and the CBCL for 6–18 year olds (Achenbach and Rescorla, 2001) which is a 112-item questionnaire designed to measure children's competencies and behavior problems. This study focused specifically the DSM anxiety scale (5-year olds: $\alpha = .50$; 6- and 7-year olds: $\alpha = .75$).

2.3.3. Observed fearful behavior

Following the passive viewing task, children completed a task designed to measure inhibited and fearful behavior in response to a novel, ambiguous stimulus (the black box task) adapted from the Laboratory Temperament Assessment Battery (LabTab; Goldsmith et al., 1995). Children were asked to place their hands inside a box that had "something scary inside". The measure of interest was the time it took the child to place their hand in the box (latency in seconds). The task lasted 2 min. Shorter latencies indicated the child's willingness to immediately put his or her hand inside the box; thus, longer latencies indicated greater fearful behavior due to hesitation or refusal to put his or her hand in the box.

2.4. EEG recording

Electroencephalography (EEG) was recorded from 64 Ag/AgCL scalp electrodes, using the ActiveTwo Biosemi System (Biosemi, Amsterdam, Netherlands) during the passive viewing task. The electrooculogram (EOG) generated from blinks and eye movements was recorded from four electrodes: horizontal EOG was recorded from one electrode placed 1 cm to the left of the left eye and another placed 1 cm to the right of the right eye. Vertical EOG was recorded from one electrode placed 1 cm above the left eye and another placed below the left eye. As per Biosemi's design, during acquisition the ground electrode was formed using the Common Mode Sense active electrode and Driven Right Leg passive electrode.

2.4.1. EEG data reduction

EEG and EOG signals were digitized on a laboratory computer using ActiView software (BioSemi). The EEG was sampled at 512 Hz. Brain Vision Analyzer (Version 2.2, GmbH, Munich, Germany) was used to process the data offline and to generate the LPP. Data were band-pass filtered with cutoffs between 0.1 Hz[4] and 30 Hz and referenced to the average of the left and right mastoids. EEG was corrected for blinks and artifacts using the method developed by Gratton et al. (1983). Artifacts were identified using the following criteria: any data with voltage steps exceeding 75 μV, changes within a segment that were greater than 200 μV, amplitude differences greater than ±120 μV within a segment, and activity lower than 0.2 μV per 100 ms were considered artifacts and excluded from analyses.

The EEG was segmented for each trial 400 ms before each picture and continuing for 2000 ms. The 400 ms window prior to the picture served as the baseline. Mean LPP amplitudes were calculated for each of three time windows; time windows were based on visual inspection of the data: early (300–700 ms), middle (700–1200 ms) and late (1200–2000 ms). The LPP was averaged in three regions: posterior, central, and anterior. Each region included clusters in the right, midline, and left hemispheres. Because there were no significant differences between these clusters, mean LPP amplitudes were computed for each region averaging across the clusters (see Fig. 1), separately by window: posterior: (PO4, PO8, O2, Oz, POz, PO3, PO7, and O1); central: (C4, C6, CP6, Cz, CPz, C3, C5, and CP5); and anterior: (FC4, F4, F6, Fpz, AFz, FC3, F3, and F5).

2.5. Data analysis

Analyses for physiological, behavioral and questionnaire data were conducted using PASW version 18 using general linear model and correlation software. In addition, Greenhouse–Geisser corrections were applied when assumptions of sphericity were not met and Bonferroni corrections were applied to *p* values with multiple-*df* comparisons.

3. Results

The first hypothesis was that LPP amplitudes would be greater for unpleasant and pleasant compared to neutral pictures. Fig. 2 presents the stimulus-locked ERPs at posterior, central, and anterior recording sites, separately. Table 1 presents descriptive statistics for LPP amplitudes in each region and window of analysis. Comparisons among regions were not made because the LPP shows a voltage shift downward in central and anterior regions compared to the posterior region (while the absolute value of the waveform remains positive) making amplitude differences between regions difficult to interpret. Thus, analyses were conducted separately for each region using a 3 (picture type: unpleasant, pleasant, neutral) × 3 (window: early, middle, late) × 2 (gender) repeated measures ANOVA to examine effects of picture type, and whether these effects varied over the time course of the LPP and between girls

[4] When data were instead filtered with a high-pass filter of 0.01, results did not differ from those reported in this manuscript using a high-pass filter of 0.1.

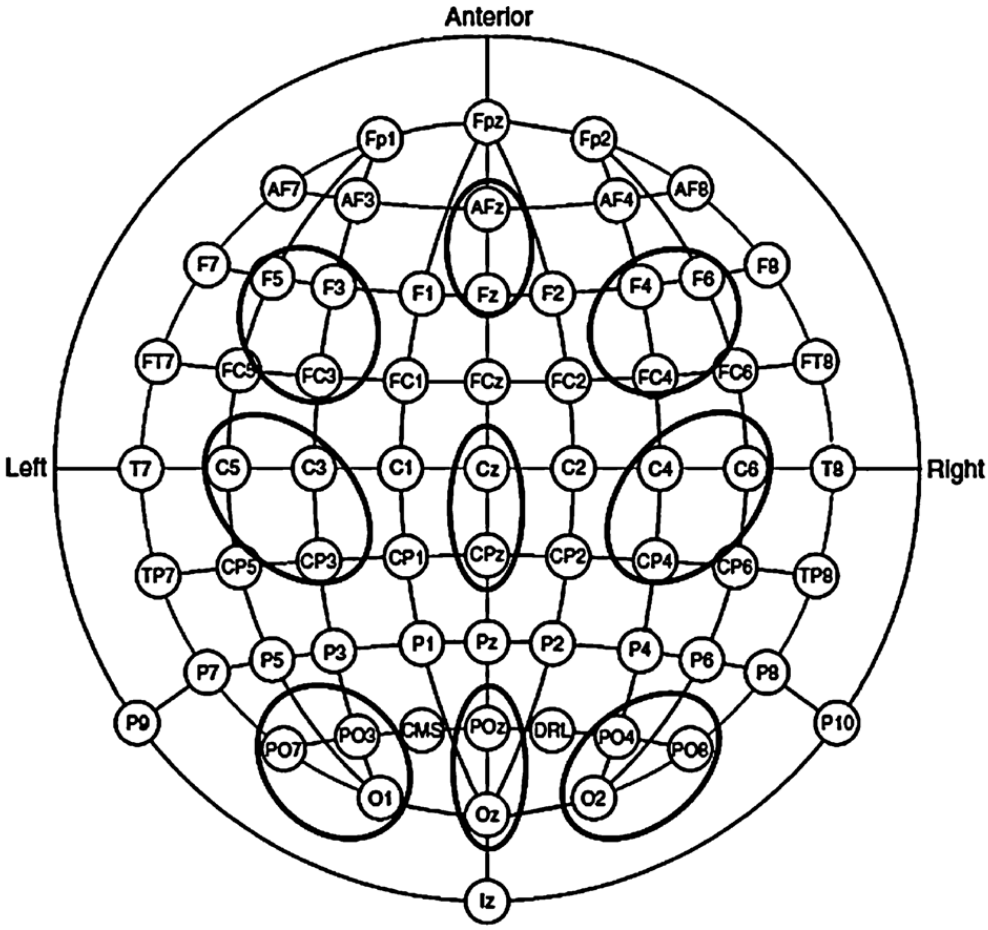

Fig. 1. Electrode clusters used to quantify mean LPP amplitudes in posterior, central and anterior regions.

Table 1
Means and standard deviations for LPP amplitudes for emotional and neutral stimuli for the three regions, averaged across left, right, and midline electrode clusters.

	Early		Middle		Late	
	M	SD	*M*	SD	*M*	SD
Posterior						
Unpleasant	24.73	11.56	20.63	10.79	16.33	10.20
Pleasant	25.58	9.69	21.46	8.85	17.03	7.99
Neutral	22.93	10.16	14.81	9.88	11.63	8.70
Central						
Unpleasant	−13.39	7.10	−3.24	7.23	.15	6.81
Pleasant	−15.71	6. 38	−3.54	6.14	1.08	5.79
Neutral	−13.39	7.38	−5.19	5.10	−2.23	6.11
Anterior						
Unpleasant	−15.83	6.67	−5.29	7.39	.03	7.90
Pleasant	−17.96	7.57	−4.58	6.58	1.58	8.18
Neutral	−17.46	7.85	−5.57	5.57	−1.64	6.65

Note: LPP time windows divided into early (300–700 ms), middle (700–1200 ms), and late (1200–2000 ms).

and boys.[5] Fig. 3 shows the scalp distribution of the pleasant minus neutral (top) and the unpleasant minus neutral (bottom) LPP difference in the early (300–700), middle (700–1200), and late (1200–2000) analysis windows.

3.1. Posterior region

In the posterior region, the LPP varied by picture type, $F(2, 74) = 11.92$, $p = .000$, $\eta^2 = .24$, window, $F(1.46, 53.95) = 59.19$, $p = .000$, $\eta^2 = .62$, and their interaction, $F(3.16, 116.99) = 6.43$, $p = .000$, $\eta^2 = .15$. Post hoc analyses indicated that, as predicted, LPP amplitudes were greater for unpleasant, $t(38) = 3.57$, $p = .001$, and pleasant, $t(38) = 4.67$, $p = .000$, compared to neutral pictures. LPP amplitudes were also greater during the early window compared to the middle, $t(38) = 6.33$ $p = .000$, and late, $t(38) = 9.00$, $p = .000$, windows (see Table 1). In addition, LPP amplitudes were greater for the middle compared to the late window, $t(38) = 6.96$ $p = .000$. The significant interaction between picture type and window showed that in the middle and late windows, LPP amplitudes were greater for pleasant and unpleasant versus neutral pictures, all *p*s < .05. Additionally, in the early window, LPP amplitudes were greater for pleasant versus neutral pictures, $t(38) = 2.92$, $p = .000$, but this difference was significant at the level of a trend for unpleasant versus neutral pictures, $t(38) = 1.72$, $p = .09$. There were no significant gender effects.

3.2. Central region

In the central region, the LPP varied by picture type, $F(2, 74) = 2.88$, $p = .06$, $\eta^2 = .07$, window, $F(1.50, 55.62) = 288.50$, $p = .000$, $\eta^2 = .89$, and their interaction, $F(4, 148) = 7.52$,

5 Effects did not differ when Hemisphere was included in the analyses. Thus, analyses reported below do not include Hemisphere as a variable.

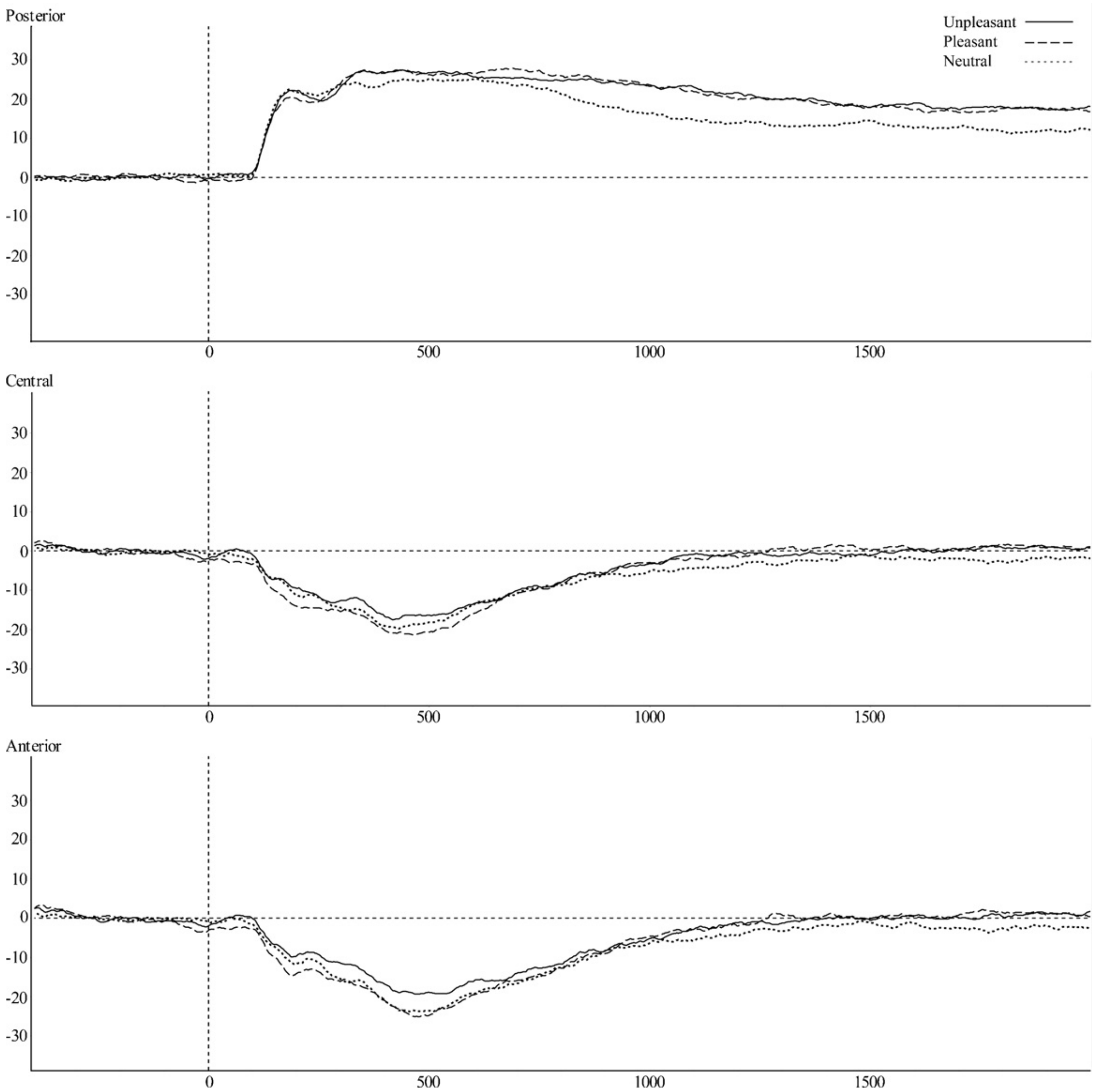

Fig. 2. LPP amplitudes elicited by passively viewing unpleasant, pleasant and neutral IAPS in anterior, central and posterior regions.

$p = .000$, $\eta^2 = .17$. Post hoc analyses indicated that LPP amplitudes across windows were larger for unpleasant versus neutral stimuli, $t(38) = 2.40$, $p = .02$. In addition, LPP amplitudes were larger in the late versus middle, $t(38) = -8.01$, $p = .000$, and early windows, $t(38) = -18.62$, $p = .000$, as well as in the early versus middle window, $t(38) = -17.50$, $p = .000$. The significant interaction showed that in the middle and late windows, LPP amplitudes were greater for unpleasant and pleasant compared to neutral pictures (all $ps < .05$). In the early window, however, LPP amplitudes were larger for unpleasant versus pleasant pictures ($p = .003$). There were no significant gender effects.

3.3. Anterior region

In the anterior region, the LPP varied by window, $F(1.43, 52.90) = 248.26$, $p = .000$, $\eta^2 = .87$. The interactions between picture type and window, $F(4, 148) = 4.72$, $p = .001$, $\eta^2 = .11$, and between picture type and gender, $F(2, 74) = 3.49$, $p = .04$, $\eta^2 = .09$, also reached significance. Post hoc analyses revealed that LPP amplitudes were the largest in the late window compared to the middle, $t(38) = -10.45$, $p = .000$, and early windows, $t(38) = -18.39$, $p = .000$. In addition, LPP amplitudes were larger for the middle versus early window, $t(38) = -14.44$, $p = .000$. The significant interaction between picture type and window showed that LPP amplitudes were greater in the late window for pleasant compared to neutral pictures, $t(38) = 2.27$, $p = .03$. Additionally, LPP amplitudes were greater in the early window for unpleasant versus pleasant pictures at the level of a trend, $t(38) = 1.76$, $p = .09$. Finally the significant interaction between picture type and gender revealed that in the early window, girls displayed greater LPP amplitudes to unpleasant, $t(16) = 3.15$, $p = .006$, and neutral, $t(16) = -2.33$, $p = .03$, compared to pleasant pictures, whereas boys showed larger LPP amplitudes to pleasant

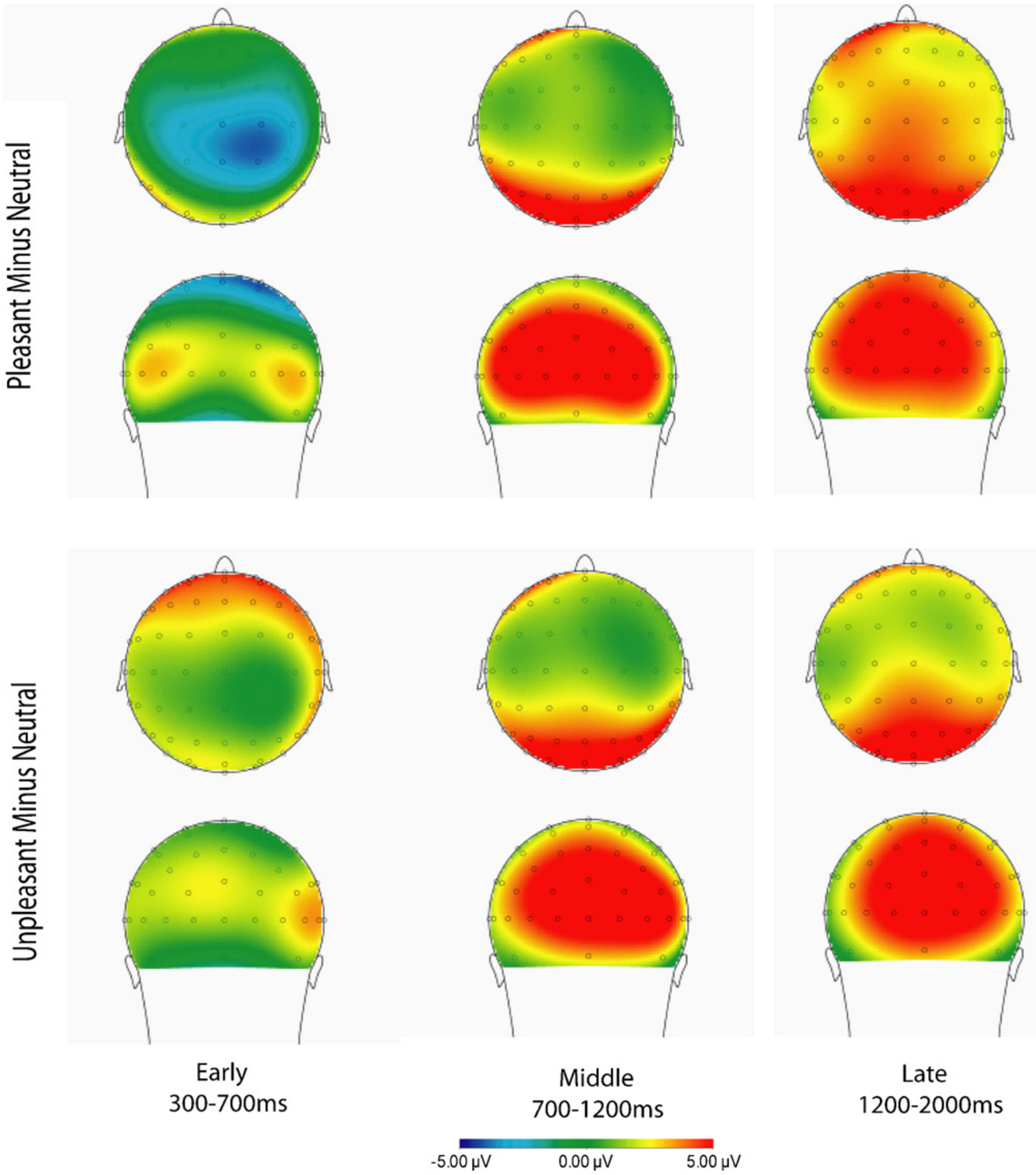

Fig. 3. Scalp distribution of unpleasant minus neutral (top) and pleasant minus neutral (bottom) LPP difference waveforms in the early (300–700 ms), middle (700–1200 ms) and late (1200–2000 ms) time windows.

pictures compared to neutral pictures, $t(21) = 2.09$, $p = .05$ in the late window and greater LPP amplitudes to unpleasant versus pleasant pictures in the middle window at the level of a trend, $t(21) = -1.98$, $p = .06$. There were no significant gender effects.

In summary, predicted effects of picture type (unpleasant and pleasant > neutral) emerged in all regions and windows, but became less stable at later windows and in the central and anterior scalp regions. Although gender effects emerged suggesting that boys and girls show unique effects of picture type and window in the anterior region, there were no significant between-group main effects.

3.4. Correlations between the LPP and child fear and anxiety

The degree to which children preferentially process unpleasant versus neutral emotional information may reflect state and trait differences in emotional processing related to anxiety and temperamental fear. To examine this possibility, we examined correlations between the effect of picture type on the LPP (LPP unpleasant–neutral and LPP pleasant–neutral) and three measures of fear and anxiety—observed fearful behavior, maternal report of fearful temperament, and maternal report of anxiety symptoms.[6] Difference scores were used as the measure of interest because they quantify relative processing of emotional versus neutral stimuli (thus accounting for baseline differences in picture processing) and because they have been shown to be sensitive to individual differences in anxiety (e.g., MacNamara and Hajcak, 2009). To construct these

[6] Correlational analyses were conducted with age in months as a covariate and results remained the same. When intercorrelations among maternal-report and observational measures of fear and anxiety were examined, no significant correlations emerged.

Table 2
Correlations between LPP difference scores and anxiety, temperamental fear, and observed fearful behavior.

Difference score	Region/window	Anxiety (N = 39)	Temperamental fear (N = 39)	Observed fear (N = 37)
Unpleasant–neutral	Posterior/early	.07	.08	.28[†]
	Central/late	.04	.19	.31[†]
	Anterior/late	.24	.17	.38[*]
Pleasant–neutral	Posterior/early	.17	.08	.17
	Central/late	.15	−.04	.16
	Anterior/late	.19	−.03	.13

[*] $p < .05$.
[†] $p < .10$.

difference scores, we selected LPPs in regions and time windows in which the predicted effects of picture type (LPP unpleasant and pleasant > LPP neutral) were maximal.

As seen in Table 2, larger unpleasant–neutral LPP difference scores in the anterior region (late window) were significantly correlated with greater observed fearful behavior. Non-significant trends showed that larger unpleasant–neutral LPP difference scores in the central region/late window and in the posterior region/early window were also associated with greater observed fearful behavior. No other correlations reached significance.

4. Discussion

The goal of the current study was to examine emotional processing in 5- to 7-year-old children as measured by the LPP and to build on findings from the only other extant study of the LPP in a passive viewing paradigm for children (Hajcak and Dennis, 2009). We also explored whether the LPP, as a potential measure of preferential emotional processing, was sensitive to individual differences in fear and anxiety. Overall, findings support those found in both the adult (e.g., Schupp et al., 2000) and child literature (Hajcak and Dennis, 2009): LPP amplitudes were larger to emotional versus neutral stimuli. Over the time course of the LPP (300–2000 ms), however, we found that this effect became more variable in the anterior region and in relation to gender. In terms of gender effects, boys had larger LPP amplitudes for pleasant versus neutral stimuli, whereas girls showed larger LPP amplitudes to unpleasant and neutral pictures compared to pleasant pictures in the anterior region. Although there were no between-gender differences, results suggest that boys and girls at this age may show subtle differences in how they process emotional stimuli.

Taken together, these findings capitalize on the excellent temporal resolution of ERPs to show that the LPP can be used to measure rapid stages of emotional processing (300–2000 ms) in children, and that the LPP shows similar properties in children and adults. There were some interesting differences between the results of this study and the Hajcak and Dennis (2009) study. Most notably, while Hajcak and Dennis (2009) found the predicted effects of picture type primarily in the early and middle windows (the latter only showing a significant difference between unpleasant and neutral pictures), the current study identified significant effects of picture type throughout the time course of the LPP. This difference, suggesting that children do indeed show ongoing evaluation of emotional stimuli for the first 2000 ms of emotional processing, is likely attributed to the current study examining the LPP over multiple scalp regions; Dennis and Hajcak (2009) only examined occipital–parietal recording sites. This highlights the importance of examining the LPP as a topographically dynamic electrocortical response.

Indeed, the subtle gender differences that emerged were detected in the LPP measured in the anterior region. These effects may be attributable to a number of factors. One possibility, because the LPP is sensitive to subjective arousal (Hajcak and Nieuwenhuis, 2006), is that males and females differed in their perception of how arousing the unpleasant and pleasant stimuli were. We cannot directly evaluate this possibility since piloting indicated that children in this young age range were not able to reliably report on subjective arousal during picture viewing, and thus we do not have subjective rating data. Hajcak and Dennis (2009), however, found that *pleasant* stimuli were subjectively rated as more arousing than unpleasant stimuli in 5- to 10-year-olds. In the current study, boys showed larger LPP amplitudes for pleasant versus neutral stimuli (anterior region/late time window), which could reflect increased subjective arousal and more elaborated attention to pleasant stimuli. This is consistent with a previous study showing that males have increased amygdala activation to pleasant pictures (Wrase et al., 2003).

We found that girls showed distinct LPP patterns in the anterior region: they showed larger LPP amplitudes to unpleasant and neutral compared to pleasant images in the *early* window, perhaps reflecting initial attention capture by unpleasant arousing pictures and neutral pictures. These findings are in line with a previous neuroimaging study showing that both fearful and neutral faces recruit increased emotional responses (i.e., increased amygdala activity) in children (Thomas et al., 2001a,b). In this study, it was argued that enhanced amygdala activity for neutral faces could signal the increased effort needed to interpret neutral facial expressions because they are perceived as ambiguous, and that this ambiguity might also be interpreted as conveying emotion. Indeed, behavioral research has shown that before 9 years of age, children commonly rate neutral faces as happy or sad (Durand et al., 2007). In addition, our finding that girls showed larger LPPs to unpleasant versus pleasant stimuli is consistent with research showing that females are more emotionally reactive to unpleasant emotional stimuli in terms of enhanced limbic (Hall et al., 2004), and medial frontal neural activation (Lang et al., 1998; Wrase et al., 2003). Future research should carefully consider the role that gender plays in the time course and nature of emotional processing, and seek developmentally appropriate ways to obtain subjective arousal ratings of emotional stimuli.

When examining associations between anxious/fearful child behavior and the LPP, one predicted association emerged: greater LPP amplitudes to unpleasant compared to neutral pictures (in the anterior region/late window) were significantly correlated with greater observed fear. This finding is interesting in light of the finding that in adults, greater LPP amplitudes to unpleasant compared to neutral stimuli is correlated with greater state anxiety (MacNamara and Hajcak, 2009). It is also interesting to note that while other regions/windows showed a similar trend, it was only in the later window at anterior recording sites that this pattern reached significance—suggesting that later-emerging attentional processes might be most closely implicated in the link between emotional processing and fearful behavior. Overall, this finding suggests that LPP could be sensitive to patterns of preferential emotional processing that characterize anxious and fearful behavior and states. Interestingly, in the current study, neither the LPP nor observed fearful behavior were correlated with the more trait-like measures of anxious and fearful behavior—maternal report of fearful temperament or symptoms of anxiety. This may be due to the restricted range of scores in this typically developing group of children. Furthermore, this suggests, like the finding with adults (MacNamara and Hajcak, 2009), that if the LPP is measured when cognitive and performance demands are relatively low, variability in the LPP might best capture state rather than trait individual differences. Future research should measure the LPP during a range of affective and cognitive tasks to examine this hypothesis directly.

Limitations of the current study include the lack of information on children's subjective ratings of emotional pictures in terms of their valence and arousal properties—although overall, findings suggest that like adults, children generally perceive unpleasant and pleasant pictures as equally more salient and arousing than neutral pictures. Future studies of the LPP in children should also examine the boundary conditions under which the LPP is modulated in relation to a wider range of stimuli, including more arousing IAPS images and emotional faces (Leppänen et al., 2007). Moreover, to fully evaluate the potential for the LPP as a biomarker for fear and anxiety-related attentional biases in children, future research should examine the LPP in a group of anxious children, and in children at risk for anxiety disorders.

This is one of the few studies examining the LPP in children. Findings from this study demonstrate that the LPP operates in a way similar to that in adults, and suggest that the LPP holds promise as neurophysiological measure of rapid stages of emotional processing in children. Moreover, results suggest that the LPP should be examined further as a potential neural marker for attentional biases linked to risk for specific problems, such as fearful behavior and anxiety.

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References

Achenbach, T.M., Rescorla, L.A., 2000. Manual for the ASEBA Preschool Forms & Profiles. University of Vermont, Research Center for Children, Youth, & Families, Burlington, VT.

Achenbach, T.M., Rescorla, L.A., 2001. Manual for the ASEBA School-age Forms & Profiles. University of Vermont, Research Center for Children, Youth, & Families, Burlington, VT.

Bradley, M.M., Codispoti, M., Sabatinelli, D., Lang, P.J., 2001. Emotion and motivation: II. Sex differences in picture processing. Emotion 1, 300–319.

Casey, B.J., Giedd, J.N., Thomas, K.M., 2000. Structural and functional brain development and its relation to cognitive development. Biol. Psychol. 54, 241–257.

Cicchetti, D., Curtis, W.J., 2005. An event-related potential study of the processing of affective facial expressions in young children who experienced maltreatment during the first year of life. Dev. Psychopathol. 17, 641–677.

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. Biol. Psychol. 52, 95–111.

DeCicco, J.M., Solomon, B., Dennis, T.A., in press. Neural Correlates of Cognitive Reappraisal in Children: An ERP Study. *Developmental Cognitive Neuroscience*.

Dennis, T.A., Hajcak, G., 2009. The late positive potential: a neurophysiological marker for emotion regulation in children. J. Child Psychol. Psychiatry 50, 1373–1383.

Derry, P.A., Kuiper, N.A., 1981. Schematic processing and self-reference in clinical depression. J. Abnorm. Psychol. 90, 286–297.

Dunning, J.P., Hajcak, G., 2009. See no evil: directed visual attention modulates the electrocortical resposne to unpleasant images. Psychophysiology 46 (1), 28–33.

Durand, K., Gallay, M., Seigneuric, A., Robichon, F., Baudouin, J.Y., 2007. The development of facial emotion recognition: the role of configural information. J. Exp. Child Psychol. 97, 14–27.

Foti, D., Hajcak, G., 2008. Deconstructing reappraisal: descriptions preceding arousing pictures modulate the subsequent neural response. J. Cogn. Neurosci. 20, 977–988.

Goldsmith, H.H., Reilly, J., Lemery, K.S., Longley, S., Prescott, A., 1995. The Laboratory Temperament Assessment Battery-preschool Version: Description of Procedures. University of Wisconsin.

Gratton, G., Coles, M., Donchin, E., 1983. A new method for off-line removal of ocular artifact. Electroencephalogr. Clin. Neurophysiol. 55, 468–484.

Hajcak, G., Dennis, T.A., 2009. Brain potentials during affective picture viewing in children. Biol. Psychol. 80, 333–338.

Hajcak, G., Nieuwenhuis, S., 2006. Reappraisal modulates the electrocortical response to negative pictures. Cogn. Affect. Behav. Neurosci. 6, 291–297.

Hajcak, G., Olvet, D.M., 2008. The persistence of attention to emotion: brain potentials during and after picture presentation. Emotion 8, 250–255.

Hajcak, G., Moser, J.S., Simons, R.F., 2006. Attending to affect: appraisal strategies modulate the electrocortical response to arousing pictures. Emotion 6, 517–522.

Hajcak, G., Dunning, J.P., Foti, D., 2007. Neural response to emotional pictures is unaffected by concurrent task difficulty: an event-related potential study. Behav. Neurosci. 121 (6), 1156–1162.

Hajcak, G., Dunning, J.P., Foti, D., 2009. Motivated and controlled attention to emotion: time-course of the late positive potential. Clin. Neurophysiol. 120, 505–510.

Hall, G.B., Witelson, S.F., Szechtman, H., Nahmias, C., 2004. Sex differences in functional activation patterns revealed by increased emotion processing demands. Neuroreport 15 (2), 219–223.

Johnson Jr., R., 1984. P300: a model of the variables controlling its amplitude. Ann. N. Y. Acad. Sci. 425, 223–229.

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, 641–649.

Lang, P.J., Greenwald, M., Bradley, M.M., Hamm, A.O., 1993. Looking at pictures: evaluative, facial, visceral, and behavioral response. Psychophysiology 30, 261–273.

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, 199–210.

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. University of Florida, Gainesville, FL.

Leppänen, J.M., Moulson, M.C., Vogel-Farley, V.K., Nelson, C.A., 2007. An ERP study of emotional face processing in the adult and infant brain. Child Dev. 78, 232–245.

Levin, R.L., Heller, W., Mohanty, A., Herrington, J.D., Miller, G.A., 2007. Cognitive deficits in depression and functional specificity of regional brain activity. Cogn. Ther. Res. 31, 211–233.

Lithari, C., Frantzidis, C.A., Papadelis, C., Vivas, A.B., Klados, M.A., Kourtidou-Papadeli, C., Pappas, C., Ioannides, A.A., Bamidis, P.D., 2010. Are females more responsive to emotional stimuli? A neurophysiological study across arousal and valence dimensions. Brain Topogr. 23, 27–40.

MacLeod, C., Mathews, A., Tata, P., 1986. Attentional bias in emotional disorders. J. Abnorm. Psychol. 95, 15–20.

MacNamara, A., Hajcak, G., 2009. Anxiety and spatial attention moderate the electrocortical response to aversive pictures. Neuropsychologia 47, 2975–2980.

Mather, M., Canli, T., English, T., Whitfield, S., Wais, P., Ochsner, K., Gabrielie, J.D.E., Carstensen, L.L., 2004. Amygdala responses to emotionally valenced stimuli in older and younger adults. Psychol. Sci. 15, 259–263.

Mathews, A., MacLeod, C., 2002. Induced emotional biases have causal effects on anxiety. Cogn. Emotion 16, 310–315.

McClure, E.B., Monk, C.S., Nelson, E.E., Parrish, J.M., Adler, A., et al., 2007. Abnormal attention modulation of fear circuit function in pediatric generalized anxiety disorder. Arch. Gen. Psychiatry 64, 97–106.

McNally, R.J., 1996. Anxiety sensitivity is distinguishable from trait anxiety. In: Rapee, R.M. (Ed.), Current Controversies in the Anxiety Disorders. Guilford Press, New York, pp. 214–227.

Mogg, K., Bradley, B.P., 1998. A cognitive-motivational analysis of anxiety. Behav. Res. Ther. 36, 809–848.

Parker, S.W., Nelson, C.A., 2005. The impact of early institutional rearing on the ability to discriminate facial expressions of emotion: an event-related potential study. Child Dev. 76, 54–72.

Phelps, E.A., 2006. Emotion and cognition: insights from studies of the human amygdala. Annu. Rev. Psychol. 24, 27–53.

Pollak, S.D., Klorman, R., Thatcher, J.E., Cicchetti, D., 2001. P3b reflects maltreated children's reactions to facial displays of emotion. Psychophysiology 38, 267–274.

Rothbart, M.K., Ahadi, S.A., Hershey, K., Fisher, P., 2001. Investigation of temperament at three to seven years: the Children's Behavior Questionnaire. Child Dev. 72, 1394–1408.

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

Sabatinelli, D., Lang, P.J., Keil, A., Bradley, M.M., 2007. Emotional perception: correlation of functional MRI and event related potentials. Cereb. Cortex 17, 1085–1091.

Shackman, J.E., Shackman, A.J., Pollak, S.D., 2007. Physical abuse amplifies attention to threat and increases anxiety in children. Emotion 7, 838–852.

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, 257–261.

Somerville, L.H., Casey, B.J., 2010. Developmental neurobiology of cognitive control and motivational systems. Curr. Opin. Neurobiol. 20, 1–6.

Squires, K.C., Donchin, E., Herning, R.I., McCarthy, G., 1977. On the influence of task relevance and stimulus probability on event-related-potential components. Electroencephalogr. Clin. Neurophysiol. 42, 1–14.

Thomas, K.M., Drevets, W.C., Dahl, R.E., Ryan, N.D., Birmaher, B., Eccard, C.H., Axelson, D., Whalen, P.J., Casey, B.J., 2001a. Amygdala response to fearful faces in anxious and depressed children. Arch. Gen. Psychiatry 58, 1057–1063.

Thomas, K.M., Drevets, W.C., Whalen, P.J., Eccard, C.H., Dahl, R.E., Ryan, N.D., Casey, B.J., 2001b. Amygdala response to facial expressions in children and adults. Biol. Psychiatry 49, 309–316.

Weinberg, A., Hajcak, G., 2010. Electrocortical evidence for vigilance-avoidance in Generalized Anxiety Disorder. Psychophysiology, 1–10.

Weinberg, A., Olvet, D.M., Hajcak, G., 2010. Increased error-related brain activity in Generalized Anxiety Disorder. Biol. Psychol. 85, 472–480.

Wrase, J., Klein, S., Gruesser, S.M., Hermann, D., Flor, H., Mann, K., Braus, D.K., Heinz, A., 2003. Gender differences in the processing of standardized emotional visual stimuli in humans: a functional magnetic resonance imaging study. Neurosci. Lett. 348, 41–45.