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Brain potentials during affective picture processing in children

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ABSTRACT

In adults, emotional (e.g., both unpleasant and pleasant) compared to neutral pictures elicit an increase in the early posterior negativity (EPN) and the late positive potential (LPP); modulation of these ERP components are thought to reflect the facilitated processing of, and increased attention to, motivationally salient stimuli. To determine whether the EPN and LPP are sensitive to emotional content in children, high-density EEG was recorded from 18 children who were 5–8 years of age (mean age = 77 months, SD = 11 months) while they viewed developmentally appropriate pictures selected from the International Affective Picture System. Self-reported ratings of valence and arousal were also obtained. An EPN was not evident following emotional compared to neutral pictures; however, a positivity maximal at occipital–parietal recording sites was increased from 500 to 1000 ms following pleasant pictures and from 500 to 1500 ms following unpleasant pictures. Comparisons between the EPN and LPP observed in children and adults, and implications for developmental studies of emotion, are discussed.

Studies have begun to examine neural correlates of emotional processing in children—especially with regard to the development of psychopathology (Cole et al., 2004; Lewis et al., 2006, 2007; Lewis and Stieben, 2004). For instance, studies that employ functional magnetic resonance imaging (fMRI) have indicated that anxious children might be characterized by abnormal amygdala response to threatening stimuli (McClure et al., 2007; Thomas et al., 2001a). Because of its excellent spatial resolution, fMRI is ideal for elucidating which neural structures are both implicated in emotional processing *and* sensitive to individual differences—work that has important implications with regard to understanding the abnormal neural architecture related to the development of psychopathology (Cole et al., 1994; Dahl, 2001, 2003; Pollak, 2003, 2005; Stieben et al., 2007).

In addition to fMRI, electrocortical measures of brain function can also be used to study abnormal emotional processing relevant to the development of psychopathology. For example, using event-related potentials (ERPs), several studies have provided evidence that early adverse experience alters neural responses to negative facial expressions within the first 300 ms of perceptual processing (Cicchetti and Curtis, 2005; Parker and Nelson, 2005; Pollak et al., 2001; Pollak and Tolley-Schell, 2003) and at later, more elaborated stages of processing (Pollak et al., 2001). Such findings have the potential to reveal specific mechanisms by which early experience impacts emotional processing and adjustment, ones that neural measures with less fine-grained temporal resolution may not reveal. Therefore, ERPs provide a powerful measurement tool for capturing neural activity related to emotional responding.

In fact, many studies have examined ERP responses to complex images from the International Affective Picture System (IAPS; Lang et al., 2005) to study both emotion and emotion regulation in adults (Cuthbert et al., 2000; Dunning and Hajcak, in press; Foti and Hajcak, 2008; Foti et al., in press; Hajcak and Olvet, 2008; Hajcak et al., 2006; Hajcak and Nieuwenhuis, 2006; Sabatinelli et al., 2007; Schupp et al., 2000, 2003a,b, 2004a,b). The IAPS is a standardized set of hundreds of color photographs that are designed to evoke a range of emotional responses; content ranges from unpleasant (e.g., threat scenes, mutilation), to neutral (e.g., household objects) to pleasant (e.g., erotica, sports scenes). Particularly relevant to the current study, both pleasant and unpleasant IAPS stimuli are associated with increases in two particular ERP components in adults: the early posterior negativity (EPN) and the late positive potential (LPP).

Approximately 150 ms following the onset of emotional (e.g., both pleasant and unpleasant) stimuli, the EPN becomes more negative, and this difference is maximal approximately 200–300 ms after stimulus onset (Schupp et al., 2003a,b, 2004b). This enhancement of the EPN is more pronounced for pictures with higher levels of emotional arousal, such that erotic stimuli and mutilations produce the largest posterior negativities (Schupp et al., 2003a,b). The EPN is prominent at bilateral temporo-occipital sites (Junghofer et al., 2006; Schupp et al., 2004a,b, 2003a,b). In

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light of this scalp distribution, it is believed that the EPN originates from the visual cortex and reflects increased activity in relatively early visual processing (Schupp et al., 2003b, 2004c).

Following the EPN, emotional stimuli elicit a rather sustained positive deflection in the ERP that has been referred to as the late positive potential. Specifically, the LPP is evident approximately 200–300 ms after the onset of pleasant and unpleasant compared to neutral stimuli, and is maximal at midline parietal recording sites (Cuthbert et al., 2000; Foti and Hajcak, 2008; Foti et al., in press; Hajcak and Olvet, 2008; Hajcak et al., 2006; Hajcak and Nieuwenhuis, 2006; Keil et al., 2002; Schupp et al., 2000, 2004b). In terms of its initial timing and scalp topography, the LPP resembles the classic P300 which appears larger following the presentation of task-relevant stimuli (Johnson, 1984, 1986; Magliero et al., 1984; Squires et al., 1977; Sutton et al., 1965). However, whereas the P300 appears as a more transient response, the LPP is sustained for as long as the affective stimulus is presented (Cuthbert et al., 2000), and is even evident following stimulus offset (Hajcak and Olvet, 2008). The increased LPP following emotional compared to neutral stimuli is observed at both posterior and anterior recording sites after approximately 1000 ms of stimulus presentation (Foti and Hajcak, 2008; Hajcak and Olvet, 2008; cf., Cuthbert et al., 2000). Just as the P300 appears to index transient increases in attention toward targets, the LPP might reflect the continued increase in attention toward emotional stimuli. In one combined fMRI/ERP study, the LPP correlated with neural activity in the lateral occipital, inferotemporal, and parietal visual areas, supporting the notion that it reflects increased perceptual and/or attentional processes engaged by motivationally relevant, emotional stimuli (Sabatinelli et al., 2007).

Although many studies in adults have examined ERP responses to the IAPS, comparable data in children has not been reported. In fact, the IAPS have not been used extensively in children. In one study, McManis et al. recorded self-report and peripheral psychophysiological responses from 7 to 10-year-old children while they viewed a developmentally appropriate subset of images from the IAPS. McManis et al. found that activity of the corrugator muscle and heart rate deceleration varied as a function of IAPS picture content in children, whereas skin conductance and startle reactivity were sensitive to picture content in female, but not male, children (McManis et al., 2001). A more recent study by Sharp et al. (2006) suggest that children's self-reported ratings of IAPS followed a similar pattern as that found in adults. Thus, there is initial evidence that children generally respond to complex emotional stimuli in a similar manner as adults, and these data further suggest that developmentally appropriate images from the IAPS can be used to assess emotional processing in developmental studies.

Because of their superior temporal resolution and relative ease to record from younger participants, ERPs might be ideal for examining relatively early neural responses to emotional stimuli in children (cf., Banaschewski and Brandeis, 2007). The EPN and LPP might be useful measures for studying both normative emotional development—and the development of psychopathology. The goal of the present study was to provide an important first step toward this aim—and to examine ERPs elicited by the IAPS in children. In an effort to examine whether children, like adults, will be characterized by a modulation of early (EPN) and late (LPP) ERPs to emotional compared to neutral IAPS images, the present study recorded ERPs from twenty five 5–10-year-old children. We chose this age range because early school age is a period marked by the cognitive and neural development needed to perform well under the attentional processing demands imposed by the experimental task (Casey et al., 2000). Participants passively viewed 90 developmentally appropriate IAPS images (30 pleasant, 30 neutral, and 30 unpleasant), and later provided valence and arousal ratings for each picture. Based on adult work, we predict that both the EPN and LPP would be enhanced for pleasant and unpleasant compared to neutral images. Based on previous studies, we predicted that children would rate pleasant and unpleasant images as more arousing than neutral, and would increase ratings of pleasantness from unpleasant to neutral to pleasant images.

1. Method

1.1. Participants

Twenty-five children (12 male, 13 female) and their caregivers provided informed consent to participate in the current study. Data from two subjects (both female) were excluded due to poor quality EEG recording, and data from 5 of the oldest remaining subjects were not included in these analyses so as to increase the homogeneity of age among the subjects. Thus, the final sample was comprised of 18 children who were 5 to 8 years of age; this sample included 9 males (mean age = 79.56 months, SD = 9.58 months) and 9 females (mean age = 74.56 months, SD = 12.31 months). All participants' families were paid $50 for their participation.

1.2. Stimulus materials

A total of 90 developmentally appropriate pictures were selected from the International Affective Picture System (IAPS; Lang et al., 2005); of these, 30 depicted pleasant scenes (e.g., smiling faces, fun scenes depicting sports, family, and animals), 30 depicted neutral scenes (e.g., neutral faces, household objects), and 30 depicted unpleasant scenes (e.g., sad/angry faces, wreckages, aggressive/attack pictures).[1] As a general criterion, the authors selected pictures that children might see either on television or in the news; erotica and mutilation pictures were not included. In terms of normative *adult* ratings (Lang et al., 2005), the picture categories differed in terms of valence ratings (M = 7.45, SD = 0.58, for pleasant picture content; M = 5.29, SD = 0.74, for neutral picture content; and M = 3.36, SD = 0.73, for unpleasant picture content). In addition, the emotional pictures were reliably higher on normative arousal ratings (M = 4.76, SD = 0.75, for pleasant picture content; M = 5.70, SD = 0.69, for unpleasant picture content; and M = 2.81, SD = 0.65, for neutral picture content). Note that these scores represent ratings that range from 1 to 9, where 9 would reflect extreme pleasantness and high arousal. Although we selected IAPS that were developmentally appropriate, the normative adult valence and arousal ratings of stimuli used in the current study are similar to those reported in existing studies on the LPP in adults (Bradley et al., 2007; Cuthbert et al., 2000; Foti et al., in press; Hajcak et al., 2007; Hajcak and Olvet, 2008; Schupp et al., 2004b).

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.

1.3. Procedure

After a brief description of the experiment, electroencephalograph (EEG) sensors were attached and the subject was given detailed task instructions. Subjects first viewed a practice series of pictures as they were displayed on the screen. Fifteen pictures were randomly selected for each experimental block, with a total of 6 blocks. Thus, each of the 90 pictures, randomly selected, was displayed once. The order of picture presentation was completely random such that there would be no confound of preceding picture type. At the beginning of each block, an instruction was presented for 2000 ms ("Simply view these pictures"). Each picture was presented for 2000 ms, and a fixation mark (+) was presented for 500 ms between each picture.

Next, all participants were asked to rate each picture on the valence and arousal scales of the self-assessment manikin (Lang, 1980; Lang et al., 2005). An abbreviated SAM scale was used that ranged from 1 to 5, rather than the standard 1 to 9 range used in adult studies. The valence scale was presented as an analogue scale that depicts five characters who range from happy to unhappy; below this scale are the numbers '1' through '5' ('1' corresponded to the happiest figure, '5' to the least happy figure, and '3' is located between the previous two). Participants were told to rate each picture on this scale based on how happy or sad it made them feel. The arousal scale of the self-assessment mannequin depicts five characters who appear

[1] The number of the IAPS pictures used were: unpleasant (1050, 1120, 1201, 1300, 1321, 1930, 2120, 2130, 2688, 2780, 2810, 2900, 3022, 3230, 3280, 5970, 6190, 6300, 7380, 9050, 9250, 9404, 9421, 9470, 9480, 9490, 9582, 9594, 9600, 9611); Neutral (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, 7950); pleasant (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, 8620).

to have a very strong visceral response to no visceral response; again, the numbers '1' through '5' are presented below this scale, and participants are told to rate the picture based on the strength of their feeling in response to the picture. Because some children did not understand either the valence or arousal scale (sometimes both), arousal ratings were obtained from 11 participants, and valence ratings were obtained from 12 participants. For data presentation, the scales were reverse-scored such that a '5' reflected the most pleasant rating and a '5' reflected the highest arousal rating.

1.4. Psychophysiological recording, data reduction and analysis

The continuous EEG was recorded using the ActiveTwo BioSemi system (BioSemi, Amsterdam, Netherlands). Recordings were taken from 64 scalp electrodes based on the 10/20 system, as well as two electrodes placed on the left and right mastoids. The electrooculogram (EOG) generated from blinks and eye movements was recorded from four facial electrodes: two approximately 1 cm above and below the subject's left eye, one approximately 1 cm to the left of the left eye, and one 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). All data were converted to an average reference and band-pass filtered with cutoffs of 0.1 and 30 Hz. The EEG was segmented for each trial, beginning 500 ms before each picture onset and continuing for 2500 ms. The EEG was corrected for blinks and eye movements using the method developed by Gratton et al. (1983).[2] Specific intervals for individual channels were rejected in each trial using a semi-automated 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 200.0 μV within a trial, and a maximum voltage difference of less than 0.50 μV within 100 ms intervals.[3]

ERPs were constructed by separately averaging the three picture types (pleasant, neutral, and unpleasant). For each ERP average, the average activity in the 500 ms window prior to picture onset served as the baseline. The LPP was evaluated as the average activity at left (O1, P3, P7) and right (O2, P4, P8) occipital–parietal recording sites; the LPP was defined as the average activity in three time windows following stimulus onset: 500–1000 ms (early window), 1000–1500 ms (middle window), and 1500–2000 ms (late window). The EPN was evaluated at these sites as the average activity between 175 and 275 ms following stimulus onset.

Behavioral ratings, the EPN, and LPP were statistically evaluated using SPSS (Version 14.0) General Linear Model software; Greenhouse-Geisser correction was applied to *p* values associated with multiple-df comparisons.

2. Results

2.1. Behavioral results

2.1.1. Valence

Fig. 1 presents the average valence and arousal ratings for each picture type. Valence ratings differed as a function of Picture Type ($F(2,22) = 53.32$, $p < .001$); pleasant pictures ($M = 3.23$; SD = .55) were rated as more pleasant than neutral ($M = 2.31$; SD = .49; $t(11) = 5.10$, $p < .001$) and unpleasant ($M = 1.08$; SD = .40; $t(11) = 9.44$, $p < .001$) pictures; additionally, neutral pictures were rated as more pleasant than unpleasant pictures ($t(11) = 5.71$, $p < .001$). Overall, then, valence ratings increased from unpleasant to neutral and from neutral to pleasant pictures.

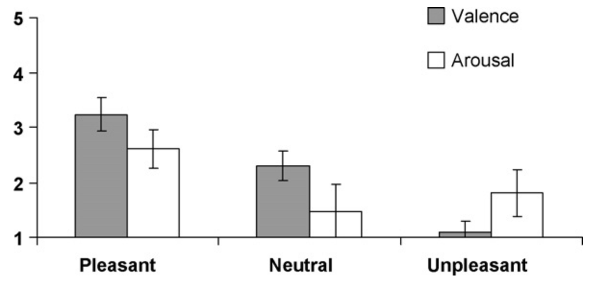

Fig. 1. Average arousal and valence ratings for pleasant, neutral, and unpleasant IAPS pictures. Error bars represent ± 2.04 standard errors, the 95% confidence interval.

2.1.2. Arousal

Arousal ratings also varied as a function of Picture Type ($F(2,20) = 5.09$, $p < .05$); pleasant ($M = 2.61$, SD = .64) pictures were rated as more arousing than neutral ($M = 1.48$, SD = ..87; $t(10) = 4.05$, $p < .01$) but not unpleasant ($M = 1.81$, SD = .77; $t(10) = 2.20$, $p > .05$) pictures; unpleasant and neutral pictures also did not differ on arousal ratings ($t(10) = .76$, $p > .45$).

2.2. Early posterior negativity

Fig. 2 presents the stimulus-locked ERPs at the occipital–parietal electrode clusters, collapsing across the left and right hemisphere. The EPN was evaluated statistically using a 2 (Hemisphere) × 3 (Picture Type) repeated measures ANOVA. The EPN did not vary as a function of Picture Type overall ($F(2,34) < 1$) or Hemisphere ($F(1,17) = 3.16$, $p > .05$); Picture Type also did not vary as a function of Hemisphere ($F(2,34) < 1$). Because previous studies have suggested that the EPN might be maximal at more inferior electrodes, we conducted a similar analysis at the more inferior Iz electrode: again, no effect of Picture Type was found ($F(2,34) < 1$).

2.3. Late positive potential

Fig. 3 presents the scalp distribution of the pleasant minus neutral (top), and unpleasant minus neutral (bottom) difference in the time window of the early (500–1000 ms), middle (1000–1500 ms), and late (1500–2000 ms) analyses windows. In the early window, a 2 (Hemisphere: Left, Right) × 3 (Picture Type:

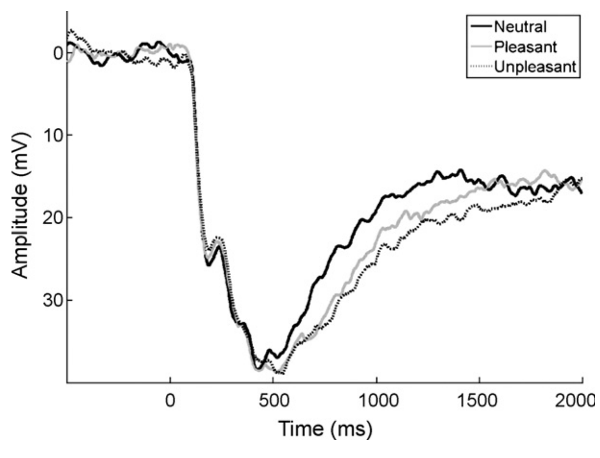

Fig. 2. Stimulus-locked ERPs elicited by pleasant, neutral, and unpleasant IAPS at occipital–parietal recording sites. Stimulus onset occurred at 0 ms; negative is plotted up.

[2] The number of identified blinks did not differ between pleasant (M = 42.94, SD = 11.01), neutral (M = 41.44, SD = 12.09), and unpleasant (M = 43.28, SD = 10.08) trials ($F(2,34) < 1$). Moreover, to assess for systematic differences in ocular activity as a function of picture type, the horizontal (HEOG) and vertical (VEOG) channels were analyzed in the early (500–1000 ms), middle (1000–1500 ms), and late (1500–2000 ms) windows. HEOG activity did not vary as a function of picture type in the early, middle, and late windows ($F(2,34) < 1$, $F(2,34) = 1.44$, $p > .25$, and $F(2,34) = 1.71$, $p > .20$, respectively). Similarly, VEOG activity did not differ as a function of picture type in the early ($F(2,34) < 1$), middle ($F(2,34) < 1$), or late windows ($F(2,34) < 1$).

[3] The total number of identified artifacts did not differ between pleasant ($M = 173.89$, SD = 243.58), neutral ($M = 172.44$, SD = 234.60), and unpleasant ($M = 203.89$, SD = 308.60) trials ($F(2,34) = 1.56$, $p > .30$). The minimum number of trials included in pleasant, neutral, and unpleasant ERP averages was 20, 22, and 26 trials, respectively. The mean (and standard deviation) number of trials included in pleasant, neutral, and unpleasant ERP averages was 26.80 (3.04), 26.93 (2.69), and 26.33 (3.36), respectively.

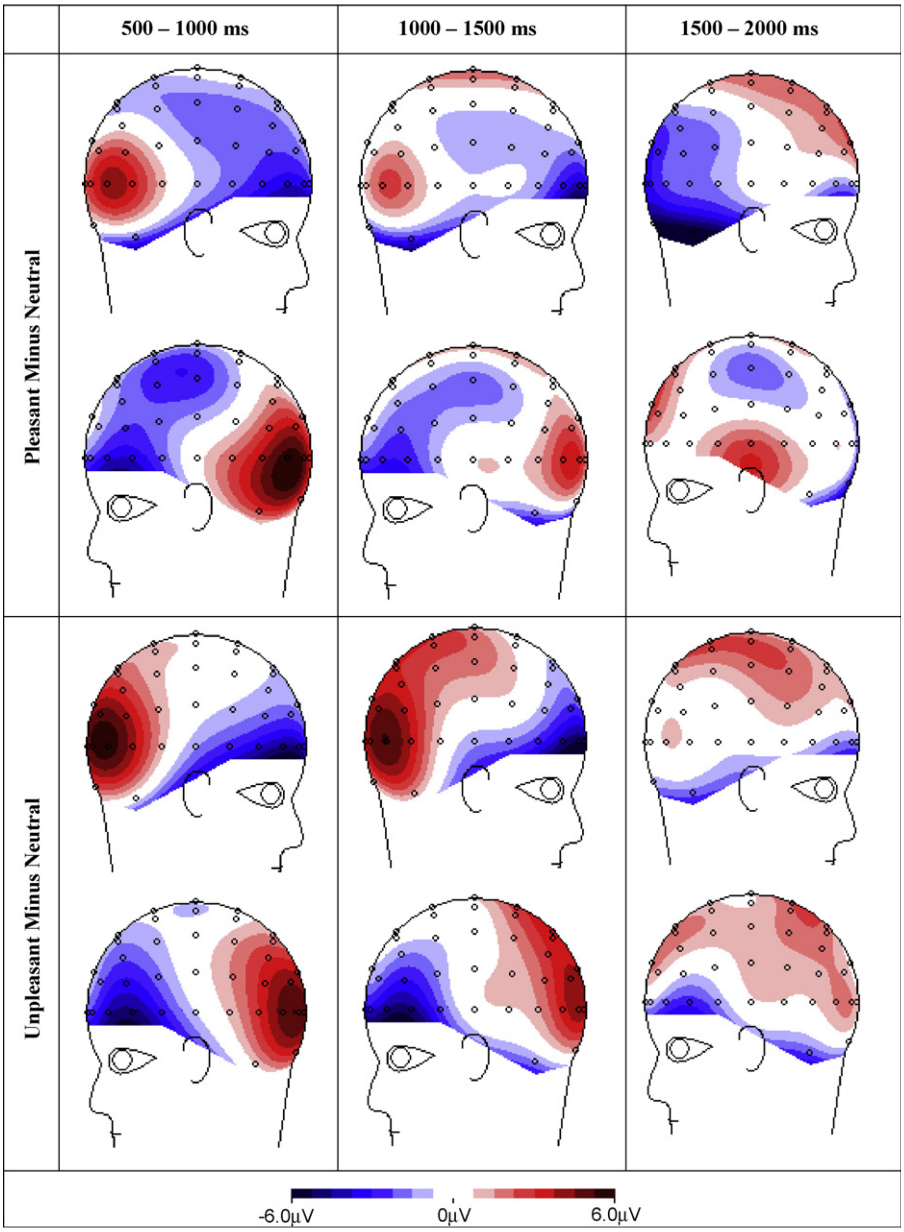

Fig. 3. Scalp distribution of the pleasant minus neutral (top) and unpleasant minus neutral (bottom) difference waveform in the time window of the early LPP (i.e., 500–1000 ms; left), middle LPP (i.e., 1000–1500 ms; middle), and late LPP (i.e., 1500–2000 ms; right).

unpleasant, neutral, pleasant) repeated measures ANOVA indicated that the amplitude of the LPP varied as a function of picture type ($F(2,34) = 5.39$, $p < .01$). The LPP did not differ between left and right hemisphere ($F(1,17) = 2.15$, $p > .15$); hemisphere did not interact with picture type ($F(2,34) = 1.32$, $p > .25$). Post hoc comparisons indicated that the early LPP, collapsing across the left and right clusters, was larger for both pleasant ($M = 29.85$, $SD = 8.13$) and unpleasant ($M = 30.91$, $SD = 9.84$) compared to neutral ($M = 25.29$, $SD = 10.05$; $t(17) = 2.53$, $p < .05$ and $t(17) = 3.04$, $p < .01$, respectively) pictures; the LPP elicited by pleasant and unpleasant pictures did not differ from one another ($t(17) = .59$, $p > .50$).

In the middle window (1000–1500 ms), the LPP continued to vary by picture type ($F(2,34) = 4.51$, $p < .05$), but not by hemisphere ($F(1,17) < 1$); hemisphere and picture type did not interact ($F(2,34) = 1.49$, $p > .20$). From 1000 to 1500 ms, post hoc comparisons revealed that unpleasant pictures elicited a larger LPP ($M = 21.28$, $SD = 8.46$) than neutral ($M = 16.11$, $SD = 6.67$; $t(17) = 3.29$, $p < .01$) but not pleasant pictures ($M = 19.18$, $SD = 7.19$; $t(17) = 1.00$, $p > .30$); additionally, from 1000 to 1500 ms, pleasant pictures no longer elicited an LPP that was reliably larger than neutral pictures ($t(17) = 2.00$, $p > .05$).

By the late window (e.g., 1500–2000 ms), the LPP did not vary as a function of picture type ($F(2,34) = 1.21$, $p > .30$) or hemisphere ($F(1,17) < 1$); the interaction between picture type and hemisphere also did not reach significance ($F(2,34) = 2.28$, $p > .10$).[4]

[4] Many studies that measure the LPP have utilized average activity of the mastoid sensors as the reference (Cuthbert et al., 2000; Foti and Hajcak, 2008; Hajcak et al., 2007, 2006; Hajcak and Olvet, 2008; Hajcak and Nieuwenhuis, 2006). When the present data were evaluated with respect to the average activity at mastoid sensors, the LPP was maximal at central-parietal midline recording sites and was reliably greater for both pleasant and unpleasant (compared to neutral) pictures in the middle and late (but not early) windows; there was no evidence for emotional modulation of the EPN using mastoid referenced data.

3. Discussion

The present study is among the first to document that the LPP is sensitive to meaningful differences in the emotional content of complex visual stimuli in children. In particular, children were characterized by an increased positivity in their ERP at bilateral occipital–parietal sites between 500 and 1500 ms following the presentation of unpleasant compared to neutral stimuli; a similar effect was evident for pleasant compared to neutral pictures in the 500–1000 ms window.

An increased positive-going ERP component has previously been described as the late positive potential (Cuthbert et al., 2000) following the presentation of emotional compared to neutral pictures. In adults, the LPP is evident first at posterior recording sites, beginning just 200–300 ms following presentation of emotional stimuli (Foti and Hajcak, 2008; Hajcak et al., 2007, 2006; Hajcak and Nieuwenhuis, 2006; Schupp et al., 2000, 2004a). In children in the current study, however, this effect appeared maximal at slightly more occipital recording sites relative to adult studies, and was not evident in the ERP beyond 1500 ms. When the LPP was evaluated using mastoid referenced data, the LPP was larger for pleasant and unpleasant pictures from 1000 to 2000 ms following picture presentation at midline central-parietal recording sites—a pattern more similar to results reported in adult samples.

On the other hand, the present study did not find evidence for a modulation of the EPN by emotional pictures. The EPN has been taken to reflect early facilitated perception of motivationally significant environmental stimuli (Schupp et al., 2004a,b, 2003a,b). In the context of the present LPP results, the failure to find an EPN in children may suggest that the relatively earlier and automatic detection of emotional stimuli indexed by the EPN may not become evident until later in development. However, it is also important to note that the EPN has not always been reported using a 64-channel montage (De Cesarei and Codispoti, 2006) and appears to depend heavily on stimulus selection. In particular, recent studies suggest that the EPN may be largest for erotica (Bradley et al., 2007; De Cesarei and Codispoti, 2006; Schupp et al., 2004b). Bradley et al. (2007) reported non-affective modulation of the EPN in comparing figure-ground stimuli to more complex scenes; moreover, there was no evidence of an emotional modulation of the EPN in this study. Bradley et al. suggest that the EPN might either be specifically related to erotica, or to the relatively simple figure-ground composition of these stimuli. The absence of the EPN in the current study is consistent with these possibilities, as we did not include erotica.

It is interesting to consider the ERP findings in terms of children's self-report ratings in the current study. First, children in the current study did report increasing valence ratings from unpleasant to neutral to pleasant pictures; thus, valence ratings were consistent with normative adult ratings. However, children tended to report relatively lower (less pleasant) ratings across the board. For instance, pleasant pictures were rated just above the midpoint of the valence scale, and neutral pictures were actually rated *below* the midpoint of the valence ratings, on average. This pattern of results contrasts with adult rating data in which neutral pictures tend to be rated as slightly *pleasant* (Bradley and Lang, 2007).

Arousal ratings in the current study did not mirror the pattern found in normative adult ratings. Specifically, children rated *pleasant* images as more arousing than both neutral and unpleasant pictures. Unpleasant pictures, however, were not rated as more arousing than neutral pictures. Thus, unpleasant stimuli, which elicited an equally large LPP as pleasant stimuli in the early window, and were uniquely related to a larger LPP in the middle window, were not rated as particularly arousing. These self-report results are identical to those reported by McManis et al. (2001), who found that only pleasant IAPS images were rated by children as more arousing than the others. Future research may focus on the degree to which children understand this rating scale, whether they mistakenly interpret higher arousal ratings in terms of a positively valenced reaction, and how arousal ratings in children change developmentally.

Although children did not report higher arousal for both unpleasant and pleasant pictures, their ERP data appeared to reflect the typical pattern observed in adults: both unpleasant and pleasant pictures were associated with an increased LPP. In this way, the observed pattern of children's LPPs was more 'adult-like' than their arousal ratings. Because the LPP can be used to assess early neural activity over time, it might be ideal for studying the time-course of emotional processing, or what has been referred to as affective chronometry (Davidson, 1998, 2002). The LPP might, therefore, be useful for studying individual differences and the development of emotion, and tracking the time-course of abnormalities in attention toward emotional stimuli as a function of risk for anxiety disorders and depression (cf. Davidson and Irwin, 1999; Rothbart and Bates, 1998).

Additionally, the LPP could be used to study the development of emotion regulation. For instance, instructions to reappraise unpleasant stimuli in adults has been shown to decrease the magnitude of the LPP (Hajcak and Nieuwenhuis, 2006; Moser et al., 2006); similarly, when unpleasant stimuli are described in a more neutral manner prior to their presentation, the subsequent LPP is reduced relative to when the stimuli are described in a more negative manner (Foti and Hajcak, 2008). Finally, focusing on emotional compared to less emotional aspects of pictures results in a relative increase in the LPP (Dunning and Hajcak, in press; Hajcak et al., 2006). Whether children can modulate their LPP via emotion regulation remains to be seen; we are currently investigating this in ongoing experiments.

In summary, this is the first study to examine the EPN and LPP following the presentation of complex emotional pictures in children. Results suggest potential similarities and differences between children and adults in both the early and later processing of emotionally and motivationally significant stimuli: specifically, emotional stimuli failed to elicit an enhanced EPN, but did potentiate the amplitude of the LPP, in children. Future research should explore developmental changes over time within childhood, and pay special attention to issues related to picture selection, as well as reference montage. In particular, it will be important to examine the LPP and EPN in children in response to a winder range of IAPS images as well as other visual stimuli such as emotional faces and words—both of which have been associated with an increased LPP in adults (Naumann et al., 1992; Schupp et al., 2004b).

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