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Age-related changes in emotional face processing across childhood and into young adulthood: evidence from event-related potentials

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Abstract

Socio-emotional processing is an essential part of development, and age-related changes in its neural correlates can be observed. The late positive potential (LPP) is a measure of motivated attention that can be used to assess emotional processing; however, changes in the LPP elicited by emotional faces have not been assessed across a wide age range in childhood and young adulthood. We used an emotional face matching task to examine behavior and event-related potentials (ERPs) in 33 youth aged 7 to 19 years old. Younger children were slower when performing the matching task. The LPP elicited by emotional faces but not control stimuli (geometric shapes) decreased with age; by contrast, an earlier ERP (the P1) decreased with age for both faces and shapes, suggesting increased efficiency of early visual processing. Results indicate age-related attenuation in emotional processing that may stem from increased efficiency and regulatory control when performing a socio-emotional task.

Keywords

late positive potential; LPP; development; faces; emotion; affect; P1; event-related potential; ERP; children; neural; adolescent

From a young age, the ability to perceive, process and respond to socio-emotional stimuli is central to effective navigation of the social environment and to psychological wellbeing (Izard, 2001). For example, children's ability to recognize facial expressions has been found to predict social success (A. L. Miller et al., 2005) and even scholastic performance (Agnoli et al., 2012). Moreover, children's understanding of others' emotions and norms regarding emotional display predicts their ability to modulate emotional response (Hudson & Jacques, 2014) – a key part of social success (McDowell, O'Neil, & Parke, 2000). On the other hand, deficits in socio-emotional processing are evident among children diagnosed with (Collin, Bindra, Raju, Gillberg, & Minnis, 2013) and at risk for (Kujawa et al., 2014; Kujawa, Hajcak, Torpey, Kim, & Klein, 2012) psychiatric disorders. Neurobiological measures can provide insight into the mechanisms underlying socio-emotional processing that may be difficult to discern using behavioral measures or subjective report, alone (Santerre & Allen, 2007). Therefore, these measures may play an important role in understanding both typical and atypical development of socio-emotional processing across childhood and adolescence.

In recent years, considerable progress has been made in understanding age-related changes in affective processing using functional magnetic resonance imaging (fMRI). For example, several studies have shown that amygdala reactivity to emotional compared to neutral stimuli (fearful faces, Guyer et al., 2008; emotional scenes, Hwang, White, Nolan, Sinclair, & Blair, 2014; Vink, Derks, Hoogendam, Hillegers, & Kahn, 2014) is reduced in adolescents or adults compared to children (but see Hare et al., 2008; and adolescents at risk for depression, Swartz, Williamson, & Hariri, 2014). One reason for this age-related reduction in emotional stimulus processing might be the development and improved functioning of regulatory brain regions such as the prefrontal cortex (PFC). In a sample of 4- to 22-year olds, Gee and colleagues (2013) found that children less than 10 years old were characterized by positive prefrontal-amygdala connectivity; children 10 years and above were, however, characterized by negative connectivity between these regions (a reciprocal relationship suggestive of increased regulatory control). Other studies have also found evidence of changing connectivity between the PFC and the amygdala as children age (Hwang et al., 2014; Vink et al., 2014). Therefore, age-related changes that facilitate emotional control might underlie reductions in affective responding from childhood to adulthood.

Compared to fMRI, event-related potentials (ERPs) provide a well-tolerated, cost-effective and temporally sensitive means of assessing socio-emotional processing. Several ERP components are sensitive to emotion in adults. For instance, the P1 is an early, occipital component that occurs approximately 100 ms after stimulus onset and is larger for affective faces than neutral stimuli (Batty & Taylor, 2003, 2006; Dennis, Malone, & Chen, 2009). Prior work examining the P1 across childhood and adolescence has reported age-related decreases in amplitude; however these reductions have been found to be nonspecific – evident for both affective and non-affective stimuli (Hileman, Henderson, Mundy, Newell, & Jaime, 2011; Meaux et al., 2014). Therefore, age-related reductions in P1 amplitude have been taken to reflect reduced cortical activity for early visual processing, which may correspond to increasing automaticity of visual processing across childhood and adolescence (Batty & Taylor, 2006).

The late positive potential (LPP) is a positive-going deflection in the ERP waveform that begins approximately 300 ms after stimulus onset and is larger for emotional stimuli, such as pictures of mutilations or erotica compared to neutral stimuli, such as pictures of household furniture or neutral people (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Feng, Wang, Wang, Gu, & Luo, 2012; Olofsson, Nordin, Sequeira, & Polich, 2008). The LPP is also enhanced to socio-emotional stimuli. For example, the LPP has been shown to be larger for pictures of faces compared to geometric shapes (MacNamara, Post, Kennedy, Rabinak, & Phan, 2013), as well as for pictures of human faces compared to pictures of dolls' faces or pictures of clocks (Wheatley, Weinberg, Looser, Moran, & Hajcak, 2011). Personally salient social stimuli, such as pictures of one's own relatives or loved ones, also elicit larger LPPs (Grasso & Simons, 2011; Vico, Guerra, Robles, Vila, & Anllo-Vento, 2010). Finally, the LPP is also larger for stimuli that have been described in a negative compared to a neutral manner (MacNamara, Foti, & Hajcak, 2009). Therefore, the LPP is believed to measure *motivated attention* (Lang, Bradley, & Cuthbert, 1997) toward stimuli, and it appears to be sensitive to individual differences in the perceived salience of stimuli.

The LPP has been used extensively as a measure of emotional face processing among adults, and of late, the LPP has been found to be reliably elicited in children (Kujawa, Klein, & Proudfit, 2013; see also Babkirk, Rios, & Dennis, 2014; DeCicco, O'Toole, & Dennis, 2014; Dennis & Hajcak, 2009; Hajcak & Dennis, 2009; Solomon, DeCicco, & Dennis, 2012). Recent work has also sought to characterize age-related changes in the LPP using cross-sectional and longitudinal approaches. For instance, Kujawa and colleagues (Kujawa, Klein, & Hajcak, 2012) found that 11- to 13-year olds showed smaller LPPs to sad, happy and neutral faces as well as unpleasant, pleasant and neutral scenes when compared to a group of 8- to 10-year olds. Importantly, the age-related decrease in the LPP was observed across both emotional and neutral stimuli, suggesting that it might reflect a more general shift in attentional allocation and stimulus processing or even increasing skull thickness (which tends to reduce ERP amplitudes, Frodl et al., 2001; see also Beauchamp et al., 2011), rather than a reduction in affective processing per se. In another study by the same group, children aged 8- to 13-years old were assessed at two time-points, spaced two-years apart (Kujawa, Klein, et al., 2013). Results showed that the LPP elicited by emotional and neutral scenes decreased over time as children aged. Of note, although the topographic distribution of the LPP shifts from primarily occipital sites in children (Hajcak & Dennis, 2009; Kujawa, Weinberg, Hajcak, & Klein, 2013), to more centroparietal sites in adults (Hajcak, Weinberg, MacNamara, & Foti, 2012), age-related decreases in the LPP appear to reflect more than simply a shift in topographic distribution (Kujawa, Klein, et al., 2013).

In total, three studies have reported age-related decreases in the LPP during childhood (P.-X. Gao, Liu, Ding, & Guo, 2010; Kujawa, Klein, et al., 2012, 2013) – two of these used emotional and neutral scenes (P.-X. Gao et al., 2010; Kujawa, Klein, et al., 2013) and one used a combination of scenes and faces (Kujawa, Klein, et al., 2012). One additional study reported an age-related *increase* in the parietal LPP elicited by emotional and neutral scenes (Zhang et al., 2012). In contrast to the fMRI literature, all of these studies have reported age-related changes in the processing of emotional *and* neutral stimuli, rather than changes in affective processing specifically. Additionally, no study has examined the LPP from childhood into young adulthood, and age effects have typically been found using between-

group comparisons (e.g., 8- to 10-year olds versus 11- to 13-year olds), rather than in a continuous fashion, which would parallel fMRI work (e.g., Ferri, Bress, Eaton, & Proudfit, 2014).

In light of these limitations, the current study set out to replicate and extend prior findings. To this end, we examined age-related change in ERPs elicited by emotional faces across a continuous age span of 7- to 19-year olds. We used an affective face matching task previously validated for use with ERPs (MacNamara et al., 2013), in order to assess developmental effects on both behavioral and ERP measures. We expected to observe overall, age-related reductions in both the P1 (Hileman et al., 2011; Meaux et al., 2014) and the LPP (P.-X. Gao et al., 2010; Kujawa, Klein, et al., 2012, 2013), rather than specific decreases in *affective* processing. We also expected younger children to be slower and less accurate in matching affective faces, especially for negatively valenced faces (Kujawa et al., 2014).

Methods

Participants

Thirty-nine healthy children and adolescents were recruited from the community through advertisements placed on websites, in university facilities, and in local newspapers. Data from six participants were excluded due to poor quality EEG – defined as recordings in which artifact rejection would have left less than 50% of trials available for analyses. The final sample was comprised of 33 children and adolescents (ages 7 – 19 years, $M = 14.12$ years, $SD = 4.03$ years), and included 18 females (ages 7 – 19 years, $M = 13.67$ years, $SD = 4.17$ years) and 15 males (ages 7 – 19 years, $M = 14.67$ years, $SD = 3.92$ years). Participants or their guardians provided written informed consent for participation in the study. Initial assessment included a structured psychiatric interview (K-SADS-PL; Kaufman et al., 1997) conducted by Masters/Ph.D./MD-level clinicians with experience in conducting interviews in children and adolescents, and comprehensive medical history obtained by a physician. Participants with lifetime DSM-IV (APA, 2000) psychiatric disorders or current medical diagnoses and current use of psychotropic/psychoactive medications that could have interfered with the study aims were excluded from the study. Participants were financially compensated on an hourly basis (\$15/hour). All procedures were approved by the Institutional Review Boards at the University of Michigan and University of Illinois at Chicago.

Materials

Twenty-four angry, 24 fearful, 24 happy and 36 neutral faces were selected from a validated emotional faces set (Gur et al., 2002; Kohler et al., 2003)¹. Half of the faces depicted male actors and the other half depicted female actors. In addition, 3 geometric shapes -a circle, a

¹Stimuli used were as follows. Angry: ANG-01, ANG-03, ANG-04, ANG-05, ANG-06, ANG-07, ANG-09, ANG-10, ANG-11, ANG-12, ANG-13, ANG-14, ANG-16, ANG-18, ANG-20, ANG-21, ANG-22, ANG-18, ANG-24, ANG-25, ANG-26, ANG-28, ANG-29, ANG-30; Fearful: FER-01, FER-03, FER-04, FER-05, FER-06, FER-07, FER-09, FER-10, FER-11, FER-12, FER-13, FER-14, FER-16, FER-18, FER-20, FER-21, FER-22, FER-18, FER-24, FER-25, FER-26, FER-28, FER-29, FER-30; Happy: HAP-01, HAP-03, HAP-04, HAP-05, HAP-06, HAP-07, HAP-09, HAP-10, HAP-11, HAP-12, HAP-13, HAP-14, HAP-16, HAP-18, HAP-20, HAP-21, HAP-22, HAP-18, HAP-24, HAP-25, HAP-26, HAP-28, HAP-29, HAP-30; Neutral: NEU-01, NEU-02, NEU-03,

square and a triangle- were used as control stimuli (see task description, below). The shapes were presented in white on a black background; faces were presented in color on a black background, on a 19" computer screen using Presentation software (Neurobehavioral Systems, Inc., Albany, CA). Participants were seated approximately 60 cm from the screen.

Task

Figure 1 depicts task timing and example stimuli. Participants completed a modified version of the Emotional Face Processing Task (Hariri, Tessitore, Mattay, Fera, & Weinberger, 2002). On each trial, participants performed a matching task using either emotional and neutral faces or geometric shapes (as a control condition). On "face" trials, participants viewed one target face, centered at the top of the computer screen and two probe faces, presented at either side of the bottom of the screen, for 3,000 ms. Each image subtended a visual angle of about 9 horizontally and 12 degrees vertically. The two stimuli at the bottom of the screen were positioned approximately 5 degrees (of visual angle) to the left or right of the center of participants' field of view and 7 degrees (of visual angle) below participants' center of vision; the picture at the top of the screen was positioned approximately 7 degrees (of visual angle) above participants' center of vision. All three stimuli were presented simultaneously. Participants were instructed to indicate which probe face bore the same emotional expression as the target face. The target and congruent probe face displayed one emotional expression (angry, fearful, or happy), and the other (incongruent) probe face always displayed a neutral expression. The identity of all three faces was always different, and an equal number of male and female faces were presented throughout the task. On the "shape" trials, participants matched three simple, simultaneously presented geometric shapes (circles, rectangles, or triangles) instead of faces.

The task was divided into two blocks, with each block having 12 angry, 12 fearful, 12 happy and 12 shape-matching trials; trials were presented randomly within each block, for a total of 96 trials across both blocks. The inter-trial interval varied between 1,000 and 3,000 ms, during which time a white fixation cross was centrally presented on a black background. During presentation of the images, participants were instructed to maintain focus on the screen, but were permitted to look freely among the images. Participants responded by pressing the left or right response buttons with their dominant hand.

EEG recording, data reduction and analysis

Continuous EEG was recorded using an elastic cap and the ActiveTwo BioSemi system (BioSemi, Amsterdam, Netherlands). Thirty-four electrode sites (standard 32 channel setup, as well as FCz and Iz) were used, based on the 10/20 system; in addition, one electrode was placed on each of the left and right mastoids. The electrooculogram (EOG) generated from eyeblinks and eye movements was recorded from four facial electrodes: vertical eye movements and blinks were measured with two electrodes placed approximately 1 cm above and below the right eye; horizontal eye movements were measured using two electrodes placed approximately 1 cm beyond the outer edge of each eye. The EEG signal was pre-

NEU-04, NEU-05, NEU-06, NEU-07, NEU-08, NEU-10, NEU-11, NEU-12, NEU-13, NEU-14, NEU-15, NEU-16, NEU-17, NEU-18, NEU-20, NEU-22, NEU-23, NEU-24, NEU-25, NEU-27, NEU-28, NEU-29, NEU-30, FN_13, MN_223, MN_21, FN_30, FN_228, FN_204, FN_141, MN_202, MN_111, MN_205.

amplified at the electrode to improve the signal-to-noise ratio. The data were digitized at 24-bit resolution with a Least Significant Bit (LSB) value of 31.25 nV and a sampling rate of 1024 Hz, using a low-pass fifth order sinc filter with a - 3dB cutoff point at 204.8 Hz. The voltage from each active electrode was referenced online with respect to a common mode sense active electrode producing a monopolar (non-differential) channel.

Off-line analyses were performed using Brain Vision Analyzer 2 software (Brain Products, Gilching, Germany). Data from correct trials were segmented for each trial beginning 200 ms prior to picture onset and continuing for 3,200 ms (3,000 ms beyond picture onset); baseline correction for each trial was performed using the 200 ms prior to picture onset. Offline, data were re-referenced to the average of the two mastoids and band-pass filtered with high-pass and low-pass filters of 0.01 and 30 Hz, respectively. Eye blink and ocular corrections used the method developed by Miller, Gratton & Yee (1988). Artifact analysis was used to identify a voltage step of more than 50.0 μ V between sample points, a voltage difference of 300.0 μ V within a trial, and a maximum voltage difference of less than 0.50 μ V within 100 ms intervals. Trials were also inspected visually for any remaining artifacts, and data from individual channels containing artifacts were rejected on a trial-to-trial basis². For Figures 3B and 4 (depicting the LPP), a digital low-pass (12 Hz) filter was applied offline before plotting the waveforms; statistical analyses were conducted using the original filter settings.

In line with prior work in children and adolescents (Dennis et al., 2009) and following visual inspection of the data, the P1 was scored by averaging mean amplitudes at electrodes Oz, PO3 and PO4 in a 20 ms window around peaks identified from 80-180 ms after stimulus onset. The LPP was scored using mean amplitudes from electrodes Pz, Oz, PO3 and PO4 from 300 to 3,000 ms after picture onset, on correct trials only (Kujawa, Klein, et al., 2012, 2013)^{3,4}.

Accuracy data were computed as the percentage of correct trials per condition. Reaction time was computed as the amount of time it took participants to respond from picture onset, on correct trials only. Condition effects on behavioral and ERP data were analyzed using a repeated measures analysis of covariance, with age as a covariate of interest⁵. Statistical analyses were performed using SPSS (Version 22.0) General Linear Model software. Greenhouse-Geisser corrections were applied when assumptions of sphericity were not met; the Benjamini-Hochberg procedure (1995) was used to control the false discovery rate (FDR) for multiple comparisons.

²Across all conditions, 7.73% ($SD = 4.61\%$) of trials contained artifacts. The percentage of trials with artifacts did not differ by condition, $F(3,96) = 1.23$, $p = .30$ (angry, $M = 7.00\%$, $SD = 5.39\%$; fearful, $M = 7.55\%$, $SD = 5.05\%$; happy, $M = 7.70\%$, $SD = 6.16\%$; shapes, $M = 8.66\%$, $SD = 5.57\%$) and did not correlate with age (examined separately for each condition; all $ps > .64$).

³We did not see evidence of an N170/vertex positive potential, which may show complex changes in latency and topography throughout childhood (for a review of prior work, see Taylor et al., 2004).

⁴When the LPP was scored at separate parietal and occipital groups of electrodes, age-related changes were evident at both occipital and parietal sites and the overall pattern of results was unchanged. When the LPP was subdivided into smaller time windows, the overall pattern of results was also unchanged.

⁵The inclusion of sex (male, female) as a factor did not affect result interpretation.

Results

P1

Table 1 shows means and standard deviations of P1 amplitudes; Figure 2 depicts grand-averaged waveforms at parieto-occipital sites where the P1 was scored. There was a significant main effect of age, $F(1,31) = 14.96$, $p = .001$, $\eta_p^2 = 0.32$, which indicated the P1 (averaged across all conditions) was smaller among older participants: $t(31) = -.57$, $p < .001$. The main effect of condition and the interaction between age and condition failed to reach significance (both $ps > .15$).

LPP

Table 1 shows means and standard deviations of LPP amplitudes. Figure 3 depicts grand-averaged waveforms at the parieto-occipital sites where the LPP was scored. Results depicted in Figure 4 are presented separately for younger participants (top row) and older participants (bottom row), based on a median split that was performed for illustrative purposes only: Figure 4A depicts scalp distributions of the voltage difference for each face type minus shapes; Figure 4B depicts grand average waveforms. Figure 5 shows a scatterplot depicting the association between age and the LPP elicited in each condition.

There was a significant effect of condition $F(3,93) = 7.06$, $p < .001$, $\eta_p^2 = 0.18$, with angry faces, $t(32) = 4.80$, $p < .001$, fearful faces, $t(32) = 4.80$, $p < .001$, and happy faces $t(32) = 5.37$, $p < .001$ eliciting larger LPPs than shapes (LPPs elicited by angry, fearful and happy faces did not differ from each other, all $ps > .64$). Smaller LPPs among older participants were reflected in a main effect of age, $F(1,31) = 11.07$, $p = .002$, $\eta_p^2 = 0.26$. Main effects of condition and age were qualified by an interaction, $F(3,93) = 3.54$, $p = .02$, $\eta_p^2 = 0.10$ (Figures 4A, 4B and 5). Follow-up analyses revealed that the LPP elicited by faces decreased with age: angry, $t(31) = -.42$, $p = .02$; fearful, $t(31) = -.40$, $p = .02$; happy, $t(31) = -.54$, $p = .001$; all $ps < .05$ FDR. The LPP elicited by shapes did not correlate with age, $t(31) = -.10$, $p = .58$.

Using Fisher's r -to- z transformation, followed by Steiger's (1980) equations, the magnitude of the correlation between age and the LPP elicited by happy faces was found to be larger than the magnitude of the correlation between age and the LPP elicited by shapes ($z = 2.34$, $p = .01$, one-tailed). Neither the age and fearful faces LPP correlation nor the age and angry faces LPP correlation were found to be significantly larger than the age and shapes LPP correlation (fearful versus shapes: $z = 1.52$, $p = .06$; angry versus shapes: $z = 1.58$, $p = .06$, one-tailed).

Behavioral Performance

Mean RT and accuracy values are shown in Table 1. For RT, significant effects of condition, $F(3,93) = 44.41$, $p < .001$, $\eta_p^2 = 0.59$ revealed that RT was fastest for shapes, then happy faces, then fearful faces, then angry faces: angry > fearful, $t(32) = 3.38$, $p = .002$; fearful > happy, $t(32) = 4.36$, $p < .001$; happy > shapes, $t(32) = 14.76$, $p < .001$, controlling for age (all $ps < .05$ FDR). Slower response times among younger participants were reflected in a main effect

of age, $F(1,31) = 42.81, p < .001, \eta_p^2 = 0.58$. An interaction between age and condition, $F(3,93) = 7.33, p < .001, \eta_p^2 = 0.19$ was observed; however, RTs were slower among younger participants in all conditions - angry, $t(31) = -.72, p < .001$; fearful, $t(31) = -.77, p < .001$; happy, $t(31) = -.73, p < .001$; shapes, $t(31) = -.69, p < .001$; all p s < .05 FDR.

To further interpret the age X condition interaction, we performed a median split, dividing participants into younger (7- to 14-years, $n = 16$) and older (15- to 19-years, $n = 17$) groups. Repeated measures analysis of variance (ANOVAs) performed separately for each group revealed significant effects of condition in each group: younger, $F(3,45) = 98.82, p < .001, \eta_p^2 = 0.87$; older, $F(3,48) = 117.88, p < .001, \eta_p^2 = 0.88$. Nevertheless, some differences between conditions were observed in one group but not the other - a) young group: angry < > fearful, $t(15) = .73, p = .48$; angry > happy, $t(15) = 5.45, p < .001$; fearful > happy, $t(15) = 4.49, p < .001$; happy > shapes, $t(15) = 10.19, p < .001$; b) older group: fearful < > happy, $t(16) = 1.93, p = .07$, angry > fearful, $t(16) = 5.66, p < .001$; angry > happy, $t(16) = 5.49, p < .001$; happy > shapes, $t(16) = 11.12, p < .001$.

For accuracy, a significant effect of condition, $F(3,93) = 9.23, p < .001, \eta_p^2 = 0.23$ indicated that performance was best for shapes, followed by happy and fearful faces, followed by angry faces: shapes > fearful, $t(32) = 3.24, p = .003$; shapes > angry, $t(32) = 10.07, p < .001$; fearful > angry, $t(32) = 7.23, p < .001$ and happy > angry, $t(32) = 8.01, p < .001$, controlling for age (all p s < .05 FDR). Accuracy did not differ for happy faces versus shapes, $t(32) = 1.97, p = .06$ or for fearful versus happy faces, $t(32) = 1.69, p = .10$. The main effect of age did not reach significance ($p = .16$); neither did the interaction between condition and age, $F(3,93) = 2.54, p = .06, \eta_p^2 = 0.08$.

Discussion

We set out to replicate and extend prior research by examining age-related changes in ERPs and behavioral responses elicited by affective faces in a sample of children and adolescents with a wide range in age from 7 to 19 years old. Emotional faces elicited larger LPPs than shapes, and LPP amplitudes decreased with age for faces only (i.e., not shapes). The magnitude of age-related change in the LPP was largest for happy faces compared to shapes. There was no effect of condition on the P1, however an overall age-related reduction in P1 amplitude was observed. Behaviorally, participants were slower at matching faces compared to shapes and younger children were slower overall.

The results are broadly in line with prior work, which found that the LPP was smaller among older compared to younger 8- to 13-year olds (Kujawa, Klein, et al., 2012, 2013) and smaller among older compared to younger 12- to 21-year olds (P.-X. Gao et al., 2010). However, the results contradict one prior study, which found that the LPP increased with age across a group of adolescents (Zhang et al., 2012). Task differences might account, in part, for this discrepancy. For instance, only the Zhang and colleagues (2012) study asked participants to rate their affective response to images, which could have influenced neural activation (Monk et al., 2003).

Unlike in prior studies (P.-X. Gao et al., 2010; Kujawa, Klein, et al., 2012, 2013), we found that age-related reductions in the LPP were only evident for emotional stimuli. One possible explanation for this difference is that control/neutral stimuli used in prior work (neutral faces and scenes) may have been more emotionally arousing than control stimuli used in the current study (geometric shapes). For instance, among children, neutral faces may be perceived negatively (Tottenham, Phuong, Flannery, Gabard-Durnam, & Goff, 2013), and may activate brain regions implicated in affective processing (Ferri et al., 2014). Therefore, reductions in the LPP may have been observed for both neutral and affective stimuli in prior work, because even neutral stimuli may have been perceived as somewhat affectively arousing.

The magnitude of age-related reductions in the LPP was strongest for happy faces. In adults, happy faces have been found to elicit smaller LPPs than angry or fearful faces (Smith, Weinberg, Moran, & Hajcak, 2013). Moreover, some evidence suggests that happy faces may elicit robust neural activation in children but not adults (Todd, Evans, Morris, Lewis, & Taylor, 2011), in line with the notion of a “positivity bias” early on during development (Boseovski & Lee, 2008; Sato & Wakebe, 2014; but see Tottenham et al., 2013). In addition to developmental changes in affective bias, recognition skills may vary for different affective expressions across childhood. For instance, children tend to be better at recognizing happy faces compared to other face types (X. Gao & Maurer, 2009; Kujawa et al., 2014); therefore, happy faces may be both more salient and more recognizable for younger children.

Results from the fMRI literature are generally in agreement that the processing of affective stimuli decreases across childhood and adolescence (Guyer et al., 2008; Hwang et al., 2014; Vink et al., 2014; but see Hare et al., 2008). However, different results were recently observed by Ferri and colleagues (2014), who found that amygdala activation to *neutral* - but not fearful - faces decreased with age across childhood and adolescence. Of note, neutral face displays in Ferri and colleagues' (2014) study always included one fearful or happy face. Happy faces were most strongly associated with age in the current study; therefore, one hypothesis is that age-related reductions in amygdala reactivity to neutral faces may have depended in part upon age-related reductions in reactivity to happy faces that were interspersed with neutral faces. To clarify these issues, future work may wish to include purely neutral face displays, along with affective faces and non-social control stimuli (e.g., geometric shapes), to more thoroughly parse changes in affective processing from changes in non-affective processing. Moreover, further work examining relationships between fMRI and ERP measures of emotional face processing (e.g., Rotshtein et al., 2010) should lead to a more cohesive understanding of developmental changes in affective stimulus processing across different neural measures.

Research has suggested that age-related reductions in the processing of affective stimuli might result from the development of prefrontal brain regions, which mature, both structurally and functionally, later in development than subcortical brain regions (Casey, Jones, & Hare, 2008; Giedd et al., 1996; Gogtay et al., 2004; Kolb et al., 2012; Monk et al., 2003; Tsujimoto, 2008). This developmental discrepancy might explain age-related shifts in the processing of and response to affective stimuli across childhood and adolescence. For example, early development of the amygdala might lead to increased signaling early on

during life, which may decrease with time as top-down signaling in the prefrontal cortex matures, leading to greater control over the processing of affective stimuli. Along these lines, connectivity between the amygdala and prefrontal brain regions has been observed to shift from positive to negative throughout childhood, suggesting increased regulation of emotional stimulus processing (Gee et al., 2013). Of note, both unpleasant and pleasant stimuli can cause behavioral interference (Beall & Herbert, 2008; Ihssen, Heim, & Keil, 2007); therefore, increased cognitive control over the processing of both these types of stimuli might be expected among older children. The LPP is believed to depend on activation in fronto-parietal attention networks (Moratti, Saugar, & Strange, 2011), with contributions from subcortical regions, such as the amygdala (Liu, Huang, McGinnis-Deweese, Keil, & Ding, 2012). Therefore, a reduction across development in the LPP might signify increasing involvement of the PFC, which could result in reductions in subcortically-driven processing of affective stimuli as children age.

We also observed age-related processing changes that were not specific to affective stimuli. For instance, P1 amplitudes, which were not modulated by condition (Batty & Taylor, 2006), were found to decrease with age. These results are in line with prior work (Taylor, Batty, & Itier, 2004), and may reflect age-related increases in the efficiency of early, holistic processing of visual stimuli arising from synaptic pruning (Itier & Taylor, 2004). Also in line with prior work, younger children performed the matching task more slowly than older children (Kujawa et al., 2014; Mancini, Agnoli, Baldaro, Ricci Bitti, & Surcinelli, 2013), which likely reflects overall improvements in decision making and response speed, as well as improvements in recognition of facial emotions that are evident from age 4 through adolescence (Kolb, Wilson, & Taylor, 1992; Montiroso, Peverelli, Frigerio, Crespi, & Borgatti, 2010; Vicari, Reilly, Pasqualetti, Vizzotto, & Caltagirone, 2000).

As far as the behavioral data for specific facial expressions were concerned, children were most accurate when matching shapes, followed by happy and fearful faces, then angry faces. These results are broadly in line with prior work, which has found evidence of a recognition advantage for happy faces relative to other facial expressions in both adults (for a meta-analysis, see Nummenmaa & Calvo, 2015) and children (Montiroso et al., 2010). While there are several possible reasons why happy faces may be recognized more easily than other affective faces, one likely explanation is their perceptual distinctiveness (Calvo & Beltrán, 2013; Nummenmaa & Calvo, 2015). Specifically, the smile - a salient and unique characteristic - may facilitate the recognition of happy faces. By contrast, negatively valenced facial expressions (anger, fear) may appear more similar, slowing decision making and response time, as evidenced in the current study by slower RTs for both fearful and angry compared to happy faces. It is less clear why children in the current sample were the *least* accurate in recognizing angry faces, however we note that prior work using the same task and same facial stimuli in an adult sample also found that performance was lowest for angry faces (MacNamara et al., 2013). Moreover, mean accuracy for angry faces may have been lower overall in this sample because recognition of facial displays of anger in particular may have a protracted developmental course throughout childhood and adolescence (Montiroso et al., 2010).

This is the first LPP study to examine age-related change in the processing of socio-emotional versus non- socio-emotional stimuli (geometric shapes) and adds to prior work by examining continuous, age-related change in the LPP to affective faces across a wide age range (from childhood into young adulthood). Our results indicate significant age-related changes in the behavioral and electrocortical processing of affective faces. Some of these changes were nonspecific (i.e., faster RTs and smaller P1s to all trial types with increasing age). Other changes were observed specifically for affective stimuli (i.e., decreasing LPPs to emotional – and in particular, happy – faces). Limitations of the present study include the use of a cross-sectional instead of a longitudinal design (Kujawa, Klein, et al., 2013). In addition, we were not able to determine whether age-related decreases in the LPP were driven by “bottom-up” or “top-down” factors (i.e., reduced salience or increased cognitive control). Nevertheless, complementary work from the fMRI literature (e.g., Gabard-Durnam et al., 2014; Hwang et al., 2014; Vink et al., 2014) points to the latter as a likely possibility. Overall, our results indicate that in typical development, the processing of affective social stimuli decreases with time across childhood and that it is possible to track these changes using the LPP. Future work may wish to use the LPP determine whether irregularities in this trajectory predict individual differences in psychiatric disorders (Gee et al., 2013).

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Figure 1.

Example face-matching and shape-matching trials from the task. On face trials, participants were instructed to indicate which of the two faces appearing at the bottom of the screen bore the same emotional expression as the face appearing at the top center of the screen. On shape trials, participants selected the shape at the bottom of the screen that matched the shape presented at the top center of the screen.

Figure 2. Grand-average waveforms (all participants) at parieto-occipital sites where the P1 was scored (in a 20 ms window around peaks identified from 80-180 ms after stimulus onset).

Figure 3.
Grand-average waveforms (all participants) at parieto-occipital sites where the LPP was scored (from 300-3000 ms after stimulus onset).

Figure 4.

A) Headmaps depicting the spatial distribution of voltage differences for emotional faces minus shapes, in the time window in which the LPP was scored (300-3,000 ms after stimulus onset), shown separately for angry faces (left column), fearful faces (middle column), and happy faces (right column), and for younger (top row) and older (bottom row) participants, based on a median split (performed for illustrative purposes only). B) Grand-average waveforms at parieto-occipital sites where the LPP was scored (from 300-3000 ms after stimulus onset), shown separately for younger (top row) and older (bottom row) participants, based on a median split (performed for illustrative purposes only).

Figure 5. Scatterplot depicting the association between age and the LPP elicited by emotional faces and shapes.

Table 1

Means (and Standard Deviations) for Response Time (RT), Accuracy, P1 and LPP Amplitudes

Condition	RT (ms)	Accuracy (% correct)	P1 (μ V)	LPP (μ V)
Angry faces	1414.12 (323.08)	84.60 (8.03)	7.65 (5.58)	7.31 (6.24)
Fearful faces	1337.61 (341.95)	94.57 (7.97)	8.83 (5.20)	6.45 (5.52)
Happy faces	1240.58 (302.16)	96.72 (6.81)	8.39 (5.97)	5.51 (7.49)
Shapes	790.97 (208.35)	98.86 (2.39)	6.90 (5.48)	0.70 (4.45)