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Affective Facial Expression Processing in 15 Month-old Infants Who Have Experienced Maltreatment: An Event-Related Potential Study

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Abstract

This study examined the neural correlates of facial affect processing in 15 month-old maltreated and nonmaltreated infants. Event-related potentials (ERPs) were elicited while infants passively viewed standardized pictures of female models posing angry, happy, and neutral facial expressions. Differences between maltreated (N=25) and nonmaltreated (N=20) infants were observed on three ERP components: P1, P260, and Nc. Compared to nonmaltreated infants, maltreated infants had greater P1 amplitude in response to happy facial affect while nonmaltreated infants had greater P1 amplitude in response to angry faces compared to the maltreated infants. Within the maltreated group, P1 was greater in response to happy relative to angry facial affect, whereas for nonmaltreated infants the opposite pattern was observed, with greater P1 amplitude in response to angry affect relative to happy. For the P260, nonmaltreated infants had greater amplitude than maltreated infants in response to happy facial affect. P260 amplitude was greater in response to angry relative to happy facial affect within the maltreated group. Amplitude of the Nc component in response to angry facial affect was greater in the nonmaltreated infants relative to the maltreated infants. Further, within the maltreated group, Nc was greater for happy compared to angry faces. In contrast, within the nonmaltreated group, Nc amplitude was greater in response to angry versus happy faces. The results provided further support for the hypothesis that the experience of maltreatment and the predominantly negative emotional tone in maltreating families alters the functioning of neural systems associated with the processing facial emotion. These results exemplify the importance of early preventive interventions focused on emotion for children who have experienced maltreatment early in life.

Keywords

child maltreatment; event-related potentials; emotion; face processing

The experience of maltreatment is associated with a broad range of deleterious developmental biological and psychological outcomes across virtually all domains of development (Cicchetti & Toth, 2005; Cicchetti & Valentino, 2006; McCrory & Viding, 2010), and it is further associated with the development of a variety of psychopathological outcomes, including aggression/antisociality, depression, anxiety, dissociation, and post-traumatic stress disorder (Cicchetti & Valentino, 2006). Affective interchanges between caregiver and infant play a paramount role in the development of adaptive socio-emotional functioning (e.g., Izard, 2009; Malatesta, 1990), thus one of the likely contributors to the poor developmental outcomes in maltreated children is the atypical emotional experiences these children have early in life (Pollak, Cicchetti, Hornung, & Reed, 2000). In particular, there is ample evidence that maltreatment experienced in early life exerts a negative influence on the development of emotion discrimination and recognition, due to the atypical emotional experiences that accompany all types of maltreatment (Pollak et al., 2000; Pollak & Sinha, 2002).

Whereas typically developing children in nonmaltreating homes experience more positive compared to negative emotion (Malatesta & Haviland, 1982), parents in homes where maltreatment occurs express fewer positive and more negative emotions (e.g., Kavanaugh, Youngblade, Reid, & Fagot, 1988; Lyons-Ruth, Connell, Zoll, & Stahl, 1987). There are also very high rates of verbally and physically aggressive interactions between family members in such homes (e.g., Azar, 2002; Bousha & Twentyman, 1984). In homes where there is child neglect, where there is omission of basic care of children and increased family stressors (e.g., Connell-Carrick & Scannapieco, 2006), there also are high levels of family conflict, negative affect, and domestic violence relative to comparison families (Cicchetti & Lynch, 1993; Connell-Carrick & Scannapieco, 2006; Gaudin, Polansky, Kilpatrick, & Shilton, 1996). From a developmental psychopathology perspective, the transactions between the developing child and the negative affective environment found in maltreating homes likely eventuate in the maladaptive outcomes frequently observed in maltreated children.

There is evidence that the experience of maltreatment is associated with alterations in the development of processing of facial affect. For example, children who have experienced maltreatment exhibit less accurate recognition of emotions than nonmaltreated children (e.g., Camras et al., 1988). Maltreated children also appear to have a selective bias, or hypersensitivity, toward the detection of anger, perceiving angry faces as more salient and distinctive relative to other emotions (Pollak et al., 2000). Physically abused school-aged children recognize angry facial affect more quickly and also more readily relative to non-abused comparison children (Pollak & Kistler, 2002; Pollak, Messner, Kistler, & Cohn, 2009; Pollak & Sinha, 2002). Further, neglected children have more difficulty in accurately discriminating emotional expressions than physically abused or nonmaltreated children, and made fewer distinctions between facial emotions (Pollak et al., 2000).

In addition, a number of studies have examined the effects of maltreatment on neural processes indexing facial emotion processing utilizing event-related potentials (ERPs) (e.g., Cicchetti & Curtis, 2005; Curtis & Cicchetti, 2011; Pollak, Cicchetti, Klorman, & Brumaghim, 1997; Pollak, Klorman, Thatcher, & Cicchetti, 2001; Pollak & Tolley-Schell, 2003; Shackman, Shackman, & Pollak, 2007). ERP studies by Pollak and colleagues have

focused on the P3b component in school-aged maltreated children. The central finding of this work has indicated that maltreated children are hyper-responsive to angry facial expressions relative to nonmaltreated children. This finding of greater P3b amplitude in response to angry facial affect may reflect, at the neural level, more efficient cognitive organization in response to anger, as well as unique sensitivity in detecting anger over other facial expressions of emotion (Pollak et al., 1997; 2001). Also, Pollak and Tolley-Schell (2003) posited that early experience of physical abuse may alter the development of perceptual systems by decreasing the minimum amount of threat-related stimulation needed to engage focused attention upon such stimuli. They showed that physically abused children demonstrated an increase in P3b response to angry faces, along with behavioral evidence that abused children orient more rapidly to cues primed by anger.

Cicchetti and Curtis (2005) and Curtis and Cicchetti (2011) examined ERPs in response to facial affect in younger maltreated children, at 30 months and 42 months of age, who had experienced maltreatment in the first 12 months of life. This work examined the effects of maltreatment on neural processing of facial affect during a developmental period marked by crucial brain developmental processes, in particular synaptic pruning (Stiles, 2008). These processes, shaped in part by environmental input, could potentially be undermined by aberrant emotional experiences that often accompany maltreatment.

At 30 months of age, maltreated children had greater amplitude of an early positive ERP component (P260) in response to viewing angry facial expressions, relative to happy, compared to a group of nonmaltreated children (Cicchetti & Curtis, 2005). This component likely indexes a later perceptual process that includes the identification of affective facial expressions. As such, this finding suggested an increased sensitivity to angry facial affect in maltreated toddlers. In addition, the maltreated children in this sample exhibited greater amplitude of the Nc waveform while viewing angry faces compared to happy faces, likely reflecting increased familiarity of angry facial expressions in the maltreated group. Finally, evidence from a late positive slow wave (PSW) component, thought to index updating in working memory of partially encoded stimuli, suggested that maltreated children were more familiar with angry facial expressions relative to the nonmaltreated children.

In a subsequent ERP study of 42 month old maltreated and nonmaltreated children, Curtis and Cicchetti (2011) found that these young maltreated children also displayed hyper-responsivity to angry facial affect reflected in several ERP components. Maltreated children had greater P1 and P400 amplitude in response to angry facial affect compared to other emotions, and compared to nonmaltreated children. In addition, maltreated children had greater P240 amplitude (analogous to the P260 waveform observed in the 30 month study) in response to angry facial expressions relative to happy, whereas children in the nonmaltreated group had greater P240 amplitude in response to happy relative to angry. Further, the nonmaltreated group had greater PSW amplitude in response to angry facial affect, whereas those in the maltreated group showed greater PSW amplitude to happy facial expressions, reflecting less familiarity with these emotion expressions. The results from both of these studies have provided further support for the general hypothesis that the experience of maltreatment, and the predominantly negative emotional tone in maltreating families, is

associated with alterations in the functioning of neural systems supporting the processing of facial emotion.

While previous ERP investigations of affective facial processing in maltreated children between the ages of 30 months and later childhood have consistently found evidence for a hyper-responsivity to angry facial affect, it is not known at what age such aberrant neural responsivity would first be observed. Hence, the goal of the current study was to investigate the effects of maltreatment on neural indices of facial affect perception at an even earlier point in development. This investigation sought to determine whether a sample of 15 month old infants, who had experienced maltreatment during the first year of life, would manifest aberrations in neural processing of facial expressions of emotion. We have continued to focus our work on the early years of life because it is a period when critical aspects of neurodevelopment, driven in large part by experience in and transactions with the environment, are occurring (Cicchetti & Curtis, 2006; Huttenlocher, 2002; Stiles, 2008). Moreover, increasingly complex abilities to recognize and understand facial expressions of emotion continue to emerge throughout infancy and early childhood (e.g., Mondlach, Geldart, Maurer, & Le Grand, 2003), and brain areas relevant for facial emotion processing, such as the prefrontal cortex and amygdala, continue to develop through childhood and adolescence (e.g., Giedd et al., 1996). Thus, it is important to chart the developmental course of neural processes indexing facial affect recognition in young children and infants, and how the experience of maltreatment early in life may alter such development.

Two sets of hypotheses guided this work, formulated based on two groups of ERP components that emerged from our data. The first group of components, the P1, N220, and P400, maximal over occipital electrode sites, have been shown to be largely specific to, and modulated by, faces in typically developing infants (e.g., Batty & Taylor, 2006; Moulson, Fox, Zeanah, & Nelson, 2009). The second group of waveforms, the P240, Nc, and PSW, are maximal primarily over frontal and central scalp regions, and have been shown to be influenced by facial affect in infants and young children (e.g., Batty & Taylor, 2006; Cicchetti & Curtis, 2005; Curtis & Cicchetti, 2011; Parker & Nelson, 2005).

Occipital Components

1. P1: Previous research with typically developing children has shown this component to be sensitive to emotion in faces (Batty & Taylor, 2006). Consistent with our general expectation that maltreated infants would be hyperresponsive to angry facial affect, we hypothesized that maltreated infants would manifest greater P1 amplitude in response to angry facial expressions relative to happy, and also greater amplitude in response to angry expressions compared to nonmaltreated infants.
2. N220: This component likely corresponds to the N290 component found in studies of typically developing infants (e.g., de Haan, & Johnson, & Halit, 2007), and has been shown to be sensitive to facial affect in infants (Kobiella, Grossmann, Reid, & Striano, 2008). It was hypothesized that maltreated infants would show greater N220 amplitude in response to angry facial expressions relative to happy, and also greater amplitude in response to angry facial affect compared to nonmaltreated infants.

3. P400: This component has been shown to be sensitive to facial expressions of emotion in infants (e.g., Kobiella et al., 2008; Leppänen, Moulson, Vogel-Farley, & Nelson, 2007), and amplitude differences in this waveform in response to facial emotion have been shown to discriminate between children who have experienced early deprivation and those developing in normative contexts (e.g., Moulson et al., 2009). We hypothesized that maltreated infants would show greater amplitude of the P400 in response to angry facial expressions relative to happy, and also greater amplitude in response to angry expressions compared to nonmaltreated infants.

Frontal-Central Components

1. P260: We hypothesized that maltreated and nonmaltreated infants would differ in perceptual processes that are thought to be reflected by this component (identified as P260 by Cicchetti and Curtis (2005) and P240 by Curtis & Cicchetti, 2011). We hypothesized that maltreated infants would show larger P260 amplitude in response to angry facial expressions relative to happy, and also greater amplitude in response to viewing angry facial affect compared to infants in the nonmaltreated group.
2. Nc: Because the Nc waveform is thought to reflect allocation of attention to salient/relevant stimuli in infants (Coch & Gullick, 2012), we expected to find that the amplitude of Nc would be greater in maltreated infants in response to viewing angry stimuli. In contrast, we expected that Nc amplitude would be larger in nonmaltreated infants in response to happy facial expressions.
3. Positive Slow Wave (PSW): A preponderance of evidence has suggested that the PSW indexes the updating of working memory (e.g., Nelson & Monk, 2001). In our study of 30 month olds, nonmaltreated children exhibited greater PSW amplitude in response to angry facial expressions compared to the maltreated children, suggesting that increased neural resources were required by the nonmaltreated children to process the less familiar, angry facial expression. Accordingly, we hypothesized that maltreated infants would exhibit greater PSW amplitude in response to viewing happy versus angry facial expressions. Similarly, because anger may be a less familiar stimulus to nonmaltreated infants, we expected to find an increased PSW while viewing angry stimuli in the nonmaltreated group.

Method

Participants

Participant Recruitment—All families with an infant with a documented history of maltreatment in the first 12 months of life were recruited for the study from the Monroe County Department of Human and Health Services (DHHS). Determination of maltreatment status was based upon Child Protective Service (CPS) and Preventive Services records, coded by trained raters utilizing the Barnett, Manly and Cicchetti (1993) classification system for child maltreatment. In order to maximize demographic comparability to the maltreatment sample, low-SES comparison families identified as receiving public assistance were recruited. Nonmaltreatment status of these families was confirmed by an absence of

CPS or Preventive Services records, and by maternal interview (Cicchetti, Toth, & Manly, 2003). Thirty of the families recruited for the study (21 maltreated, 9 comparison) declined to take part; however, there were no statistically significant demographic differences between these families and those who agreed to participate.

For all infants in the maltreatment group, biological mothers were a perpetrator of maltreatment, and remained as the primary caregiver. For both groups, infants in foster care were excluded because of the potential for greater variation in the type of care received in foster homes compared to that provided by the biological mother. In addition, because of the potential for developmental delays, infants born more than four weeks prematurely and/or with severe medical complications were excluded from sample recruitment.

Participant Characteristics—The final study sample retained for analyses comprised 25 infants from maltreating families and 20 infants from nonmaltreating families. Of the 76 infants who began the ERP data collection procedure, 6 yielded no data or incomplete data due to fussiness of the infant and/or technical problems. Twenty five other infants who completed the ERP experiment yielded too few artifact free trials and/or data with poor signal-to-noise ratio. Of these 31 excluded infants, 20 were maltreated and 11 were nonmaltreated comparison infants.

Participant demographic characteristics are summarized in Table 1. The mean age of infants in both groups was 15.8 months, and gender composition of the groups was equivalent. In addition, there were no statistically significant differences between the groups on maternal age, maternal marital status or ethnicity. The groups were also equivalent on SES; 82.9% of the maltreating families and 70.8% of the families in the nonmaltreating group were in the two lowest social strata defined by Hollingshead's (1975) four factor index of social status.

Prior to data collection, mothers of all infants participating in the study received complete information about the study procedures, and provided informed consent for their infant's participation, as well as consent for examination of all DHHS records involving the family. All participant recruitment and research procedures were approved by the Research Subject Review Board at the University of Rochester.

EEG Recording—EEG was recorded from midline (Fz, Pz, Oz) and lateral scalp sites (Fp1, Fp2, F3, F4, F7, F8, C3, C4, T3, T4, T5, T6, P3, P4, O1, O2) using a Lycra Electro-Cap (Electro-Cap International, Eaton, OH) fitted with Ag-AgCl disc electrodes sewn into the cap, arrayed according to the International 10/20 system (Jasper, 1958). EEG also was recorded from left and right mastoids, as well as the reference site at the vertex (Cz), with an anterior midline site (AFz) as the ground electrode. Electro-oculogram (EOG) was recorded from above and below the right eye, and horizontally at the right and left canthus. The capping procedure was considered complete when impedances were at or below 5 k Ω for scalp electrodes and 10 k Ω for eye electrodes. EEG signal was recorded using a SYNAMPS 32 channel EEG amplifier and the Acquire module of Scan 4.2 software (Neuroscan, Inc., Charlotte, NC). Amplifier gain was set to 500 for scalp electrode channels and 150 for EOG channels. Data were sampled at 500 Hz, digitized using a 12 bit A/D converter, and bandpass filtered from 0.10 to 30 Hz.

During data collection, all participants viewed a total of 133 images, which were divided into three stimulus conditions: angry, happy, or neutral facial expressions. Angry and happy expressions were each presented across 20 trials (each comprising 15% of the total number of trials), while the neutral stimuli comprised 93 trials (70% of total trials). Trials consisted of a 200 ms pre-stimulus baseline, followed by a 1000 ms stimulus presentation. Stimulus offset was followed by a blank screen for 800 ms. The intertrial interval was 1000 ms for all trials.

Videotapes of infants during EEG data collection were coded offline by two research assistants, who were unaware of participants' maltreatment status, to determine whether the infant was looking at the computer monitor during presentation of stimuli. The two raters achieved 91% agreement for looking on a randomly selected subset of 20% of the subjects for whom data was used, with no statistically significant differences on interrater agreement across stimulus type. All trials during which the infant failed to attend for fewer than 20 of the 30 video frames spanning each of the stimulus presentation intervals were not included in the calculation of individual averages. There were no statistically significant differences in the proportion of trials attended to across the three trial types (angry, happy, neutral).

Stimuli—Participants viewed images of the face of an adult Caucasian female, randomly selected from three of the models included in the standardized face stimuli developed by Ekman (1976) (slide numbers 21, 23, 24, 51, 53, 54, 66, 68, and 69). The ordering of the three trial types was randomly determined across each of the three image sets, with no stimulus type presented more than twice consecutively. Images appeared one at a time on a computer monitor 120 cm from the subject, yielding a subtended visual angle of 8.5×13 degrees. Stimuli were presented using the STIM module of Scan 4.2 software (Neuroscan, Inc., Charlotte, NC).

ERP Data Reduction—Scalp leads were referenced to an inactive mastoid electrode and re-referenced to linked ears offline. Trials were excluded if EEG signal exceeded ± 250 μV in any 50 ms window. The influence of eye movement or blinks on the EEG were corrected based on procedures described by Gratton, Coles, and Donchin (1983), after which individual participant averages were computed for each stimulus type. Those individual averages with a minimum of 10 artifact-free trials were retained for analyses. Subsequently, a grand average for each condition and group was computed. Across all participants with data retained for analyses, there were an average of 15.3 ($s = 2.2$; range: 11–20) trials included in the averages for the angry condition, 15.4 ($s = 2.6$; range: 10–20) trials in the averages for the happy condition, and 70.1 ($s = 10.6$; range 48–90) for the neutral condition. There were no statistically significant differences between groups on the number of trials included in the averages for all conditions. All data reduction procedures were conducted without knowledge of maltreatment status.

Based on inspection of the grand averages and individual subject averages, ERP components of interest were identified. The P1 component was an early positive peak maximal over occipital electrodes occurring within the window from 90–200 ms, with an average peak latency of approximately 140 ms. The N220 was a negative deflection observed over occipital sites from 160–270 ms, with an average peak latency of approximately 220 ms.

The P400 was identified over occipital sites in the window from 270–470 ms. This component exhibited a somewhat poorly-defined peak that occurred at approximately 380 ms. A positive peak, the P260, maximal over frontal sites with an average latency of approximately 260 ms, was identified in the window between 200 and 360 ms. The Nc component, maximal over central electrodes, was observed in the window between 360 and 560 ms after stimulus onset. Finally, a long latency positive component, the positive slow wave (PSW) was identified between 900–1800 ms.

Mean amplitude relative to a 200 ms baseline was determined within these windows for all components except for the PSW. Area score (rectified) relative to baseline was computed for the PSW within its time window, using an algorithm that estimated area by computing the product of the sampling interval and the sum of all points in the interval (except the two endpoints, which were given ½ weight).

Assessment of Infant Cognitive Development—The Mental Scale of The Bayley Scales of Infant Development, 2nd Edition, (BSID-II; Bayley, 1993) was administered to all participants. This scale provides a global assessment of intellectual development, and measures cognitive functions such as memory and learning, as well as verbal communication skills. A Mental Development Index (MDI) score for each participant was derived from this measure. Although there was not a statistically significant difference between the maltreated and nonmaltreated groups on the MDI ($t(43) = 1.16, p = 0.25$), there was a wide range of scores within both groups (68–115). Thus, MDI score was employed as a covariate in all analyses in order to maximize comparability of cognitive development and mental age.

Procedure

All infants were in good health and free of any medications at the time of the EEG laboratory visit. After the capping procedure was completed, infants were seated on their mother's lap in a darkened, sound attenuated booth. During data collection, a research assistant observed the infant's behavior on a video monitor, and experimental stimuli were presented only when the infant was attending to the monitor in the subject booth. If the infant was not attending, then the mother was instructed, over an intercom system, to attempt to redirect the infant's attention. Occasionally, a "bulls eye" pattern was presented in conjunction with a rattle sound if the observer thought the infant's attention could be redirected without the assistance of the mother. If the infant became distracted or fussy to the extent that her/his attention could not be re-directed to the experimental stimuli, then the session was terminated. Parents were reimbursed for travel expenses and their time, and infants were given a small toy after the experimental session.

Results

Repeated measures analyses of variance (ANOVAs) were computed, with mean amplitude (or area score) as the dependent variable. All p -values were corrected for sphericity using the Greenhouse-Geisser procedure when epsilon was less than 0.90 (Vasey & Thayer, 1987). In cases where the ANOVA yielded statistically significant main effects or interactions, pair-wise comparisons using t -tests, with Bonferroni corrections, were employed to examine

within group differences, and independent samples *t*-tests were used to evaluate between-group differences. All statistical analyses were computed using the Statistical Package for the Social Sciences (SPSS) for Windows, Version 18 (SPSS, 2010).

For all of the ANOVAs, emotion (angry, happy, neutral) was a within subjects factor, and group (maltreating, nonmaltreating) was the between subjects factor. In preliminary analyses, hemisphere was included as a within subjects factor for all components, but no statistically significant interactions between this factor and either maltreatment status or emotion were found. Thus, subsequent analyses did not include hemisphere as a factor. In addition, infant sex was included as a between subjects factor in preliminary analyses. Likewise, no statistically significant interactions between sex and maltreatment status emerged; hence, subsequent analyses did not include sex as a factor. Chronological age and scores on the Bayley MDI were employed as covariates in all analyses.

For all frontal-central ERP components, electrode sites were combined to form three composite scalp regions, each consisting of five electrodes: frontal, which included F3, F4, F7, F8, and Fz, central, which included C3, C4, T3, T4, and Cz, and temporal-parietal consisting of P3, P4, T5, T6, and Pz. Data from each of these sites were averaged to yield a mean regional amplitude for each component (or mean area for the PSW component). For the occipital components, data from O1, O2, and Oz were combined to form an occipital composite region. For each frontal-central component, individual level and group level ERP averages were examined in order to determine in which region that component was maximal, and data from a single region where the component was of maximal amplitude were employed in the analyses. None of the study hypotheses addressed location/region differences between maltreated and nonmaltreated infants, and thus the composite regions were not included as a factor in the analyses. Front-polar electrodes (fP1, fP2) were not included in the analyses due to unacceptable noise and consequent low signal-to-noise ratios.

A by-product of the original experimental design resulted in the mean number of trials comprising the individual averages for the neutral condition being significantly larger than the number of trials in the angry and happy conditions. A greater number of trials in an individual average will generally increase the signal-to-noise ratio, and hence will tend to reduce the peak amplitude of all components (Luck, 2005). Hence, for the current study, where the results indicate lower amplitude in the neutral condition relative to angry and/or happy, it is not possible to determine whether this is due to actual differences between conditions or the increased signal-to-noise ratio in the neutral condition. However, the key questions in the study involve examining differences between the angry and happy emotion conditions, and although the findings from all three conditions will be presented, any findings concerning differences between the neutral and angry or happy conditions will not be interpreted in the discussion.

P1

For this component, there was a statistically significant Group x Emotion interaction, $F(2, 82) = 7.80, p = 0.008, \eta_p^2 = 0.17$. This finding is illustrated in Figure 1, and can be observed in the plot of the occipital ERP waveforms in Figure 2. Between group post hoc

comparisons indicated that P1 amplitude was greater in the maltreated infants in response to happy facial expressions than in the nonmaltreated infants, $t(43) = 2.12, p = 0.041$. In contrast, P1 amplitude was greater in the nonmaltreated than maltreated infants in response to angry facial affect, $t(43) = 1.83, p = 0.074$. Within group paired comparisons revealed that, within the maltreated group, greater P1 amplitude was elicited by happy compared to angry facial affect, $t(24) = 2.86, p = 0.009$, and P1 amplitude was greater in response to angry compared to happy facial expressions within the nonmaltreated group, $t(19) = 2.02, p = 0.061$.

P260

For this frontal-central component, there was a statistically significant Group x Emotion interaction, $F(2, 82) = 4.50, p = 0.017, \eta_p^2 = 0.12$, illustrated in Figure 3, as well as in the plots of the central (Figure 4) and frontal (Figure 5) waveforms. Between group post hoc comparisons revealed that the nonmaltreated group had greater P260 amplitude than the maltreated group in response to the happy face condition, $t(43) = 2.03, p = 0.050$. Post hoc comparisons within the maltreated group indicated that P260 amplitude was greater in response to angry relative to happy facial expressions, $t(24) = 4.84, p < 0.001$, and greater in response to neutral relative to happy, $t(24) = 2.63, p = 0.012$. However, within the nonmaltreated group, there were no P260 amplitude differences across facial affect.

Nc

For the Nc, there was a main effect for Emotion, $F(2, 82) = 6.92, p = 0.012, \eta_p^2 = 0.15$. Post hoc comparisons indicated that, across both groups, Nc amplitude was greater in response to viewing angry faces relative to happy faces, $t(43) = 5.62, p < 0.001$. In addition, there was a statistically significant Group x Emotion interaction, $F(2, 82) = 5.34, p = 0.026, \eta_p^2 = 0.12$, illustrated in Figure 6 that can also be observed in Figures 4 and 5. Between group comparisons indicated that Nc amplitude in response to angry facial expressions was greater in the nonmaltreated group than in the maltreated infants, $t(43) = 2.06, p = 0.046$. Further, Nc amplitude was greater in response to happy compared to angry facial expressions, $t(24) = 2.06, p = 0.054$ within the maltreated group, while the nonmaltreated infants had greater Nc amplitude in response to viewing angry compared to happy facial expressions, $t(19) = 2.32, p = 0.030$.

Discussion

A growing body of research has delineated the effects of maltreatment on children's processing of affective facial expressions. In particular, several ERP studies have demonstrated atypicalities in neural processing of facial expressions of emotion, most notably in response to anger (e.g., Pollak et al., 1997; 2001). Broadly, this research has demonstrated that the central, underlying aberration in emotion processing in children who have experienced maltreatment appears to be a hyperresponsivity to anger.

However, until recently, this research has been limited to examining the effects of maltreatment in school-aged children. This gap in the literature provided the impetus for our previous work examining a sample of 30 month olds who had experienced maltreatment

during the first year of life (Cicchetti & Curtis, 2005), as well as a sample of 42 month olds (Curtis & Cicchetti, 2011). In order to increase knowledge concerning the effects of maltreatment on neurodevelopment and patterns of neural function even earlier in development, the current study reported on a sample of 15 month old maltreated infants and a comparison group of same aged nonmaltreated infants. To date, this is the youngest age for which a measure of neural function has been employed to study facial affect perception in a maltreated sample. Although there is no previous literature on facial affect perception in maltreated infants, there is a well developed body of literature concerning the neural correlates of perception of facial affect in typically developing infants and children. This knowledge, along with previous ERP studies of maltreated children, will help to guide the discussion of the current findings.

Utilizing ERP methodology in this age range is critically important in order to gain an understanding of perception of facial affect early in development, as infants do not have the requisite verbal and cognitive abilities to provide self-reports. Thus, ERPs provide a window through which to begin to understand the effects of maltreatment on the perception of emotion in the infants comprising this sample. Knowledge of neural processing of facial affect at this age will serve to enhance our understanding of the effect of maltreatment during this early developmental period, when important brain maturational processes are occurring, as are important aspects of social and emotional development.

One of the key findings from the current study involved the P1, a face sensitive ERP component maximal over occipital electrode sites. Contrary to our hypothesis, P1 amplitude was greater in response to happy in the maltreated infants compared to the nonmaltreated infants, with the opposite finding in the angry condition, where it was greater in the nonmaltreated group compared to the maltreated infants. Further, for the maltreated infants, P1 was greater in response to happy relative to angry facial expressions, and was greater in response to angry relative to happy expressions in the nonmaltreated group.

The P1 component has been shown to index automatic early visual processing, and is believed to be an indicator of preferential attention to a wide array of sensory inputs, including faces (de Haan et al., 2007). It is also sensitive to affective facial expressions in typically developing infants and young children (e.g., Batty & Taylor, 2006; Dennis, Malone, & Chen, 2009; Todd, Lewis, Meusel, & Zelazo, 2008), and evidence from both adults and children strongly suggest that the P1 broadly indexes early discrimination of facial affect.

The current results suggest that P1 amplitude is modulated by relative novelty of facial affect. The negative affective climate found in maltreating homes would imply that, for maltreated infants, happy facial expressions are novel relative to angry expressions. Although happy facial expressions are likely not completely absent in maltreating homes, research investigating the emotional experiences of maltreated children has consistently demonstrated a predominantly negative affective environment (Azar, 2002; Rogosch, Cicchetti, Shields, & Toth, 1995). In contrast, infants in nonmaltreating homes likely experience primarily positive emotion and hence an angry facial expression would be relatively novel (Malatesta & Haviland, 1982). Thus, the differential amplitude of the

P1 between maltreated and nonmaltreated infants in the current sample, found in response to angry and happy facial affect, is perhaps a reflection of the contrasting emotional milieu experienced by these two groups of infants.

However, the current finding is not consistent with findings concerning the P1 from our previous study of 42 month olds, where maltreated children had greater P1 amplitude in response to angry facial affect compared to the nonmaltreated children (Curtis & Cicchetti, 2011). This result in these older children was consistent with the neural hyper-responsivity to anger that has been previously observed in maltreated children. The current finding in maltreated 15 month olds suggests that early perceptual-attentional neural processes in response to affective facial expressions, represented by the P1, may initially be more responsive to novelty in facial affect. Later in development, when children gain a clearer cognitive and conceptual understanding of the meaning of facial affect, and its connection with behavior, angry facial expressions likely are interpreted as threat or prelude to aggression, and patterns of neural responses reflect this in greater amplitude of the P1.

Largely consistent with the pattern of findings from the P1 occipital component, the amplitude of the Nc component was greater in response to angry facial affect in the nonmaltreated group compared to the maltreated infants. Whereas there were no between group differences for the happy condition, within group findings revealed that maltreated infants had greater Nc amplitude in response to happy relative to angry faces, and the opposite pattern emerged for the nonmaltreated infants whereby Nc amplitude was greater in response to angry relative to happy.

Broadly, the Nc in infants is believed to index a general orienting response associated with attention, and has been characterized as an obligatory attentional response sensitive to stimulus familiarity (Courchesne, Ganz, & Norica, 1981; Richards, 2003). In studies of the normative development of infant face perception, the Nc is commonly observed to index relative familiarity of a face, as it is typically greater in amplitude in response to mother versus stranger face (e.g., de Haan & Nelson, 1999). However, there are few studies of the Nc and perception of facial affect in typically developing infants. Nelson and de Haan (1996) found greater Nc amplitude in response to fearful relative to happy faces in 7 month olds. More recently, Grossmann, Striano, and Friederici (2007) reported greater Nc amplitude in response to happy compared to angry facial affect in typically developing 7 month olds; however, in a sample of 12 month olds in the same study, Nc amplitude was greater for angry compared to happy expressions.

Grossmann et al. (2007) suggest that the period from 7 to 12 months is one during which infants gain the capacity to detect threat as a significant cue, based on a process requiring pre-existing knowledge about the world (Öhman & Mineka, 2001). While able to discriminate between emotions at 7 months, typically developing infants have not had sufficient exposure to angry faces to learn that this expression likely conveys threat of a negative consequence, with some research suggesting that this is associated with the onset of increased locomotive abilities and greater parental expressions of anger when infants become more mobile (e.g., Campos, et al., 2000).

The greater Nc reactivity to angry compared to happy facial affect displayed by the nonmaltreated infants in the current sample is parallel to that reported in the typically developing 12 month olds in Grossmann et al. (2007). In contrast, however, the maltreated infants in the current sample exhibited greater Nc in response to the happy compared to the angry expressions. This pattern of greater reactivity to happy facial affect in the maltreated infants is perhaps due to an effective increase in the novelty of a happy facial expression that may come about as a result of an increase in the angry affect directed at maltreated infants at this age. At 15 months, infants are exhibiting increased self-development and the concomitant expressions of will and autonomy, enhanced cognitive development, and increased locomotor abilities allowing them to move independently. The behaviors accompanying these advances in development become more challenging for parents, and likely elicit more anger from maltreating parents. Thus, while angry facial affect is more familiar relative to happy for maltreated infants from the beginning of life, later in the infancy period the frequency of caregiver anger directed at the infant, relative to happy affect, may become even greater. Further, in conjunction with this greater parental expression of anger is an increased understanding of the connection between angry facial affect and negative behavioral consequences, contributing to a shift toward increased relevance of angry facial affect. At the neural level this may be reflected in increased Nc amplitude in response to angry facial affect as was observed in our sample of 30 month old maltreated children (Cicchetti & Curtis, 2005).

In interpreting the current results, it is also important to consider that there is only one previous study of the Nc in response to angry and happy facial affect in similar aged infants (i.e., Grossmann et al., 2007), and there is overall a relative paucity of ERP evidence on the Nc and facial affect in this age range. In particular, in the absence of longitudinal data, it is not possible to definitively address the processes leading to the differences found in the Nc component between the maltreated and nonmaltreated infants in the current study. However, it is likely that the atypical, predominantly negative emotional experiences encounter by maltreated infants early in life alter the course of neural development through a complex transactional process between the affective environment and neurodevelopmental processes.

The P260 component also showed group differences dependent on emotion. In particular, the nonmaltreated infants had greater P260 amplitude in response to happy facial affect compared to the maltreated infants. Also, within the maltreated group, amplitude of this waveform was greater in response to angry compared to happy facial expressions. The current findings are parallel to those from our study of 42 month olds, where maltreated children had greater amplitude in response to angry and nonmaltreated children showed greater amplitude in response to happy on an analogous ERP component (Curtis & Cicchetti, 2011). In addition, the current findings are largely consistent with those from our previous ERP study of 30 month olds (Cicchetti & Curtis, 2005), where maltreated children exhibited greater amplitude of a similar early positive component in response to viewing angry facial expressions, compared to the nonmaltreated comparison children. The current findings add further support to the hypothesis that maltreated children are relatively more responsive to angry facial affect.

This waveform's apparent sensitivity to facial affect, demonstrated in previous studies of young children (e.g., Cicchetti & Curtis, 2005; Curtis & Cicchetti, 2011; Moulson et al., 2009; Parker & Nelson, 2005), suggests that it may index a later perceptual process that includes recognition of the affective component of a face. The current finding may be further indicative of the impact of maltreatment on neurofunctional processes underlying the identification of anger, and provides further evidence of this effect in an even younger aged population. For maltreated infants and children, detecting anger in the face of a caregiver would be of particular relevance, as this facial expression may be associated with threat and an impending episode of abuse. This again points to the additional and early experience with angry faces that maltreated children likely have, consistent with evidence demonstrating increased negative affect in maltreating homes (e.g., Kavanaugh et al., 1988).

Overall, the current findings demonstrate that, by 15 months of age, infants who have experienced maltreatment in the first year of life do manifest alterations in neural indices of processing facial affect. For one of the ERP components examined, the P260, the maltreated infants in this sample exhibited a hyperresponsivity to anger. However, for the other components examined, the opposite effect was observed, with the maltreated infants manifesting greater reactivity in response to happy facial expressions. These novel findings contribute to our understanding of the rapid, ongoing neurodevelopmental processes taking place early in development that may transform the way that an aberrant affective environment alters perceptual and cognitive processes supporting facial emotion processing. In essence, there may be a developmental progression of the effects of maltreatment on neural functioning. Within a developmental psychopathology framework, such changes would be consistent with a dynamic, transactional view of the bi-directional influence of biological and environmental-contextual forces in development (e.g., Cicchetti & Tucker, 1994).

Further, because experience-dependent processes are influenced by exposure to trauma and aberrant emotional environments, the neurodevelopmental processes of children who encounter atypical emotional experiences, such as those associated with maltreatment, may eventuate in neuropathological instead of functional neuronal connections (Black, Jones, Nelson, & Greenough, 1998; Courchesne, Chisum, & Townsend, 1994). In addition, such early experiential abnormalities may lead to the development of aberrant neural circuitry that may increase risk for the development of relatively enduring forms of psychopathology (Cicchetti & Cannon, 1999).

Also, it is important to keep in mind that studies of typically developing children's ability to recognize, discriminate, and understand facial affect indicate that these abilities develop slowly through infancy and reach adult levels by approximately 4 to 5 years of age (e.g., Nelson, 1987). Understanding of the meaning of facial emotion is in its earliest stages at 15 months. Over the first year of life, experience with social stimuli contributes to the development of an infant's capacity to understand intention and affective state displayed by others. Most studies have indicated that it is not until 5 to 7 months of age, at the earliest, that infants can demonstrate recognition of emotional facial expressions (e.g., Ludemann, 1991; Nelson & Dolgin, 1985), and behavioral data suggest that infants are able to categorize some emotions by 7–8 months (e.g., Nelson & de Haan, 1997).

The ability to perceive differences in facial expressions (discrimination) does not imply that the meaning of the emotion is understood (Batty & Taylor, 2006). For example, Klinnert (1984) demonstrated that 2–6 month olds did not react differently to expressions of joy or anger, but by 12 months maternal expression did appear to influence behavior. Further, it has been shown that children's capacity to connect adults' emotional reactions with specific consequences does not occur until the second year of life (Pons, Lawson, Harris, & de Rosnay, 2003). At 15 months there is the beginning of understanding of facial affective expression, and thus this age range represents the early part of a sensitive period during which emotional experiences may have a profound influence on the neurodevelopmental processes associated with encoding and understanding of facial emotion.

One of the limitations of the current cross-sectional study is that it is not possible to draw firm conclusions about the likely dynamic nature of the alterations of the ERP components examined. Thus, future studies of the consequences of early maltreatment on brain functioning should utilize longitudinal designs in to not only further explore the neurofunctional alterations associated with maltreatment in children, but also to gain a clearer sense of the typical development of ERP components elicited by facial emotion, beginning in early infancy and continuing through early childhood. One such study was undertaken with children during the first year of life, yielding important findings on the development of face-sensitive ERPs (Webb, Long, & Nelson, 2005). A more comprehensive understanding of the normative development of emotion face processing would serve to inform studies of children who experience adversity early in life, and the potential cascade of effects in response to adverse social experience (Cicchetti & Curtis, 2006; Cicchetti & Tucker, 1994; Pollak, 2008).

Furthermore, it is imperative that investigations of brain functioning in children who have experienced maltreatment inform prevention and intervention efforts (e.g., Cicchetti & Gunnar, 2008). Results from the current study suggest that infants who have experienced maltreatment during the first year of life exhibit clear brain-based abnormalities in processing facial affect at 15 months of age, arguing for the importance of early preventive interventions with children who have experienced maltreatment in order to avert the potential cascade of effects this experience may have on brain development and functioning. A developmental psychopathology perspective points to the importance of such early preventive interventions as a way to move maltreated young children onto more adaptive developmental pathways, such that the risk for psychopathological outcomes is reduced.

The current results, as well as previous ERP findings with maltreated children (e.g., Cicchetti & Curtis, 2005; Curtis & Cicchetti, 2011; Pollak et al., 1997; 2001), suggest that such interventions might focus on training in facial affect recognition. While such training would likely be at a very basic level for infants at 15 months of age, later in development more intensive intervention efforts might attempt to change the salience and/or representation of emotion, in particular that of anger. For example, an attachment intervention could focus on changing representations of cognitive and emotional processes, such as that demonstrated by Toth, Maughan, Manly, Spagnola, and Cicchetti (2002). Finally, it would be useful to include baseline and post-intervention measures of ERPs elicited by facial affect in evaluations of treatment efficacy. Given that behavioral and

representational changes have been shown to improve in attachment-informed interventions (e.g., Bernard et al., 2012; Cicchetti, Rogosch, & Toth, 2006; Moss et al., 2011; Toth et al., 2002), it would also be important to ascertain if ERPs, a manifestation of brain functioning, exhibit post-intervention improvement (Cicchetti & Curtis, 2006; Curtis & Cicchetti, 2003).

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Figure 1.

Amplitude of P1 component across angry and happy face emotion conditions for maltreated and nonmaltreated children, illustrating Group x Emotion interaction. Error bars are standard errors of the means. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

Figure 2.

Grand averages of occipital ERP components elicited in response to the (a) angry, (b) happy, and (c) neutral face conditions. Plot is of average amplitude of 3 occipital electrodes (O1, O2, Oz). Amplitude is represented on the vertical axis in microvolts, and time (milliseconds) is on the horizontal axis.

Figure 3.

Amplitude of P260 component across angry and happy face emotion conditions for maltreated and nonmaltreated children, illustrating Group x Emotion interaction. Error bars are standard errors of the means. ⁺p < 0.10, *p < 0.05, **p < 0.01, ***p < 0.001.

Figure 4.

Grand averages of central ERP components elicited in response to the (a) angry, (b) happy, and (c) neutral face conditions. Plot is of average amplitude of 5 central electrodes (C3, C4, T3, T4, Cz). Amplitude is represented on the vertical axis in microvolts, and time (milliseconds) is on the horizontal axis.

Figure 5.

Grand averages of central ERP components elicited in response to the (a) angry, (b) happy, and (c) neutral face conditions. Plot is of average amplitude of 5 frontal electrodes (F3, F4, F7, F8, Fz). Amplitude is represented on the vertical axis in microvolts, and time (milliseconds) is on the horizontal axis.

Figure 6.

Amplitude of Nc component across angry and happy face emotion conditions for maltreated and nonmaltreated children, illustrating Group x Emotion interaction. Error bars are standard errors of the means. ⁺p < 0.10, *p < 0.05, **p < 0.01, ***p < 0.001.

Table 1

Demographic Characteristics of Infants Retained for ERP Analyses

	Maltreated	Nonmaltreated
N	25 (55.6%)	20 (44.4%)
Mean Child Age in Months	15.8 (0.70)	15.8 (1.3)
Range	14.6 – 17.2	14.1 – 19.0
Mean Maternal Age in Years	29.3 (6.2)	27.6 (5.9)
Sex of Child		
Female	13 (52.0%)	12 (60.0%)
Male	12 (48.0%)	8 (40.0%)
Maternal Marital Status		
Single	16 (64.0%)	13 (65.0%)
Married/Partner	9 (36.0%)	7 (35.0%)
Maternal Race		
African American	17 (68.0%)	10 (50.0%)
European American	4 (16.0%)	3 (15.0%)
Hispanic American	3 (12.0%)	7 (35.0%)
Mixed Race/Other	1 (4.0%)	0 (0.0%)
Mean Hollingshead	20.7 (7.1)	21.2 (6.8)
Bayley MDI	91.5 (10.0)	95.2 (11.6)