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Parental emotionality is related to preschool children's neural responses to emotional faces

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Abstract

The ability to accurately decode others' facial expressions is essential for successful social interaction. Previous theories suggest that aspects of parental emotionality—the frequency, persistence and intensity of parents' own emotions—can influence children's emotion perception. Through a combination of mechanisms, parental emotionality may shape how children's brains specialize to respond to emotional expressions, but empirical data are lacking. The present study provides a direct empirical test of the relation between the intensity, persistence and frequency of parents' own emotions and children's neural responses to perceiving emotional expressions. Event-related potentials (ERPs) were recorded as typically developing 3- to 5-year-old children (final *N*s = 59 and 50) passively viewed faces expressing different emotional valences (happy, angry and fearful) at full and reduced intensity (100% intense expression and 40% intense expression). We examined relations between parental emotionality and children's mean amplitude ERP N170 and negative central responses. The findings demonstrate a clear relation between parental emotionality and children's neural responses (in the N170 mean amplitude and latency) to emotional expressions and suggest that parents may influence children's emotion-processing neural circuitry.

Keywords: emotion perception; parental emotionality; event-related potentials; neural correlates; children

Introduction

Humans thrive in the social world by actively decoding and extracting useful information from other people's facial expressions (Leppänen *et al.*, 2007a). Neuroscience research has revealed an underlying neural network (e.g. involving the amygdala, insula, anterior cingulate gyrus and prefrontal cortex) that supports this critical emotion perception (for review, see Phillips *et al.*, 2003), and this neural activity is measurable in infants, children and adults (Leppänen *et al.*, 2007b). Intriguingly, there are documented developmental changes in neural responses to perceiving faces and emotional expressions, suggesting that at least some aspects of the emotion neural network may undergo specialization over the first few years of life. For example, neural responses change over infancy and early childhood to distinguish familiar from unfamiliar faces (Halit *et al.*, 2003) and to distinguish different emotional expressions (Leppänen and Nelson, 2009). In addition to these and other functional developments (Johnson, 2001), parts of the emotion neural network (e.g. amygdala, insula and prefrontal cortex; see meta-analysis by Phan *et al.* (2002)) also show structural change over this same time period (Grossmann and Johnson, 2007). These findings indicate the existence of a neural system supporting emotion perception that changes and specializes with development.

However, despite the evidence for development in the emotion-perception neural system, the factors that may influence this development are comparatively under-explored. Given that emotion perception is central to a broad range of social skills [e.g. prosocial and empathic responding (Olderbak and Wilhelm, 2017) and social problem solving and conflict resolution (Jordan and Troth, 2004)], an understanding of the variables that may shape the development of this emotion-perception neural system has implications for a broad set of social outcomes. Moreover, given that several disorders (e.g. anxiety and depression) show altered emotion perception (Ladouceur *et al.*, 2005; Brühl *et al.*, 2011), an understanding of factors shaping its underlying neural circuitry—especially if experiential in nature—also has implications for intervention and prevention programs. In the present study, we take a first step in examining the role that parents' own emotional characteristics may play in the specialization of children's emotion-perception neural system. Specifically, we test the hypothesis that individual differences in parents' awareness, persistence and intensity of the parents' own emotions—termed

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parental 'emotionality'—are related to individual differences in the neural activity underlying their children's perception of and attention to emotional faces.

Theoretical perspectives describe the importance of emotion-related parental characteristics and behaviors for the development of infants' and children's emotion perception (see, e.g., Morris *et al.*, 2007 for review; Gottman *et al.*, 1996; Eisenberg *et al.*, 1998; Hajal and Paley, 2020). In support of these theories, empirically, there are demonstrated links between observable parenting behaviors and infants' and children's emotion perception as assessed both behaviorally (Dunsmore and Halberstadt, 2009; Castro *et al.*, 2015) and in terms of emotion-perception neural correlates (see Tan *et al.*, 2020 for review). For example, neuroimaging studies with functional magnetic resonance imaging (Romund *et al.*, 2016; Pozzi *et al.*, 2020) and functional near-infrared spectroscopy (Porto *et al.*, 2020) demonstrate relations between parental characteristics (e.g. maternal warmth and support, negative maternal affect and behaviors) and adolescents' and school-aged children's brain activity during emotional face perception (e.g. in the amygdala and inferior frontal gyrus). Such relations also exist in infants, commonly assessed with the event-related potential (ERP) technique: several studies show the influence of parent's negative emotion-related behaviors and contexts (e.g. anxiety, depression, abuse and neglect) on infant's neural responses to emotional faces (Bowman *et al.*, 2022; see also Belsky and De Haan, 2011), and other studies show similar relations with positive parental characteristics such as positive affect and parental sensitivity to infants' emotions and behaviors (De Haan *et al.*, 2004; Taylor-Colls and Pasco Fearon, 2015). Thus, taken together, both theory and empirical research demonstrate relations between observable parental emotion-related behaviors and characteristics and infants' and children's developing emotion-related neural circuitry.

Despite the important foundation provided by this existing research, it does not directly investigate the role of parental 'emotionality' in children's developing emotion-related neural circuitry. As discussed in theoretical and empirical work (Morris *et al.*, 2007; Are and Shaffer, 2016; Hajal and Paley, 2020), the emotion-related parenting behaviors (such as parent emotion coaching, emotional socialization and emotion-sensitivity) that have been assessed in existing research are possible downstream products that are influenced by parental emotionality. As such, parental 'emotionality' is thought to constitute an overarching influence on parents' emotion-related behaviors and expressions (Morris *et al.*, 2007 for review; Gottman *et al.*, 1996, 1997; Eisenberg *et al.*, 1998: Dunsmore and Halberstadt, 2009; Castro *et al.*, 2015) thereby serving as a potentially more powerful, proximal and direct influence on children's emotion-perception neural circuitry (Hajal and Paley, 2020). To elaborate, emotionality refers to one's own reactivity to given emotion stimuli in terms of awareness, persistence and intensity of the emotional reaction (Rothbart *et al.*, 2001) and is considered to be a relatively stable trait across time and situations (Eisenberg *et al.*, 2000). Emotionality is therefore separate from the parental behaviors and characteristics assessed in existing research, but importantly there is evidence that emotionality dictates one's expressed and experienced emotions (Cumberland-Li *et al.*, 2003; Are and Shaffer, 2016). Indeed, parents' awareness, intensity and persistence of their own emotional expressions (i.e. their emotionality) is a feature of several parental characteristics each shown to influence children's emotion perception such as direct emotion coaching (for example, see Gottman *et al.*, 1996; Dunsmore *et al.*, 2013) and experience with and observation of parental emotional expressions (see meta-analysis by Halberstadt and Eaton (2002). As such, investigations of relations between children's neural responses to emotional faces and more direct measures of parental emotionality *per se* are needed. These investigations are necessary to reveal the influence of this potential primary source of variability in parents' emotion-related characteristics on children's development and specialization of their emotion-related neural circuitry.

The current study

The current study takes this needed approach and directly examines relations between children's neural responses to emotional faces and parental emotionality as assessed by the Emotion Reactivity Scale (ERS; Nock *et al.*, 2008), wherein parents self-report on their own emotional sensitivity (i.e. how likely they are to feel emotional), intensity (i.e. how intense the emotional experiences are) and persistence (i.e. how long these emotional experiences last). We examine the critical time period of preschool when children's emotion identification and interpretation skills become more relevant and accurate (MacDonald *et al.*, 1996). This preschool period is critical to evaluate given parents' emotionality may be especially influential during this time of advancement in children's emotion perception. We uniquely assess children's neural responses to both full-intensity and reduced-intensity emotional expressions to measure potential individual differences in children's perception of these variable intensity faces as a function of variability in their parents' own emotional intensity. Moreover, to isolate the unique influence of parental emotionality on children's neural responses to emotional faces, we include children's own emotionality as a covariate given it can covary with both parental emotionality (Dunsmore and Halberstadt, 2009) and children's brain activity (Martinos *et al.*, 2012). Findings from this study will provide the first direct assessment of relations between parental emotionality and young children's neural responses to emotions, shedding important light on the role of parental emotionality in children's own emotion-perception neural systems, and laying import foundation for future research to unpack the mechanisms of such a relation, should it exist.

ERP components and hypotheses

We use ERPs to assess children's emotion-perception neural correlates and focus on two components of interest based on prior research that have each been shown to be related to preschool children's emotion perception: the N170 (Batty and Taylor, 2006; Dennis *et al.*, 2009) and the negative central (Nc) (Todd *et al.*, 2008; Dennis *et al.*, 2009). We use this prior research to inform our hypotheses for how relations between parental emotionality and children's neural responses to emotional faces may manifest in these target components of interest.

N170

The N170 component is a negative deflection recorded at posterior occipital scalp sites occurring around 150 ms to 240 ms post-stimulus onset (Dennis *et al.*, 2009). We targeted this component because it is commonly associated with the structural encoding of faces (e.g. Eimer, 2011) and has been shown to be modulated by characteristics of faces (Bentin *et al.*, 1996), including emotional facial expressions (Batty and Taylor, 2003; Dennis *et al.*, 2009; Blau *et al.*, 2007; Leppänen *et al.*, 2007a). Thus, the inclusion of this component allows investigation of associations between parental emotionality and encoding of structural/featural aspects during face perception that occur early in the processing stream. Importantly, reduction in amplitude has been interpreted as greater neural efficiency for processing familiar face stimuli, which the brain may have specialized to perceive. For example, adults show a reduction in N170 amplitude and shorter N170 latency when viewing upright human faces (a stimulus they encounter daily) compared to inverted human faces and compared to monkey faces (stimuli that are rarely encountered) (De Haan *et al.*, 2002), and infants show a gradual increase of this specificity to upright human faces over 3 to 12 months of age in two ERP components thought to constitute precursors to the N170 (i.e. N290 and P400; Halit *et al.*, 2003).

Based on this collection of findings, we reasoned that an influence of parental emotionality on children's neural responses to perceiving emotional faces may be reflected in modulation of children's N170 amplitude and latency. Specifically, we hypothesized that children would exhibit greater neural efficiency when processing faces that they may be more likely to frequently encounter. That is, children of parents with high emotionality (who thus are more likely to receive more direct emotion coaching and experience and observe more frequent and intense parental emotional expressions; Gottman *et al.*, 1996; Halberstadt and Eaton, 2002; Dunsmore *et al.*, 2013) will show reduced N170 amplitude and shorter N170 latencies to emotional compared to neutral stimuli and to more intense *vs* less intense emotional stimuli.

Nc

The Nc component is a negative deflection recorded at central scalp sites occurring around 300 ms to 500 ms post-stimulus onset (Todd *et al.*, 2008). We targeted this component because it has also been shown to be modulated by different emotional expressions (De Haan and Nelson, 1998); in particular, the Nc has been used to index attention allocation when processing emotional faces (De Haan *et al.*, 2004) as well as processing of emotion salience (De Haan *et al.*, 2003). In particular, an increase in Nc amplitude has been interpreted as more attention allocated to the perceived stimuli (Xie *et al.*, 2019; Bowman *et al.*, 2022) and a perception of the stimulus as more salient (Nelson, 1994). Thus, the inclusion of this component allows investigation of associations between parental emotionality and emotion-related attentional and salience-detection processes during face perception that occur later in the processing stream. Infants' Nc amplitude has also been shown to relate to variability in parental emotion-related characteristics, showing both positive and negative relations. Specifically, maternal positivity was negatively related to infants' Nc amplitude to happy faces compared to fearful faces (De Haan *et al.*, 2004), whereas maternal sensitivity was positively related to infants' Nc to happy faces compared to neutral faces (Taylor-Colls and Pasco Fearon, 2015), and maternal anxiety was positively related to infants' Nc amplitude to both happy and fearful faces (Bowman *et al.*, 2022).

Based on this collection of findings, we reasoned that an influence of parental emotionality on children's neural responses to perceiving emotional faces may also be reflected in modulation of children's Nc amplitude. Given evidence for both positive and negative relations with parental characteristics, we did not further hypothesize a particular direction of effect. As discussed earlier, because emotionality could influence the type, frequency and intensity of parents' emotional expressions, children's attention allocation toward emotions that are more familiar to them (i.e. more frequently experienced at home) may be different according to different attention-related accounts. For example, in line with a 'sensitization' account (e.g. Taylor-Colls and Pasco Fearon, 2015), children of more overall emotional parents and more emotionally intense parents may have a larger Nc amplitude to emotional faces compared to neutral faces and to more intense emotional faces *vs* less intense. Alternatively, in line with a 'habituation' account (De Haan *et al.*, 2004; Bowman *et al.*, 2022), increased parental emotionality and parental emotion intensity could be associated with a reduced Nc amplitude to emotional *vs* neutral faces and more intense emotional faces *vs* less intense.

Method

Participants

A community sample of typically developing children ($N = 78$) and one of their primary caregivers participated in a one-time laboratory visit when children were 3 to 5 years old (44 children were tested prior to the onset of the COVID-19 global pandemic and 34 were tested post pandemic onset). Parents of all participants provided informed consent, and all procedures were approved by the institutional review board. All participants were compensated with small gifts (a toy and a gift card).

Seven children were excluded due to electroencephalogram (EEG) equipment failure at the time of collection. There were additional participant exclusions for each of our final ERP analyses. First, for our amplitude analyses, we used linear mixed effects (LME) models and maximal likelihood for missing data, and thus all children who had at least one ERP amplitude difference wave were included in analyses (see Heise *et al.*, 2022). For these LME analyses, 12 additional children were excluded from the 71 children with EEG data because they had zero 'matching' trials for the amplitude difference wave analysis (see later). Excluded participants did not differ from included participants on age, gender or reported racial identity ($ps > 0.16$), and the final sample of included participants consisted of 59 children (40 girls and 19 boys, $M_{age} = 4.23$ years, s.d. = 0.77 years, range = 3–5 years) and one of their primary caregivers (53 mothers and 6 fathers). Fifty-five children were biologically related to their parent, one child was adopted or fostered, and three did not answer. Demographics of this final sample are representative of the US residential community from which they were recruited: 43 were White (26% Latinx, Chicanx or Hispanic), 7 were multi-racial, 5 were Asian or Asian-American (not Latinx, Chicanx or Hispanic), and 1 was black (see Supplemental Appendix I, Figure SIA).

Second, for our latency analyses, we used linear regression given that the use of LME to analyze single-trial ERP latencies has not yet been validated and may introduce high-frequency noise resulting from individual-trial latency extractions (which differ from individual-trial mean amplitude extractions, see Heise *et al.*, 2022). For these linear regression analyses, additional exclusions were necessary. Specifically, 21 additional participants were excluded from the 71 with EEG data: 12 due to missing parental ERS data and 9 due to poor EEG data quality (as determined by evaluation of the analytic standardized measurement error; aSME, Luck *et al.*, 2021; see later). Excluded participants did not differ from included participants on age, gender or reported racial identity ($ps > 0.10$), and the final sample of included participants consisted of 50 children (45 girls, 5 boys, $M_{age} = 4.2$ years, s.d. = 0.78 years, range = 3–5 years) and one of their primary caregivers (45 mothers and 5 fathers). Forty-nine children were biologically related to their parent, and one child was adopted or fostered. Demographics of this final sample are also representative of the US residential community from which they were recruited: 41 were White (17% Latinx, Chicanx or Hispanic), 5 were multi-racial, 3 were Asian or Asian-American (not Latinx, Chicanx or Hispanic), and 1 was black (see Supplemental Appendix I, Figure SIB).

ERP faces task

Face stimuli for the ERP task paralleled common developmental ERP tasks designed to study the N170, Nc and other face- and emotion-sensitive ERP components (e.g. De Haan *et al.*, 2004; Batty and Taylor, 2006; Taylor-Colls and Pasco Fearon, 2015), and the task was adapted directly from that used in Xie *et al.* (2019) and Bowman *et al.* (2022). Face stimuli consisted of female actors expressing full-intensity happy, fearful, angry and neutral emotions taken from the NimStim set (Tottenham *et al.*, 2009). Two additional reduced-intensity stimulus sets were created for fearful and angry faces[1] by morphing together the neutral and emotional expressions of a given actor until final images represented 40% of the actor's emotional expression and 60% of her neutral expression (i.e. 40% fear with 60% neutral and 40% anger with 60% neutral).

As was done in previous use of this task (e.g. Xie *et al.*, 2019; Bowman *et al.*, 2022), children were shown a face set that matched their own reported race or that best matched the faces children frequently saw as reported by parents at time of test—either a set of White faces, Black faces or East Asian faces (see Supplemental Appendix II for further details on different face sets).

For all face sets, participants were shown a total of 300 trials—50 trials per each of the 6 conditions—via randomized presentation using E-Prime version 3.0 (Psychology Software Tools, Pittsburgh, PA). Faces were presented on a 24-inch computer screen. The screen displayed a single static face in color, centered on a gray background (display resolution: 1024 × 768). Faces were presented for 1000 ms preceded by a fixation cross (black cross centered on gray background) for 800–1400 ms. ERPs were time-locked to the onset of the face. The ERP experiment lasted ∼25 min, and children took a short break every 10 trials. See Figure 1 for schematic of ERP task.

During the entirety of the experiment, a trained experimenter was present (sitting next to the child but out of their peripheral vision) to help children focus their attention on the screen or to redirect children's attention back to the screen as needed. Additionally, a camera was positioned above the computer screen directly in front of children's faces that allowed a second experimenter to also clearly monitor children's attention to the stimuli. This second experimenter was devoted to attentively monitoring the live camera feed, and they would give prompt notice (via walkie-talkie ear-piece) to the experimenter in the room if they noticed the child stopped attending to the screen. Importantly, the experimenter in the room stopped stimulus presentation (via a control box in their lap) when children became inattentive or otherwise needed breaks. These practices ensured that we analyzed neural responses to children's attentive viewing of the presented stimuli.

EEG recording, processing and analysis

Continuous EEG was recorded with BrainVision Recorder (BrainVision Recorder Version 1.21.0393, Brain Products GmbH, Gilching, Germany), actiCHamp amplifier (actiCHamp, Brain Products GmbH, Gilching, Germany) and a 64-channel montage High Precision fabric actiCAP Snap cap (actiCAP Snap, Brain Products GmbH, Gilching, Germany) that positioned actiCAP slim electrodes in line with the international 10-20 system (actiCAP slim, Brain Products

[1] This task was originally developed to examine links between neural responses to emotional faces and development of anxiety (e.g. Bowman *et al.*, 2022). Therefore, only the negative emotional faces were morphed in this version of the task to target relevant faces for anxiety and keep the overall trial count to a minimal level that young children could tolerate.

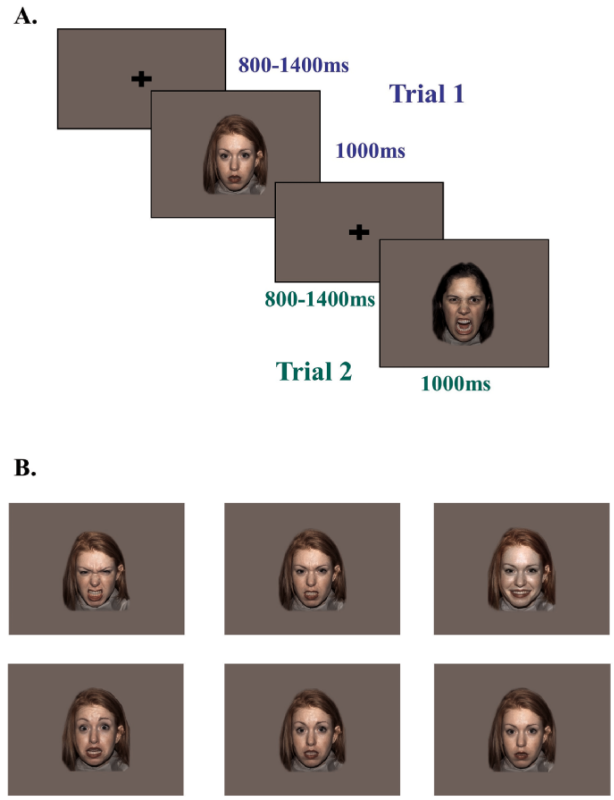

Fig. 1. ERP faces task schematic (A, top panel) shows two trials of 1000 ms stimulus presentation preceded by jittered 800–1400 ms fixation cross. Examples of face stimuli in each emotion condition depicted in bottom panel B from left to right, top to bottom: full-intensity angry, reduced-intensity angry, full-intensity happy, full-intensity fearful, reduced-intensity fearful and neutral.

GmbH, Gilching, Germany; see Supplemental Appendix III, Figure SIII.1). Impedance was kept below 25 kΩ (as recommended by the manufacturer; Brain Products GmbH, Glitching, Germany). Referenced to the vertex (Cz), data were recorded and bandpass filtered from 0 to 140 Hz and digitized at 500 Hz sampling rate.

Data were preprocessed and analyzed offline in MATLAB (The MathWorks Inc, 2019) toolboxes EEGLAB vs.2019_0 (Delorme and Makeig, 2004) and ERPLAB v.8.01 (Lopez-Calderon and Luck, 2014). For additional details on EEG data processing, see Supplemental Appendix IV.1. In brief, in line with prior ERP research (e.g. Batty and Taylor, 2006), continuous EEG was bandpass filtered (0.1–30 Hz) with a second-order Butterworth filter and visually inspected to identify areas of egregious artifact due to excessive movement or noise to improve the subsequent Independent Component Analysis (ICA) in line with Luck (2014); additional details on our protocol for removing egregious artifact from the continuous EEG at this step are in Supplemental Appendix IV.2. ICA was then performed on the resulting discontinuous EEG in EEGLAB to identify blink components which were removed (for additional details about ICA see Supplemental Appendix IV.3). Data were then re-referenced to average reference. Also in line with prior ERP research on face and emotion perception (De Haan *et al.*, 2004; Batty and Taylor, 2006; Todd *et al.*, 2008; Hoehl and Striano, 2010), artifact edited trials were then epoched from −200 ms to 1000 ms, baseline corrected and further edited via an automated process in ERPLAB in which epochs were rejected if any channel exceeded −120 to 120 μV or if sample-to-sample μV exceeded

100 μV. After epoching and artifact rejection, participants contributed an average of 25.5 trials per condition (s.d. = 11.42 trials, range 2–45 trials). Trial contribution was not related to any target variable or demographic variables including age, gender and race/ethnicity (*ps* > 0.13).

Past research on emotional face processing guided the selection of electrodand time windows for both components of interest (De Haan *et al.*, 2004; Todd *et al.*, 2008; Xie *et al.*, 2019). For N170, a time window between 150 and 240 ms after stimulus onset was defined, constrained by prior research (Hoyniak *et al.*, 2019), and finalized with visual inspection of the grand average waveform averaged across conditions so as to avoid bias due to visible condition effects. Two electrode clusters were created for N170 analysis from posterior occipital sites with the left cluster including PO7, PO3 and O1 and the right cluster including PO8, PO4 and O2, in line with prior research (D'Hondt *et al.*, 2017; Hoyniak *et al.*, 2019). For Nc, a time window of 300–500 ms after stimulus onset was defined, similarly constrained by prior research (Leppänen *et al.*, 2007a; Taylor-Colls and Pasco Fearon, 2015), and finalized with visual inspection of the grand average waveform averaged across conditions. One electrode cluster was created for Nc analysis from three central electrodes, Cz, C3 and C4, in line with prior research (De Haan *et al.*, 2004; Dennis *et al.*, 2009). Mean amplitude was extracted in the identified time windows in the target electrode clusters for both N170 and Nc. We focused analysis on difference waves for N170 and Nc mean amplitude and for N170 latency to peak amplitude, to target neural responses to emotional expressions relative to neutral expressions. Supplemental Appendix III, Figures SIII.2, SIII.3 and SIII.4 depict the grand average waveforms in target electrodes, extracted from target time windows, and demonstrate the appropriateness of these electrodes and windows for all participants in our age range.

The linear regression analysis of ERP latencies required inclusion of subjects with a minimum number of high-quality ERP trials. To identify individual subject ERPs of low data quality that should be excluded from this analysis, ERP data quality was analyzed using aSME (Luck *et al.*, 2021), wherein lower aSME values indicate single-subject ERPs of higher data quality. Separately, for each component (N170 left and right clusters averaged together), participants whose high aSME values were identified as statistical outliers using the sum of the 3rd quartile and 1.5 times interquartile range for at least one of the six conditions (happy, angry, fearful, neutral, reduced-intensity angry and reduced-intensity fearful) were excluded. Nine participants met this exclusion criterion for the N170 component (aSME range 2.52–8.08 across conditions). This aSME exclusion criterion was comparable to using a trial-count exclusion of having >10 trials per emotion condition. The final sample of included children (*N* = 50) had an average aSME value across conditions of 1.52 (s.d. = 0.38, range = 0.8–2.28) for N170. This final sample contributed an average of 169.1 trials across all conditions (s.d. = 54.32, range = 78–272) and an average of 28.18 trials per condition. Neither trial count nor aSME value was related to target variables of interest or demographic variables (*ps* > 0.19). For further details on our aSME evaluation of subject ERP quality and relations between aSME and trial count, see Supplemental Appendix V.

Parent ERS (Nock *et al.*, 2008)

The ERS is a 21-item, self-report questionnaire measuring the 'intensity' (7 items; e.g. 'I experience emotions very strongly'), 'persistence' (4 items; e.g. 'When I feel emotional, it is hard for me to imagine feeling any other way') and 'sensitivity' (10 items; e.g. 'I tend to get very emotional very easily') of one's own emotional experiences. Parents rated each item thinking about their own emotional experiences on a 5-point scale, ranging from 'not at all like me' to 'completely like me'. The total scale and subscales demonstrated high internal consistency as reported by Nock *et al.* (2008) (intensity subscale α = 0.86, persistence subscale α = 0.81 and sensitivity subscale α = 0.88) as well as from calculated coefficient alpha based on the reported final sample (total scale α = 0.94, intensity subscale α = 0.89, persistence subscale α = 0.67 and sensitivity subscale α = 0.88).

Child Emotionality Scale (adapted from Putnam *et al.*, 2006)

Children's emotionality was calculated from four subscales (24 items total) in the Parent-Report Early Childhood Behavioral Questionnaire—Short Form (ECBQ-S; Putnam *et al.*, 2006) that best matched the items of the parent-report ERS. The ECBQ subscales included children's consistent tendencies of 'fear' (e.g. 'During everyday activities, how often did your child seem frightened for no apparent reason?'), 'sadness' (e.g. 'During everyday activities, how often did your child become sad or blue for no apparent reason?'), 'positive anticipation' (e.g. 'When told that loved adults would visit, how often did your child get very excited') and 'soothability' (e.g. 'When s/he was upset, how often did your child change to feeling better within a few minutes?'). The selected subscales demonstrated high internal consistency as reported by Putnam *et al.* (2006) (fear subscale α = 0.89, sadness subscale α = 0.81, positive anticipation subscale α = 0.82 and soothability α = 0.86), as well as from calculated coefficient alpha on the created composite from selected scales based on the reported final sample (total scale α = 0.73, fear subscale α = 0.63, sadness subscale α = 0.84, positive anticipation subscale α = 0.45 and soothability α = 0.78). Parents rated the statements according to the frequency of children's behaviors from 1 (never) to 7 (always) (scored following)' procedures). The total score across all subscales was used as a covariate in analyses as an approximation of children's own emotionality.

Focal variables for analysis

ERP difference waves

The present study aimed to understand the extent to which children's brains respond differently to different emotional expressions depending on their parents' self-reported emotionality. Thus, we created ERP difference waves (in line with guidelines from Lopez-Calderon and Luck, 2014) that targeted children's neural responses to emotion-specific aspects of the presented face stimuli. Specifically, for N170 and Nc components, we calculated differences in ERP mean amplitude and latency to peak amplitude by subtracting (I) neutral faces from full-intensity (100%) emotions and (II) reduced-intensity (40%) emotions from full-intensity (100%) emotions. The calculation of difference waves is particularly useful in comparing condition differences in ERP components through avoiding ambiguities in analyzing and interpreting the ERPs by helping to isolate the neural signal that is associated with one condition from a different condition (Luck, 2005). Indeed, the use of difference waves for these components is in line with prior research (Blau *et al.*, 2007; Taylor-Colls and Pasco Fearon, 2015). We used two methods to calculate these difference waves according to the requirements of trial-level analysis for LME and subject-level analysis for linear regression. To analyze ERP amplitude with LME, to account for nuisance variability in ERP mean amplitude based on different actors for stimulus presentation, trial presentation number and target electrodes (see

Heise *et al.*, 2022), we calculated single-trial difference waves using an 'exact-match' method (see Supplemental Appendix VI, Figure SVI). This method involved pairing trials for condition-level subtraction (e.g. angry-neutral) that were first matched on actor (e.g. actor A expressing anger matched with actor A expressing neutral) and then matched on presentation number (e.g. the first trial of actor A expressing anger matched with the first trial of actor A expressing neutral). If a given exact match did not exist (i.e. because one of the trials within the exact-match pairing was excluded in the artifact-rejection pre-processing), then that trial-level difference wave was not calculated for analyses in the LME. For exact-match pairs that existed, amplitude was extracted from the same electrode (e.g. PO7). Also note that as described in Heise *et al.* (2022), LME uses 'partial pooling' to effectively weight the contributions of subjects based on trials contributed. To analyze ERP latency with linear regression, we calculated difference waves from the mean-averaged waveform. Specifically, subject-level latency averages were created for each condition, and then per-subject, condition-level subtractions were conducted to create the emotion-minus-neutral difference waves and the full-minus-reduced-intensity emotion difference waves.

ERS scores

The final measure of parents' emotional reactivity consisted of both the total ERS scale score and the intensity subscale score. The total score was taken as an index of parents' global emotional reactivity to address our broadest question of whether parent emotionality was related to children's neural responses to emotional faces. We also targeted the intensity subscale of the ERS given our ERP task enabled assessment of children's neural responses to different intensity emotions (i.e. more *vs* less intense). A handful of parents did not answer all items ($N = 9$). Thus, to maximize sample size, the subscale mean score was calculated by dividing the summed score of the intensity subscale by the number of questions answered in this subscale. To obtain the mean score of the total scale, this process was repeated for all subscales, and the mean scores of the subscales were added together.

Results

All analyses were conducted in R (version 4.1.3; R Core Team, 2019). LME models were fit using the lme4 package (version 1.1–25; Bates *et al.*, 2009), and *P*-values were obtained using lmerTest (Kuznetsova *et al.*, 2017). Follow-up pairwise comparisons of LME models (including approximation of degrees of freedom for such comparisons) were conducted in the emmeans package (version 1.8.9; Lenth, 2021). Both targeted components demonstrated substantial individual differences at the trial and subject levels (see Supplemental Appendix VII for visualizations of individual variability).

Preliminary analyses

For our trial-level amplitude analyses, to preserve the nested structure of our outcome variable, we fitted a preliminary LME model with the focal trial-level amplitude difference waves as the outcome and demographic variables as fixed effects and a random intercept of subject. The results revealed no significant contribution of demographic variables ($ps > 0.28$); thus, no demographic variable was included in the final LME model. For our subject-level latency analyses, Pearson's correlations revealed that children's ERP latency was related to child age, gender and race ($ps > 0.15$). Pearson's correlations also revealed that children's ERP latencies were not related to the number of artifact-free segments children contributed to their mean average ($r = -0.06$, $P = 0.09$). Children's and parents' emotionality were also not significantly related ($r = 0.88$, $P = 0.38$). A repeated measures Analysis of Variance (ANOVA) revealed that N170 latency did not differ across left and right channel clusters (F (1, 824) $= 1.39$, $P = 0.24$), and therefore, we collapsed across the channel clusters for subsequent analyses.

A series of one-way ANOVAs revealed that neither parent emotionality nor children's emotionality varied as a function of child's race, gender, parent education, parent marital status or household income ($Fs < 1.2$, $ps > 0.33$). Therefore, we did not control for any demographic variables in subsequent trial-level amplitude or subject-level latency analyses.

Notably, children's emotionality was not significantly related to either parental emotionality or any of the child ERP variables ($rs < 0.21$, $ps > 0.13$). We maintained inclusion of this covariate given its theoretical relevance for isolating the relation between children's neural correlates of emotion perception and parental emotionality *per se* (Dunsmore and Halberstadt, 2009; Martinos *et al.*, 2012), and because of its relevance for accounting for trial-level missingness (children who are more emotional may be less likely to tolerate lengthy ERP sessions, resulting in systematic missingness of later trials; see Heise *et al.*, 2022). We include parallel analyses without the child emotionality covariate in Supplemental Appendix IX. Importantly, the pattern of significant and non-significant results is identical regardless of whether children's emotionality is included as a covariate or not.

Focal analyses

We examined whether the difference waves of N170 and Nc mean amplitude as well as difference waves of N170 latency were modulated by emotion condition and parent emotionality. We report focal results by component, as well as by analysis method (i.e. LME with trial-level N170/Nc amplitude difference waves, linear regression with subject-level N170 latency difference waves). For trial-level ERP amplitude LME analyses, our model progression followed best practices as recommended by Barr and colleagues (2013). Details of the LME model building can be found in Supplemental Appendix VI. We analyzed four separate models—two for N170 and two for Nc. Our final LME models were two-level random slope and random intercept models in which the outcome was children's mean amplitude difference waves for N170 or Nc at the trial level. In both models, fixed effects were emotion difference condition (emotion-minus-neutral contrasts and full-minus-reduced-intensity contrasts) by parental emotionality interaction, child emotionality covariate, child age and trial presentation number; a random intercept for subject; and random by-subject slopes for emotion difference condition. The LME assumptions of linearity and a normal distribution of residuals for the final model were confirmed based on visual inspection, and homogeneity of variance was confirmed with a Levene's test ($ps > 0.36$). A normal distribution of residuals was confirmed based on visual inspection because the number of samples in our final dataset exceeded 5000 (Royston, 1995).

For subject-level N170 latency analyses, children's latency to peak amplitude difference waves for N170 constituted the dependent variable, and parental emotionality (ERS) total and intensity mean scores constituted the independent variables, with children's emotionality (ECBQ subscale composite) as the covariate.

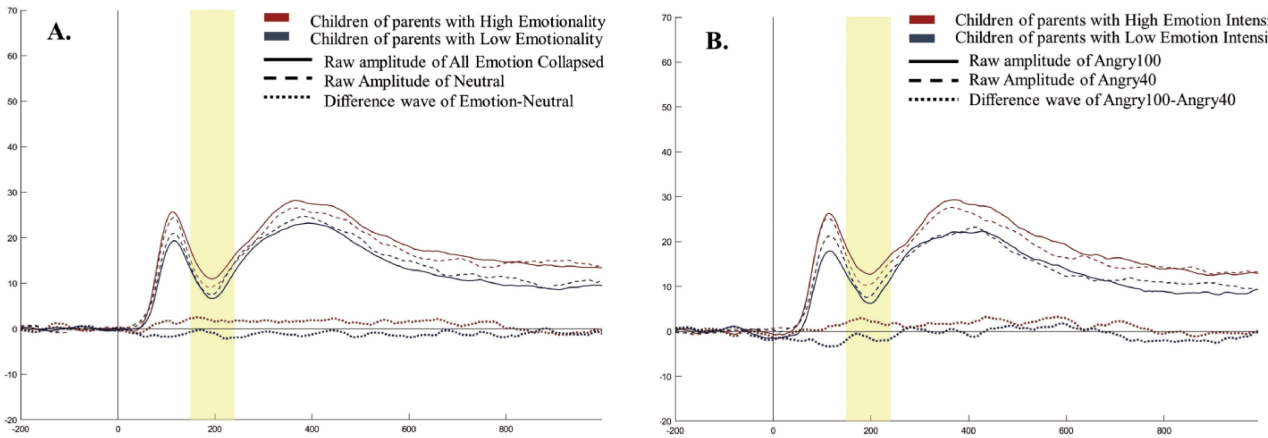

Fig. 2. Grand average ERP N170 mean amplitude differences in the left channel cluster to (A) emotional (collapsed across all full-intensity emotions) or (B) full-intensity angry faces (solid lines) *vs* (A) neutral faces or (B) reduced-intensity angry faces (dashed lines) of parents with high (red lines) *vs* low (blue lines) parental emotionality/emotional intensity (high/low ERS determined as scores above/below the mean for plotting purposes). The shaded yellow bar indicates the epoch of mean amplitude extraction. Note that although waveforms depict the grand average across subjects, analyses were performed examining relations between continuous parental emotionality and trial-level N170 amplitude.

Data visualization with histograms as well as Shapiro–Wilk normality tests demonstrated normal distribution of residuals of outcome difference wave variables ($Ws > 0.95$, $ps > 0.1$), meeting assumptions of general linear regressions. We used the false discovery rate method to correct for multiple comparisons; specifically, we corrected for three comparisons for different emotion-minus-neutral contrasts and two comparisons for full-minus-reduced contrasts. We report the corrected *P*-values.

N170

Parental general emotionality and children's N170

In line with our hypotheses, controlling for children's own emotionality, our LME model revealed that there was a significant positive main effect of parental general emotionality (total ERS score) and children's trial-level N170 mean amplitude difference waves in all emotion-minus-neutral contrasts ($\beta = 1.29$, $SE = 0.54$, $P = 0.02$). Specifically, children of parents who reported as 'more emotional' had 'smaller' N170 amplitude to the 'emotional' faces (happy, angry and fearful) compared to neutral faces, whereas children with parents who reported as 'less emotional' had 'smaller' N170 amplitude to 'neutral' faces compared to emotional faces (happy, angry and fearful). Figure 2A depicts this pattern, visualized in the grand average waveforms (see also Supplemental Appendix VIII, Figure SVIII.1a for scatterplot). However, contrary to our hypotheses, the linear regressions with subject-level N170 latency difference waves did not yield any significant relation between parental general emotionality and children's N170 latency in any emotion conditions ($\beta s < 1.4$, $ps > 0.45$).

Parental emotion intensity and children's N170

In line with our hypotheses, controlling for children's own emotionality, our LME model revealed that there was a significant positive main effect of parental emotion intensity (ERS-intensity subscale) and children's trial-level N170 mean amplitude difference waves in all full-minus-reduced emotion contrasts (full-intensity angry-minus-reduced-intensity angry and full-intensity fearful-minus-reduced-intensity fearful) ($\beta = 2.78$, $SE = 1.28$, $p = 0.04$). Following the same pattern as described for emotion-minus-neutral contrasts described earlier, children of parents who reported experiencing 'more emotion intensity' had 'smaller' N170 to 'more intense' emotional faces compared to less intense emotional faces, whereas child of parents who reported experiencing 'less emotion intensity' had 'smaller' N170 to 'less intense' emotional faces compared to more intense emotional faces. Figure 2B depicts this pattern, visualized in the grand average waveforms (see also Supplemental Appendix VIII, Figure SVIII.1B for scatterplot). Additionally, linear regressions with subject-level N170 latency to peak amplitude difference waves revealed a significant negative effect of parental emotion intensity and children's N170 difference waves for full-minus-reduced-intensity angry faces ($\beta = -9.92$, $SE = 4.17$, $P = 0.04$). Again following a similar pattern, children of parents experiencing 'more emotion intensity' had 'shorter' N170 latency to peak amplitude to 'more intense' angry faces compared to less intense angry faces; whereas children of parents experiencing 'less emotion intensity' had 'shorter' N170 latency to peak amplitude to 'less intense' angry faces compared to more intense angry faces (see Supplemental Appendix VIII, Figure SVIII.1C for scatterplot). However, no statistically significant association was observed for N170 latency for the full-minus-reduced-intensity fearful faces ($\beta = -3.49$, $SE = 3.55$, $P = 0.35$).

Nc

In contrast to significant results with N170 and contrary to our hypotheses, we did not find any statistically significant associations between parental emotionality and children's trial-level mean Nc amplitude for either parent's total ERS score ($\beta = 0.18$, $SE = 0.2$, $P = 0.35$), or for parent's ERS-intensity subscale ($\beta = 0.51$, $SE = 0.76$, $P = 0.53$).

Discussion

We hypothesized that parental emotionality may shape children's emotion-perception neural circuitry such that individual differences in children's neural responses to emotional expressions of different type and intensity would be related to individual differences in their parent's self-reported emotionality. We examined two ERP components—the N170 and the Nc—and calculated difference waves between emotional *vs* neutral faces, as well as full-intensity *vs* reduced-intensity emotional faces, as targeted indices of children's neural responses to emotional expressions (De Haan *et al.*, 2004; Dennis *et al.*, 2009).

At the broadest level, our results demonstrate that children's neural responses to emotional (happy, angry and fearful) faces—indexed by N170 mean amplitude and latency—are different depending on their parents' reported emotionality. These findings are in line with the handful of prior studies that show a link between children's neural correlates of face perception and parental characteristics (e.g. De Haan *et al.*, 2004; Taylor-Colls and Pasco Fearon, 2015). Our results importantly extend prior research by demonstrating the relation with parental 'emotionality' specifically—a hypothesized overarching influence on parents' emotion-related behaviors and characteristics (Cumberland-Li *et al.*, 2003; Morris *et al.*, 2007)—and by demonstrating this parental influence beyond infancy into the preschool years.

More specifically, the present study findings suggest that preschool children's emotion-processing neural circuitry, assessed with the N170 amplitude and latency, may have specialized differently depending on their parents' emotionality. This interpretation is in line with demonstrated functions of the N170 in prior research: in adults, N170 amplitude is reduced for faces that are more familiar (e.g. upright or human faces) compared to faces that are less familiar (inverted or monkey faces) (De Haan *et al.*, 2002), suggesting neurospecialization (in the form of more efficient neural processes indexed by reduced component amplitude and shortened latency to peak) for these more familiar, frequently experienced stimuli. Moreover, hypothesized precursors of the N170—the N290 and P400 in infants—demonstrate some similarities in amplitude differences for upright, human *vs* inverted or monkey faces (Halit *et al.*, 2003) further suggesting a gradual specialization of the brain as face stimuli become more familiar and frequently encountered. In the context of these prior findings, our results suggest that children's brains may be similarly specializing to process emotions of different intensities as a function of the type and intensity of emotions experienced and expressed by their parents as dictated by their parents' emotionality: Children with more emotional parents show reduced N170 amplitude and latency to perceiving emotional and more intense emotional expressions, whereas children with less emotional parents show reduced N170 amplitude and latency to perceiving non-emotional (neutral) expressions. There are several possible mechanisms that could support a link between parental emotionality and children's emotion-perception neural circuitry. As we have already described above, one possibility is that parental emotionality dictates the kinds of emotional expressions children most frequently encounter (as supported by empirical findings and theoretical perspectives, Cumberland-Li *et al.*, 2003; Are and Shaffer, 2016), and through this differential experience of emotions, children's emotion-perception neural circuitry specializes differently. This reasoning is in line with other experience-related mechanisms of neurospecialization for face processing discussed in related prior research on infants' neural correlates of faces and emotions (e.g. Halit *et al.*, 2003; Bowman *et al.*, 2022) and is also in line with findings of a reduced N170 to the more familiar and commonly encountered upright human faces compared to inverted human faces or monkey faces (De Haan *et al.*, 2003). Although we favor this experiential mechanism of influence, our findings cannot rule out other possibilities. For example, our observed link between parental emotionality and children's neural correlates of emotion perception may be influenced by hereditary emotionality characteristics and/or potential genetic predispositions (Plomin and Stocker, 1989; Eley and Plomin, 1997; Anokhin *et al.*, 2010), working either alone or in combination with experiential mechanisms.

We note that our latency analysis of children's neural responses to emotions of different intensities revealed a relation with parental emotionality in only the angry condition; there was a null result for analysis of the fearful condition. While the bulk of our analyses revealed a relation between parental emotionality and all emotions tested (including for full- *vs* reduced-intensity angry and fearful N170 amplitude), it is interesting that the relation between parental emotion intensity and the latency index of neural distinctions in the more subtle differences in emotion intensity was limited to angry faces. Given literature showing that young children often have difficulty labeling and distinguishing some emotion categories, including fearful and neutral faces (Widen and Russell, 2010), it is possible that there was more 'noise' or variability in children's neural responses to fear, which may have more strongly impacted the latency analysis given its increased susceptibility to noise artifacts compared to mean amplitude, contributing to the null result in that condition for the latency analysis. As children mature and their abilities to distinguish fearful face intensities strengthen, a relation between parental emotionality and latency indices of neural responses to full- and reduced-intensity fearful faces may emerge. Alternatively, and in line with a possible experience-related mechanism of influence, parents' anger may be more commonly displayed during interactions with their children compared to fear (which may be less commonly displayed and potentially more actively suppressed by parents when children are present), resulting in a less strong influence of parental emotionality on children's neural responses to fearful faces compared to angry faces. Indeed, considering the types of interactions parents commonly have with young children, there may be more frequent opportunities for parents to express anger and frustration in daily interactions with their child such as when young children are misbehaving throughout the day. We would likewise speculate that parent emotionality reflected in expressions of happy emotions would also be more frequently displayed during daily interactions (see, e.g., Havigerová *et al.*, 2015), and that a similar relation between parental emotionality and full-intensity *vs* reduced-intensity happy faces would emerge if tested. Future research that uses the present study design but adds a condition of reduced-intensity happy faces can test this hypothesis directly.

As a more general test of a possible experiential mechanism of influence, future research could also target populations with adopted children being raised by non-biological parents or include measures of direct observation of parental emotionality during naturalistic parent–child interactions or assessments of the types and intensities of emotional expressions children are frequently exposed to in their family environment (e.g. through observational recordings in the home and comprehensive surveys). Each of these methodological approaches would help target the role of experience in shaping children's neural responses to emotional expressions, especially in longitudinal designs where early and consistent parental emotional expressions may predict children's neural responses assessed later in development.

We did not find any association between parental emotionality and the Nc component for any difference wave contrasts despite the substantial individual differences in the mean Nc amplitude across all conditions. These null results were contrary to our hypotheses and contrasting with prior research that shows a relation between parental emotion-related characteristics and neural responses to emotion expressions in infants (De Haan *et al.*, 2004; Taylor-Colls and Pasco Fearon, 2015; Bowman *et al.*, 2022).

Although we interpret null results with caution, our contrasting findings between N170 and Nc could indicate that parental emotionality is differentially related to aspects of emotion perception, as captured by these different components that occur at different points in the processing stream. Specifically, the Nc component occurs later in the time course post-stimulus onset (i.e. 300 to 500 ms) and has been used to index allocation of attentional resources in processing emotional faces (De Haan and Nelson, 1998; De Haan et al., 2003). Therefore, our pattern of results could suggest that parental emotionality is not related to individual differences in children's 'attention allocation' to different emotional expressions (as reflected in Nc) but rather more readily influences early-occurring, automatic, feature-detection processes (as reflected in N170), either in general (i.e. at any point in development) or at least at developmental points beyond infancy. Future research that adopts the approach we present here, but with infant participants, could test for a possible relation between Nc and parental emotionality that may indeed exist at this earlier developmental period. Additionally, to further investigate a relation (or lack thereof) between parental emotionality and attentional processes underlying children's emotion perception, future research could examine the late positive potential—a component thought to index sustained attentional processes (Dennis et al., 2009; Brown et al., 2012)—or other downstream measures of attention such as eye-tracking while children view emotional faces to help elucidate the relation between parental emotionality and preschoolers' attention to emotional expressions. Future research should also investigate potential relations between parental emotionality and neural responses to emotional faces both earlier and later than the preschool period targeted here, to potentially identify periods in which parental emotionality is maximally influential.

Conclusion

This study provides initial evidence that normative parental emotionality (i.e. the frequency, intensity and persistence of emotions as self-reported by parents) relates to children's neural responses to emotions of different types and intensities as assessed with ERPs. Specifically, children with more emotional parents show reduced N170 amplitude and latency to perceiving emotional and more intense emotional expressions, whereas children with less emotional parents show reduced N170 amplitude and latency to perceiving non-emotional (neutral) expressions. These results suggest that children's neural circuitry supporting emotion perception may have specialized for perception of the types of emotional experiences they most frequently encounter, as dictated by their parents' emotionality. The results of this study shed light on understanding individual differences in children's emotion-perception neural circuitry and the role that parents play in children's developing brains.

Supplementary data

Supplementary data is available at *SCAN* online.

Data Availability

Data will be made available upon request.

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Conflict of interest

The authors declared that they had no conflict of interest with respect to their authorship or the publication of this article.

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