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RESEARCH ARTICLE

Maternal symptoms of depression and anxiety during the postpartum period moderate infants' neural response to emotional faces of their mother and of female strangers

Aislinn Sandre[1] · Clara Freeman[1] · Héléna Renault[1] · Kathryn L. Humphreys[2] · Anna Weinberg[1]

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Abstract

Affective exchanges between mothers and infants are key to the intergenerational transmission of depression and anxiety, possibly via adaptations in neural systems that support infants' attention to facial affect. The current study examined associations between postnatal maternal symptoms of depression, panic and social anxiety, maternal parenting behaviours, and infants' neural responses to emotional facial expressions portrayed by their mother and by female strangers. The Negative Central (Nc), an event-related potential component that indexes attention to salient stimuli and is sensitive to emotional expression, was recorded from 30 infants. Maternal sensitivity, intrusiveness, and warmth, as well as infant's positive engagement with their mothers, were coded from unstructured interactions. Mothers reporting higher levels of postnatal depression symptoms were rated by coders as less sensitive and warm, and their infants exhibited decreased positive engagement with the mothers. In contrast, postnatal maternal symptoms of panic and social anxiety were not significantly associated with experimenter-rated parenting behaviours. Additionally, infants of mothers reporting greater postnatal depression symptoms showed a smaller Nc to their own mother's facial expressions, whereas infants of mothers endorsing greater postnatal symptoms of panic demonstrated a larger Nc to fearful facial expressions posed by both their mother and female strangers. Together, these results suggest that maternal symptoms of depression and anxiety during the postpartum period have distinct effects on infants' neural responses to parent and stranger displays of emotion.

Keywords Depression · Anxiety · Parenting · Infancy · Negative central · Faces · Emotion

Introduction

Depression and anxiety are extremely common during the postpartum period. It is estimated that as many as 20% of mothers experience clinically significant depression and anxiety symptoms after childbirth (Andersson et al., 2006; Fawcett et al., 2019; Gavin et al., 2005; Wisner et al., 2013), and rates are higher for subclinical symptoms (Meaney, 2018; Polachek et al., 2014). Maternal symptoms of depression and anxiety are linked to adverse outcomes for both mothers and infants (Goodman & Gotlib, 1999; Gotlib, 1992; Moehler et al., 2006), including increased risk for these disorders or symptoms later in life among offspring (Bureau et al., 2009; Halligan et al., 2007; Murray et al., 2011). Additionally, although depression and anxiety are highly comorbid (Kaufman & Charney, 2000; Mineka et al., 1998) and tend to co-aggregate in families (Kendler et al., 1997; Mosing et al., 2009), there is evidence that the intergenerational transmission of depression and anxiety involves both shared and disorder-specific pathways (Biederman et al., 2001; Hirshfeld-Becker et al., 2012; Starr et al., 2013). However, the mechanisms involved in the intergenerational transmission of depression and anxiety are unclear (Gotlib et al., 2020), particularly neural processes that delineate specific avenues of risk for these disorders.

The quality of affective exchanges between mothers and infants may play a role in this intergenerational transmission (Goodman & Gotlib, 1999; Murray et al., 2009). In particular, a wealth of data indicate that depressed and anxious

✉ Aislinn Sandre
aislinn.sandre@mail.mcgill.ca

[1] Department of Psychology, McGill University, 2001 McGill College Avenue, Montreal, QC H3A 1G1, Canada

[2] Department of Psychology and Human Development, Vanderbilt University, 230 Appleton Place, Nashville, TN 37203, USA

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mothers often interact with their infants differently compared with nondepressed and nonanxious mothers (Creswell et al., 2013; Ewell Foster et al., 2008; Jones et al., 2021; Lovejoy et al., 2000; Murray et al., 1996). Moreover, anxiety and depression may be associated with parenting profiles that are distinct from one another. For instance, mothers with greater depressive symptoms, on average, exhibit lower sensitivity and warmth, as well as greater withdrawal and disengagement (Campbell et al., 2007; Dib et al., 2019; Feldman et al., 2009; Granat et al., 2017; Lovejoy et al., 2000). Anxious mothers tend to be more strongly characterized by intrusive interactions (Creswell et al., 2013; Epkins & Harper, 2016; Feldman et al., 2009; Murray et al., 2007). Similarly, depression and anxiety have each been associated with distinct profiles when it comes to the expression of affect: compared with nondepressed mothers, mothers with depression more frequently express sadness and anger, as well as neutral facial expressions, when interacting with their infants (Cohn et al., 1990; Dawson et al., 2003), whereas mothers with anxiety more often express fearful and neutral facial expressions (Murray et al., 2007; Nicol-Harper et al., 2007). These parenting behaviors and affective styles of depressed and anxious mothers have been linked to a wide range of developmental outcomes for infants, including poorer quality relationship with their mothers (Righetti-Veltema et al., 2003), as well as adverse emotional (Feldman et al., 2009; Kingston et al., 2012) and social outcomes (Wang & Dix, 2013).

One avenue for the long-term effects of postnatal maternal depression and anxiety, and associated parenting behaviors, on these emotional and social outcomes may be through adaptations in neural systems that support attention to facial affect in infants (Aktar & Bögels, 2017; Bowman et al., 2021; Porto et al., 2016). These neural systems are highly plastic during infancy (Johnson, 2001; Johnson et al., 2005) and are powerfully shaped by early experiences with primary caregivers (Haist & Anzures, 2017; Leppänen, 2011; Leppänen & Nelson, 2009; Slater et al., 2010). However, because collecting neural data from awake infant samples presents many challenges (Raschle et al., 2012), much of the work investigating the effect of maternal symptoms on socioemotional processing comes from behavioural and eye-tracking studies. These studies reveal mixed results. Some indicate that infants of depressed mothers show *increased* attention to aversive faces (Forssman et al., 2014; Kataja et al., 2020), whereas other evidence suggests that these infants show *decreased* attention to both aversive and appetitive facial expressions (Diego et al., 2004). More consistent evidence suggests that maternal symptoms of anxiety are associated with increased attention in infants to aversive compared with neutral faces (Creswell et al., 2011; Morales et al., 2017). However, few studies have simultaneously considered postnatal maternal depression and anxiety (Bowman et al., 2021), making it difficult to identify common and distinct effects.

The limited number of studies directly investigating associations between parenting behaviors and neural responses in offspring suggest that both low maternal warmth and high intrusiveness/aggression are associated with increased neural processing of aversive faces in children and youth (Pozzi et al., 2020; Romund et al., 2016). Other evidence suggests that low maternal sensitivity is associated with decreased neural responses when infants view happy faces (Taylor-Colls & Pasco Fearon, 2015). Together, these data provide promising evidence that variation in maternal parenting behaviors associated with depression and anxiety may contribute to adaptations in neural systems that support attention to socioemotional information in offspring. Moreover, these data indicate that there may be some specificity in the associations between different parenting styles and patterns of infant neural response.

The data above further suggest that there may be some specificity in *pathways* to anxiety and depression, given the fact that similar alterations in neural systems that support attention to socioemotional information have been implicated in both current symptoms and risk for developing symptoms. For instance, children, adolescents, and adults with depression, as well as individuals at risk for depression, have been shown to exhibit decreased neural responses when viewing both aversive and appetitive content (Grunewald et al., 2019; Kujawa et al., 2011; Lawrence et al., 2004). In contrast, children, youth, and adults with anxiety, and those at risk for anxiety, more often show increased neural responses when viewing aversive stimuli (Auday et al., 2018; Kujawa et al., 2015; Moser et al., 2008; Nelson et al., 2015; Thomas et al., 2001).

Combined, these data suggest that both postnatal maternal symptoms and parenting behaviors might contribute to abnormal patterns of neural response to socioemotional information that then make children more vulnerable to the development of depression and/or anxiety. However, it is not yet clear how early these neural adaptations might appear, nor is it well understood if distinctions observed between neural response styles associated with anxiety or depression might emerge prior to the development of symptoms.

Further complicating the picture is the fact that existing neural, behavioural, and eye-tracking research examining these questions has typically employed affective faces of strangers as stimuli (Bornstein et al., 2011; Bowman et al., 2021; Creswell et al., 2008, 2011; Forssman et al., 2014; Kataja et al., 2020; Morales et al., 2017; Striano et al., 2002; Taylor-Colls & Pasco Fearon, 2015), making it unclear whether potential early indicators of depression and anxiety risk arise through attention-related deficits specific to parental displays of emotion or displays of emotion more broadly. Yet caregivers' facial displays of emotion provide the primary means by which infants experience and learn how to encode socioemotional cues (Haist & Anzures, 2017;

Leppänen, 2011; Leppänen & Nelson, 2009; Slater et al., 2010; Winston & Chicot, 2016).

The purpose of the present study was to examine the associations between postnatal maternal symptoms of depression and anxiety, maternal parenting behaviours, and infants' neural responses to emotional facial expressions portrayed by their mother and by female strangers in a community sample of mother–infant dyads. We used event-related potentials (ERPs), a noninvasive neuroimaging modality that is relatively well-tolerated across multiple developmental phases. In this study, we relied on the Negative Central (Nc), a negative-going ERP component that indexes sustained attention toward motivationally salient information (Courchesne et al., 1981; Nelson, 1994; Richards, 2003a, 2003b). The Nc is present shortly after birth (Kurtzberg & Vaughan Jr, 1986), occurs about 400-800 ms after stimulus onset, and is maximal at frontal-central channels (de Haan, 2013). The component is larger for emotional compared to neutral faces (Grossmann et al., 2007; Kobiella et al., 2008; Nelson & de Haan, 1996) and is enhanced when typically developing infants view their mothers' compared with strangers' faces (de Haan & Nelson, 1997; de Haan & Nelson, 1999; Webb et al., 2005).

Studies in infants suggest that the magnitude of the Nc is related to activity in limbic, prefrontal, parietal, and occipital regions (Guy et al., 2016; Reynolds et al., 2010; Reynolds & Richards, 2005), key regions supporting attention to socioemotional content. Importantly, the magnitude of the Nc is related to individual differences in socioemotional processing. For example, there is evidence that the Nc is larger to happy compared with neutral faces of adult strangers in infants of more sensitive mothers (Taylor-Colls & Pasco Fearon, 2015). Additionally, emerging evidence suggests that increased maternal anxiety symptoms are associated with a larger Nc in infants for fearful and happy faces of adult strangers (Bowman et al., 2021). Together, these data suggest that the Nc may be useful in studies investigating the ways in which infants of mothers with elevated symptoms of depression and anxiety attend to emotional faces of their own mother and of female strangers.

To that end, the present study examined associations between postnatal maternal symptoms of depression and anxiety, parenting behaviours, and the Nc in infants as they viewed emotional facial expressions posed by their own mother and by female strangers. We collected postnatal mother-reported symptoms of depression and anxiety and assessed parental behaviour during mother–infant free-play interactions. In terms of parental behaviour, we focus on maternal sensitivity, intrusiveness, and positive regard (i.e., warmth), as well as infant's positive engagement with their mothers, given that these behaviours may have distinct associations with maternal symptoms of depression and anxiety (Dib et al., 2019; Feldman et al., 2009; Granat et al., 2017) and with risk for emotional and social difficulties in offspring (Dietz et al., 2008; McLeod et al., 2007; Steelman et al., 2002). We hypothesized that postnatal maternal symptoms of depression would be associated with a smaller Nc to emotional faces in infants and that this effect would be particularly pronounced for mother compared with stranger faces (Boyd et al., 2006; Diego et al., 2004). In contrast, we expected that postnatal maternal symptoms of anxiety would be associated with a larger Nc to fearful faces in infants and that this association would be stronger for mother compared to stranger faces (Bowman et al., 2021; Creswell et al., 2011; Morales et al., 2017). We further anticipated that these effects might be driven by parenting behaviors. Specifically, we predicted that decreased sensitivity and warmth would be related to a smaller infant Nc to happy faces (Taylor-Colls & Pasco Fearon, 2015), whereas increased intrusiveness would be associated with a larger Nc to fearful faces (Gulley et al., 2014; Pozzi et al., 2020) and that these associations would be stronger for mother compared with stranger faces.

Materials and methods

Participants

Mothers and their infants were recruited from Montreal and the surrounding area using online and print advertisements. To participate, mothers were required to be fluent in English, and their infants had to be between 26 weeks and 31 weeks old. Dyads were included only if the mother was the biological mother and if the infant had not had a major illness or head injury. Based on the results of the screening process, 58 mother–infant dyads were invited to the lab.

In the full sample of 58 mother–infant dyads, mothers were between the ages of 20 and 44 years old (M_{age} = 33.10, *SD* = 4.54), and infants were between the ages of 26 and 31 weeks old (M_{age} = 28.47, *SD* = 1.14; 35 females). Infants had a mean birth weight of 3,499.09 grams (*SD* = 432.51, range = 2,520–4,430) and a mean gestational age of 39.74 weeks (*SD* = 1.24, range = 37–42). Mothers were 74% white, 5% Hispanic, 3% Chinese, 3% South East Asian, 2% South Asian, 2% Native/First Nations/Aboriginal, 2% Arab/West Asian, and 9% indicated that they were another ethnicity/nationality. Finally, the median annual household income of the sample was $100,000–$149,999 (range = <$10,000–$199,999). Mother–infant interaction and maternal symptoms data were available for all mother–infant dyads (*N* = 58).

Of the 58 mother–infant dyads who completed the lab visit, 30 infants (52% of the full sample; 18 females) had usable EEG data. The 28 infants excluded from analyses were excluded for the following reasons: a technical error during EEG recording (*n* = 1), unusable and/or excessive

noise in the reference channels ($n = 2$), fewer than five artifact-free trials at all electrodes in at least one condition ($n = 10$), electrodes with fewer than five artifact-free trials that could not be interpolated because the surrounding channels were missing or had fewer than five artifact-free trials ($n = 10$), and failure to complete the faces tasks due to fussiness and/or fatigue ($n = 5$). This attrition rate (48%) is comparable to prior Nc studies in infants of a similar age as our infant sample (e.g., percentage of infants excluded from the total sample ranges from 46% to 67%; de Haan et al., 2004; Hoehl et al., 2008; Leppänen et al., 2007; Taylor-Colls & Pasco Fearon, 2015). Infants who were excluded from EEG analyses did not significantly differ from those who were included in terms of sex ($\chi^2(1) = 0.00$, $p = 0.96$), age in weeks ($t_{56} = 1.64$, $p = 0.11$), birth weight in grams ($t_{52} = 0.59$, $p = 0.56$), gestational age in weeks ($t_{56} = 0.41$, $p = 0.68$), ethnicity ($\chi^2(7) = 3.68$, $p = 0.82$), annual household income ($\chi^2(11)$, 13.30, $p = .27$), maternal age (t_{56}= 0.61, $p = 0.55$), maternal symptoms of depression and anxiety (ps > 0.05), or mother–infant interaction ratings (ps > 0.05).

Mothers were compensated $75 for their family's participation in the study. All procedures were approved by the McGill University Research Ethics Board.

Procedure

One week before their lab visit, mothers provided electronic, written, informed consent and completed a battery of questionnaires using Qualtrics online survey software (SAP America Inc.). Upon arriving in the lab, mothers provided written, informed consent for themselves and for their infants. Following this, infants' heads were measured, and photos were taken of mothers portraying happy, fearful, and neutral expressions. To elicit happy, fearful, and neutral expressions, mothers were asked to "think about a time when your child smiled at you for the first time or the look on their face when they got excited about something"; "imagine a situation in which your child was not in the place where you left them or think about seeing your baby about to fall out of their crib"; and "please try to keep a neutral face. Think about the face you make when you are about to fall asleep or think about and visualize a cardboard box," respectively. Dyads then completed a 6-minute, video-recorded, "free play" interaction. Dyads were seated on a playmat on the floor with access to age-appropriate toys and were instructed to play as they usually would at home. Video recordings were collected using a computer camera located approximately one meter away from the mother and infant. Infants were then seated on their mothers' lap in a sound-attenuated dark room, and the EEG cap was placed on their heads. EEG was then recorded while infants watched images of their mother's face and stranger faces.

All participants completed multiple computer tasks during the experiment. Other tasks included a resting-state recording while infants watched a video of floating bubbles, as well as an auditory three-stimulus oddball task. Infants completed the resting-state recording first; the order of the faces and oddball tasks were counterbalanced across participants. Data from additional tasks and questionnaires not discussed here will be reported elsewhere (Sandre et al., 2021). Task order as well as a list of all measures included in the study can be found at: https://osf.io/kzpht/?view_only=99086c0054d2402fa8d9853e57017494. Following the EEG tasks, mothers and their infants completed a second 6-minute, video-recorded, "free play" interaction using the same instructions as the first interaction.

Measures

Maternal symptoms

Maternal symptoms of depression and anxiety were measured using the expanded version of the Inventory of Depression and Anxiety Symptoms (IDAS-II; Watson et al., 2012). The IDAS-II is a self-report inventory that consists of 99 items comprising 19 factor-analytically derived scales reflecting distinct dimensions of depression and anxiety symptoms. Symptoms are reported for the past 2 weeks and are rated on a 5-point Likert-type scale ranging from 1 (*not at all*) to 5 (*extremely*). The IDAS-II has shown evidence of good internal consistency, test-retest reliability and convergent and discriminant validity with diagnoses and self-report measures in similar populations (Miller et al., 2017; Mott et al., 2011; Watson et al., 2007). The present study focused on the following IDAS-II subscales: general depression (20 items; range: 20–100, $\alpha = 0.82$), which assesses core emotional and cognitive symptoms of depression, panic (8 items; range: 8–40, $\alpha = 0.74$), and social anxiety (6 items; range: 6–30, $\alpha = 0.86$). These symptoms were selected because they are common during the postpartum period (Miller et al., 2017; Mott et al., 2011; Watson et al., 2007). Two participants had outlying values (>3 *SD*s): one for panic symptoms and one for social anxiety symptoms; these values were winsorized (Blaine, 2018) before analyses.

Mother–infant play interaction

Trained independent coders, who were blind to maternal symptoms, rated mother–infant interactions during two 6-minute, video-recorded, "free play" interactions (1 before and 1 after the EEG assessment) using the infant adaptation of the Parent-Child Interaction Rating Scales (PCIRS-IA; Bosquet Enlow et al., 2014). Videos were rated for maternal sensitivity, intrusiveness, and positive regard (i.e., warmth), as well as infant positive engagement

with the mothers. Ratings were made during each one-minute interval of each "free play" interaction; possible scores ranged from 1 (*not at all characteristic*) to 7 (*very characteristic*), increasing in half-point increments. For final analyses, we computed the mean ratings of sensitivity, intrusiveness, warmth, and infant positive engagement with the mother across all 12 one-minute intervals.

All videos were double coded. Rating discrepancies of more than one point were reviewed and re-rated following consensus between the two independent raters. Rating discrepancies of one point or less were averaged across the two raters. To eliminate a potential source of bias in coding, each video was rated by at least one coder who had not interacted with the mother and baby during their visit. In total, coders made 696 ratings for each mother-infant interaction behaviour across our sample of 58 mother-infant dyads. The total number of times coders' ratings differed by more than one point across the sample was 112 for maternal sensitivity, 129 for maternal intrusiveness, 86 for maternal warmth, and 103 for infant positive engagement with the mothers. Thus, discrepancies between coders of more than one point were infrequent across our mother-infant interaction ratings, indicating that our team of coders demonstrated high agreement with each other.

Visual stimuli

Stimuli consisted of photographs of the infant's mother portraying happy, fearful, and neutral expressions (3 images total, 1 image for each expression), and nine images of adult female actors portraying happy, fearful, and neutral expressions (portrayed by 3 different actors) from the NimStim set (Tottenham et al., 2009). Specific NimStim faces were selected based on apparent racial group. One actor was white, one was Asian, and one was black. The specific NimStim faces used in the study are listed in the Appendix. Faces of mothers and female actors were cropped so only facial expressions were visible, were resized to be 500 pixels high and 400 pixels wide, and were presented against a black background. To control for low-level stimulus effects on infant neural responses, photographs of mother faces were matched to the luminance of actor faces using functions adapted from the SHINE toolbox for MATLAB (Willenbockel et al., 2010). See Fig. S1 in the Supplemental Results for examples of stranger happy, fearful, and neutral face stimuli used in the study. All visual stimuli were presented on an Intel Core i7 computer using Presentation software (Neurobehavioral Systems, Inc.; Albany, CA).

Task

Infants were seated on their mothers' laps while EEG was recorded from infants as they passively viewed fearful, happy, and neutral faces posed by their own mother and by female strangers. Each face stimulus was shown for a duration of 1,000 ms, and images were presented in fully random order. The interstimulus interval varied randomly from 1,000 to 1,500 ms. During the task, an experimenter stood in the recording booth with the mother and infant. The experimenter initiated each trial once she judged that the infant was looking at the screen. The experimenter used the computer mouse to control the progression of the task and recorded when infants attended to or did not attend to the face on the screen. If the infant became fussy and/or did not attend to the screen, the experimenter used a toy to redirect the infant's attention to the screen. When an infant's attention could no longer be redirected to the screen due to fussiness/fatigue, the session was terminated. Breaks in the task occurred after 40 and 80 trials. Throughout the task, mothers were blindfolded with an eye mask to not influence their infant's responses. In total, there were 120 trials; 72 of those trials were stranger faces (24 fearful, 24 happy, and 24 neutral), and the remaining 48 trials were the infant's own mother's faces (16 fearful, 16 happy, and 16 neutral).

Electroencephalogram Data Acquisition and Processing

Continuous electroencephalogram (EEG) was recorded during the task using a 32-electrode BrainVision actiCHamp system (Brain Products, Munich, Germany) with the standard 10/20 layout and a ground electrode a Fpz. Data were recorded with a sampling rate of 1,000 Hz and electrode impedances were kept below approximately 20 kΩ.

Offline analysis was conducted using BrainVision Analyzer software (Brain Products, Munich, Germany). First, continuous (nonsegmented) data were bandpass-filtered with second-order low and high cutoffs of 0.1 and 30 Hz, respectively, using a Butterworth zero phase filter with a 12 dB/octave roll-off. Data were then referenced to an average of the left and right mastoids (TP9 and TP10). The EEG was segmented into 1,200-ms windows separately for mother and stranger fearful, happy, and neutral faces. These segments began 200 ms before stimulus onset and continued for 1,000 ms. Only trials where the infant was attending to the faces were included. The mean number of trials to which the infants attended, as recorded by the experimenter during the task, did not significantly differ between fearful (M = 12.63, *SD* = 2.74), happy (M = 12.87, *SD* = 2.47), and neutral (M = 12.57, *SD* = 2.37) mother faces (*p*s > 0.05). In addition, the mean number of trials to which the infants attended did not significantly differ between fearful (M = 20.33, *SD* = 3.65), happy (M = 19.77, *SD* = 3.36), and neutral (M = 20.07, *SD* = 2.73) stranger faces (*p*s > 0.05).

A semiautomatic procedure was used to detect and reject artifacts related to eye or body movements or loose contacts

(see de Haan et al., 2004 for a similar procedure). The criteria applied were a voltage step of more than 50 μV between sample points, a voltage difference of 200 μV within a trial, and a minimum voltage difference of less than 0.50 μV within 100-ms intervals. These intervals were rejected from individual channels in each trial; remaining artifacts were then manually rejected from individual channels via visual inspection of the data. Faulty recordings at single electrodes were resolved through interpolation using the signal from 3-4 surrounding electrodes. Data were baseline corrected to 200-ms prestimulus onset. Stimulus-locked mother and stranger fearful, happy, and neutral faces were then separately averaged. Consistent with previous work (Kaduk et al., 2016; Krol et al., 2015), infants were required to have at least five artifact-free trials in each condition to be included in the present analyses. For mother faces, infants had an average of 10.40 fearful ($SD = 2.96$, range: 5–16), 11.03 happy ($SD = 3.01$, range: 5–15), and 11.37 neutral ($SD = 2.79$, range: 6–16) artifact-free trial segments. For stranger faces, infants had an average of 16.37 fearful ($SD = 4.77$, range: 5–23), 15.33 happy ($SD = 4.32$, range: 5–22), and 17.00 neutral ($SD = 3.75$, range: 9–22) artifact-free trial segments. The average number of trials included in our condition averages is consistent with previous work on the Nc (e.g., average of 9 to 15 trials per condition; Addabbo et al., 2020; Grossmann et al., 2011; Hill et al., 2021; Hoehl & Striano, 2008; Kaduk et al., 2013). The number of artifact-free trials in each condition was not significantly associated with maternal symptoms or mother-infant interaction ratings, nor were they significantly associated with infants' Nc to their mother's and strangers' faces ($ps > 0.05$). See Fig. S2 in the Supplemental Results for histograms depicting the distribution of mother and stranger fearful, happy, and neutral face trials across the sample ($N = 30$).

Statistical analyses

We empirically isolated the Nc from other overlapping components through temporospatial principal components analyses (PCA). Temporospatial PCA is a data-reduction method that extracts linear combinations of data from all time points and recording sites to delineate patterned electrocortical activity (Dien, 2012; Ethridge et al., 2017; Foti et al., 2009; Weinberg & Hajcak, 2011). This method was used because it improves signal-to-noise ratios by identifying systematic sources of variance, and removing non-systematic sources of variance (e.g., noise; Kayser & Tenke, 2003). The temporal PCA was performed first, followed by a spatial ICA using the ERP PCA Toolkit (v 2.80; Dien, 2010a, 2010b; Dien et al., 2005; Dien et al., 2007) in MATLAB. The temporal PCA used all time points from each participant's average data as variables, and considered participants, trial types, and recording sites as observations. A promax rotation was conducted to rotate the simple structure in the temporal domain using the covariance matrix and Kaiser normalization (Dien, 2010a; Dien et al., 2005, 2007). Following the first rotation, a parallel analysis (Horn, 1965), comparing the scree of the real dataset to the scree from a fully random dataset (Cattell, 1966), was conducted. This analysis suggested the retention of 34 temporal factors (TF).

Following the temporal PCA, a spatial ICA was performed on each temporal factor retained in the previous step. All recording sites were specified as variables, and observations were specified as participants, trial types, and temporal factor scores. Infomax was used to rotate the factors to independence in the spatial domain (Dien, 2010a; Dien et al., 2007). Based on the results of the parallel test (Horn, 1965), two spatial factors (SF) were extracted from each temporal factor. In total, the temporospatial PCA resulted in 68 TF/SF combinations. These factor combinations accounted for 59% of the total variance in the data.

Data exported for each participant then represent the loadings of that participant's data onto the factor combination at the peak channel and time point. To directly assess timing and spatial voltage distributions, we then translated the factors back into voltages (see Dien, 2012; Foti et al., 2011, for more detailed accounts of the methods). A robust analysis of variance (ANOVA; Keselman et al., 2003) was then conducted on every temporospatial PCA factor combination that accounted for greater than 0.5% of variance in the data, to identify the factors that significantly differentiated between face (mother and stranger) and emotion type (fearful, happy, and neutral). Twenty-four factor combinations accounted for more than 0.50% of the variance. The PCA-derived factor Temporal Factor 1, Spatial Factor 1 (TF1SF1) accounted for 8.35% of the total variance and resembled the Nc in both its temporal and spatial distribution. The values extracted from this factor represent the amplitude of the Nc at the peak channel (i.e., FC2) and time-point (i.e., 465-466 ms), and were used in our statistical analyses. In addition, one infant had an outlying value (>3 *SD*s) for the Nc to happy mother faces, and one infant had an outlying value (>3 *SD*s) for the Nc to neutral mother faces. These values were winsorized (Blaine, 2018) prior to analyses in order to preserve power for analysis.

Because few studies have used temporospatial PCA to score the Nc in infants, we also scored the Nc using a conventional time-window scoring approach to facilitate cross-study comparisons. Consistent with prior work and based on visual inspection of grand-averages across the sample, we scored the Nc from 300 to 600 ms at electrode Cz (Bowman et al., 2021; Leppänen et al., 2007; Xie et al., 2019). Descriptive statistics for this scoring are reported in the Supplemental Results (Table S1). Topographic maps depicting voltage across the scalp for mother and stranger face stimuli are presented in Supplemental Results, as are

ERP waveforms at electrode Cz for mother and stranger face stimuli (Fig. S3).

We also examined the internal consistency (split-half reliability) of the time-window scored Nc by calculating the correlation between averages based on odd- and even-numbered trials for each face type condition. These estimates were then corrected using the Spearman-Brown prophecy formula (Nunnally & Bernstein, 1994). Consistent with previous research on the psychometric properties of ERPs (Meyer et al., 2014; Pontifex et al., 2010; Sandre et al., 2021), split-half reliabilities of the Nc fell within low to moderate thresholds for fearful ($r = 0.44$), happy ($r = 0.52$), and neutral ($r = 0.51$) faces portrayed by mothers and fell within moderate thresholds for fearful ($r = 0.56$), happy ($r = 0.57$), and neutral ($r = 0.54$) faces portrayed by strangers. The Nc scored using the temporospatial PCA scoring approach was used in the analyses that follow.

Statistical analyses were conducted using SPSS (Version 28.0; SPSS, Inc.). Pearson's *r* was calculated to examine bivariate associations between maternal symptoms of depression, social anxiety, and panic, mother–infant interaction ratings, and the Nc in infants to mother and stranger fearful, happy, and neutral facial expressions. Next, a two (Face type: mother, stranger) x three (Emotion type: fearful, happy, neutral) repeated-measures ANOVA was conducted for the temporospatial PCA factor corresponding to the Nc. Following this, and to examine the moderating effects of maternal symptoms of depression, panic, and social anxiety on modulation of the Nc, we conducted three (1 for each symptom type) two (Face type: mother, stranger) x three (Emotion type: fearful, happy, neutral) repeated-measures analyses of covariance (ANCOVAs), with face type and emotion as within-subject factors and IDAS scales as continuous predictors. Finally, to examine the moderating effects of maternal sensitivity, intrusiveness, and warmth on modulation of the Nc, we conducted three (1 for each parenting behaviour) two (Face type: mother, stranger) x three (Emotion type: fearful, happy, neutral) repeated-measures ANCOVAs, with face type and emotion as within-subject factors and PCIRS-IA scales as continuous predictors. Effect sizes are expressed as partial-eta squared (η_p^2), calculated using the following formula: $SS_{effect}/(SS_{effect} + SS_{error})$.

Results

Original data from this study including maternal symptoms of depression and anxiety, maternal parenting behaviours, and infants' neural responses to emotional facial expressions portrayed by their mother and by female strangers are available at Mendeley Data (https://doi.org/10.17632/2xzz7sc3vp.1).

Figure 1 displays the PCA-derived grand-averaged stimulus-locked ERPs at FC2 for mother and stranger faces. Topographic maps are also shown, depicting voltage across the scalp for mother and stranger faces in the time window of the Nc. As indicated in Fig. 1, the PCA factor combination corresponding to the Nc represented a relative negative deflection in the ERP waveform that was maximal at frontal-central sites for both mother and stranger faces, consistent with prior work on the Nc (de Haan et al., 2004; Parise et al., 2008; Richards, 2003a, 2003b; Richards et al., 2010; Webb et al., 2005).

Effects of face type and emotion on the Nc

Results of the 2 (Face type: mother, stranger) × 3 (Emotion: fearful, happy, neutral) repeated-measures ANOVA did not reveal statistically significant main effects of face type ($F(1, 29) = 0.03$, $p = 0.87$, $\eta_p^2 = 0.001$) or emotion ($F(2, 58) = 0.41$, $p = 0.66$, $\eta_p^2 = 0.01$). However, there was a statistically significant face type by emotion interaction ($F(2, 58) = 4.89$, $p = 0.01$, $\eta_p^2 = 0.14$).

To decompose this interaction, two three-level (happy, fearful, neutral) repeated measures ANOVAs were conducted, one for faces portrayed by mothers and one for faces portrayed by strangers. When infants viewed their mother's faces, we did not observe a significant main effect of emotion on the Nc ($F(2, 58) = 2.11$, $p = 0.13$, $\eta_p^2 = 0.07$). In contrast, when infants viewed stranger faces, we did observe a significant main effect of emotion on the Nc ($F(2, 58) = 3.01$, $p = 0.05$, $\eta_p^2 = 0.09$), such that the Nc was larger for fearful compared to neutral stranger faces ($t_{29} = 2.33$, $p = 0.03$, 95% CI [−9.07, −0.60]). The Nc did not significantly differ between fearful and happy stranger faces ($t_{29} = 0.34$, $p = 0.74$, 95% CI [−4.45, 3.19]), nor did it significantly differ between happy and neutral stranger faces ($t_{29} = 1.72$, $p = 0.10$, 95% CI [−9.19, 0.80]).

Associations between maternal symptoms, mother–infant interaction ratings, and the Nc

Table 1 shows the means, standard deviations, and bivariate correlations for maternal symptoms of depression, panic, and social anxiety, mother–infant interaction ratings, and the Nc in infants to mother and stranger faces. There was a small to medium negative association between maternal depression symptoms and lower sensitivity and warmth as judged by raters who were blind to mothers' self-reported symptoms. In addition, there was a small to medium negative association between maternal depression symptoms and infant's positive engagement during the mother–child interactions. Symptoms of panic and social anxiety were not significantly associated with experimenter-rated parenting

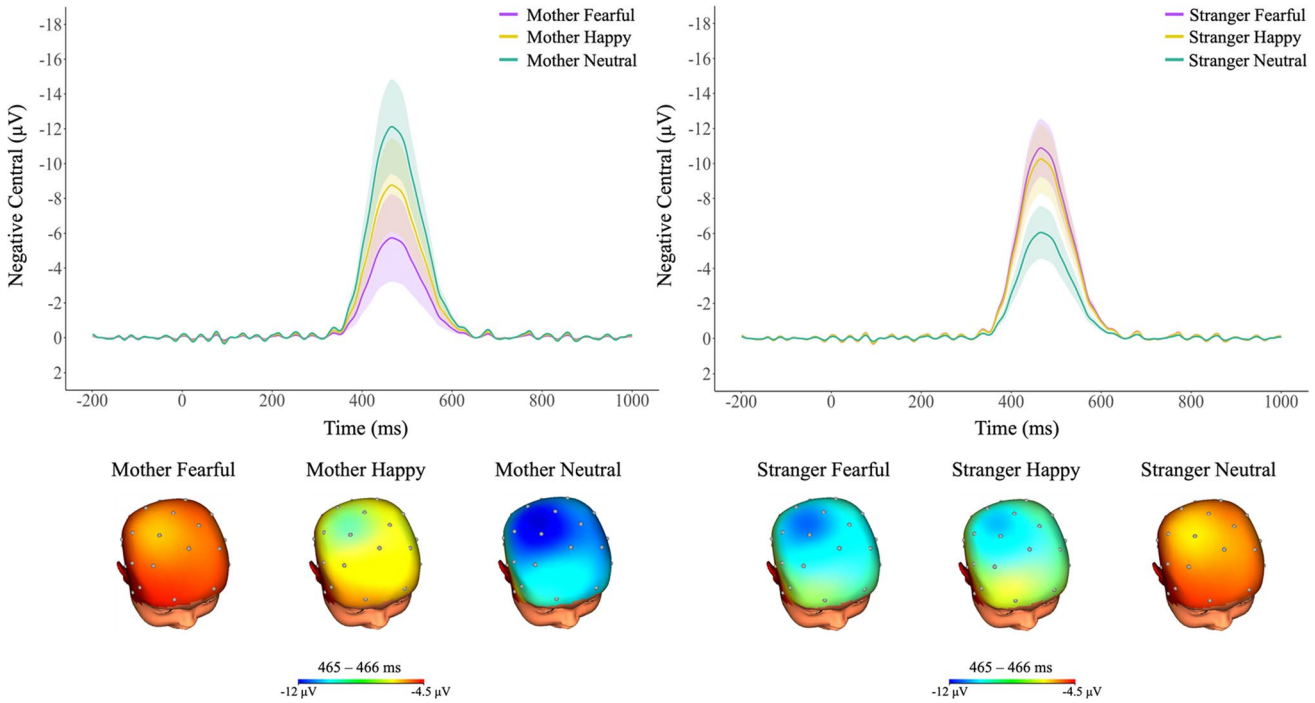

Fig. 1 Waveforms and scalp topographies depicting temporospatial factor combinations corresponding to the Negative Central in infants when they viewed their mother and strangers portraying fearful, happy, and neutral facial expressions. The Negative Central was scored at electrode FC2 between 465 and 466 ms. Shading around waveforms represents standard error of the mean across participants at each timepoint

behaviours, nor were these symptoms related to infant's positive engagement with their mother.

Additionally, infants of mothers reporting greater depression symptoms exhibited a smaller (i.e., less negative) Nc to happy and neutral mother faces, and not stranger faces. In contrast, infants of mothers reporting greater panic symptoms exhibited a larger (i.e., more negative) Nc to fearful mother and stranger faces, although the effect for fearful stranger faces was not statistically significant. The Nc elicited by mother and stranger faces was not significantly associated with mother's sensitivity, warmth, intrusiveness, or infant positive engagement with the mother.

Moderating effects of maternal parenting behaviour and maternal symptoms on the magnitude of the Nc

Maternal sensitivity, intrusiveness, warmth, and social anxiety symptoms did not significantly moderate the effects of face type, emotion type, or their interaction on modulation of the Nc (Table S2 in the Supplemental Results). However, we observed a significant interaction between face type and maternal symptoms of depression, as well as a significant interaction between emotion type and maternal symptoms of panic on modulation of the Nc (Table 2).

To decompose these interactions, bivariate correlations were conducted to examine associations between maternal symptoms of depression and the Nc to mother and stranger faces, collapsing across fearful, happy, and neutral expressions for each face type. Results of these analyses indicated that infants of mothers reporting greater depression symptoms exhibited a significantly smaller Nc to mother faces (r_{28} = 0.45, p = 0.01, 95% CI [0.11, 0.70]) and not to stranger faces (r_{28} = 0.02, p = 0.90, 95% CI [−0.34, 0.38]; Fig. 2). We further tested whether there was a significant difference between these two correlations using procedures for comparing overlapping correlations from the same sample (Williams, 1959) implemented in R (Version 1.2.5033; R Core Team, 2020) and using the *cocor* package (Version 1.1-3; Diedenhofen & Musch, 2015). The magnitude of the association between maternal depression symptoms and infants' Nc to mother faces was significantly larger than the magnitude of the association between maternal depression symptoms and infants' Nc to strangers faces (t_{27} = 2.94, p = 0.01, 95% CI [0.11, 0.72]).

Subsequently, we examined associations between maternal symptoms of panic and the Nc to fearful, happy, and neutral faces, collapsing across face type for each emotion. Infants of mothers reporting greater panic symptoms exhibited a significantly larger Nc to fearful faces (r_{28} = −0.38, p = 0.04, 95% CI [−0.65, -0.03]), and not to happy (r_{28} = −0.13, p = 0.49, 95% CI [−0.47, 0.24]) or to neutral faces (r_{28} = 0.14, p = 0.47, 95% CI −0.24, 0.47]; Fig. 2). The

Table 1 Descriptive statistics and bivariate correlations for maternal symptoms of depression, panic, and social anxiety, mother–infant interaction ratings, and the Negative Central (Nc) in infants to mother and stranger faces

	1	2	3	4	5	6	7	8	9	10	11	12	Mean	SD
1. Maternal Depression Symptoms	--												38.55	10.09
2. Maternal Panic Symptoms	0.45** [0.22, 0.64]	--											9.53	2.22
3. Maternal Social Anxiety Symptoms	0.55** [0.34, 0.71]	0.45** [0.22, 0.63]	--										8.88	3.68
4. Maternal Sensitivity	-0.27* [-0.49, -0.01]	0.08 [−0.18, 0.33]	0.00 [−0.26, 0.26]	--									4.68	0.79
5. Maternal Intrusiveness	-0.10 [-0.35, 0.17]	−0.15 [−0.40, 0.11]	−0.18 [−0.42, 0.09]	−0.62** [−0.76, −0.43]	--								1.82	0.73
6. Maternal Warmth	−0.33* [−0.54, −0.08]	0.10 [−0.17, 0.35]	−0.05 [−0.30, 0.22]	0.76** [0.63, 0.85]	−0.10 [−0.35, 0.17]	--							4.97	0.75
7. Infant Positive Engagement with Mother	−0.29* [−0.51, −0.04]	−0.15 [−0.39, 0.12]	−0.08 [−0.33, 0.18]	0.47** [0.25, 0.65]	−0.06 [−0.31, 0.21]	0.56** [0.36, 0.72]	--						3.71	0.57
8. Nc Mother Fear (μV)	0.20 [-0.17, 0.52]	−0.41* [−0.67, −0.06]	0.17 −0.21, 0.50]	0.01 [−0.35, 0.37]	−0.33 [−0.61, 0.04]	−0.23 [−0.55, 0.14]	0.04 [−0.33, 0.39]	--					−5.73	13.75
9. Nc Mother Happy (μV)	0.37* [0.01, 0.64]	−0.04 [−0.39, 0.33]	0.01 [−0.35, 0.37]	0.05 [−0.31, 0.41]	0.01 [−0.35, 0.37]	0.08 [−0.29, 0.43]	−0.07 [−0.42, 0.29]	0.33 [−0.03, 0.62]	--				−9.51	12.96
10. Nc Mother Neutral (μV)	0.46* [0.12, 0.70]	0.07 [−0.30, 0.42]	0.21 [−0.16, 0.53]	−0.33 [−0.61, 0.04]	−0.09 [−0.44, 0.28]	−0.35 [−0.63, 0.01]	−0.48** [−0.72, −0.15]	0.40* [0.05, 0.66]	0.29 [−0.07, 0.59]	--			−11.25	12.61

Table 1 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12	Mean	SD
11. Nc Stranger Fear (μV)	0.05 [−0.32, 0.40]	−0.26 [−0.57, 0.11]	0.29 [−0.08, 0.59]	−0.16 [−0.50, 0.21]	−0.09 [−0.44, 0.28]	−0.31 [−0.60, 0.06]	−0.18 [−0.51, 0.19]	0.66** [0.40, 0.83]	0.09 [−0.28, 0.44]	0.36 [0.00, 0.64]	--		−10.89	9.09
12. Nc Stranger Happy (μV)	−0.05 [−0.40, 0.32]	−0.17 [−0.50, 0.20]	0.08 [−0.29, 0.43]	−0.11 [−0.45, 0.26]	−0.03 [−0.39, 0.33]	−0.21 [−0.53, 0.17]	0.11 [−0.26, 0.46]	0.59** [0.29, 0.78]	0.12 [−0.25, 0.46]	0.10 [−0.27, 0.45]	0.48** [0.15, 0.72]	--	−10.26	10.80
13. Nc Stranger Neutral (μV)	0.08 [−0.29, 0.42]	0.18 [−0.20, 0.51]	−0.02 [−0.38, 0.34]	0.02 [−0.34, 0.38]	−0.33 [−0.62, 0.03]	−0.06 [−0.41, 0.31]	−0.15 [−0.48, 0.23]	0.24 [−0.13, 0.56]	0.33 [−0.03, 0.62]	0.31 [−0.05, 0.61]	0.14 [−0.23, 0.48]	0.03 [−0.33, 0.39]	−6.06	8.23

Above statistics include the full sample ($N = 58$) except for the Nc analyses ($N = 30$). Values in square brackets indicate the 95% confidence interval for each correlation. *SD* = standard deviation; $^{*}p < 0.05$; $^{**}p < 0.01$

Table 2 F ratios, degrees of freedom, and effect sizes for the analyses of covariance examining the moderating effects of maternal depression (model 1) and panic symptoms (model 2) on the Negative Central in infants to mother and stranger fearful, happy, and neutral faces

	F	*df*	η_p^2
Model 1			
Face type	10.71**	1, 28	0.28
Emotion	0.40	2, 56	0.01
Depression symptoms	2.98	1, 28	0.10
Face type × emotion	1.16	2, 56	0.04
Face type × depression symptoms	11.46**	1, 28	0.29
Emotion × depression symptoms	0.40	2, 56	0.01
Face type × emotion × depression symptoms	0.48	2, 56	0.02
Model 2			
Face type	0.33	1, 28	0.01
Emotion	4.35*	2, 56	0.13
Panic symptoms	0.95	1, 28	0.03
Face type × emotion	1.55	2, 56	0.05
Face type × panic symptoms	0.30	1, 28	0.01
Emotion × panic symptoms	4.35*	2, 56	0.13
Face type × emotion × panic symptoms	0.93	2, 56	0.03

$^{*}p < 0.05$; $^{**}p < 0.01$

magnitude of the association between maternal panic symptoms and infants' Nc to fearful faces was significantly larger than the magnitude of the association between maternal panic symptoms and infants' Nc to neutral faces ($t_{27} = 2.90$, $p = 0.01$, 95% CI [−0.85, −0.13]). We did not observe significant differences in the magnitude of associations between maternal panic symptoms and infants' Nc to fearful and to happy faces ($t_{27} = 1.49$, $p = 0.15$, 95% CI [−0.57, 0.09]), nor between maternal panic symptoms and infants' Nc to happy and to neutral faces ($t_{27} = 1.23$, $p = 0.23$, 95% CI [−0.16, 0.66]).

Discussion

The present study examined whether maternal symptoms of depression and anxiety and parenting behaviours during the postpartum period were associated with infants' neural responses to emotional facial expressions portrayed by their mother and by female strangers. We found that mothers with higher levels of depression symptoms were rated by coders as less sensitive and warm, and their infants exhibited decreased positive engagement with the mothers, supporting the notion that maternal depression symptoms are associated with disruptions in affective exchanges between mothers and their infants (Goodman, 2007; Lovejoy et al., 2000). Moreover, infants of mothers with increased depression symptoms showed a smaller Nc to their mothers' faces, whereas infants

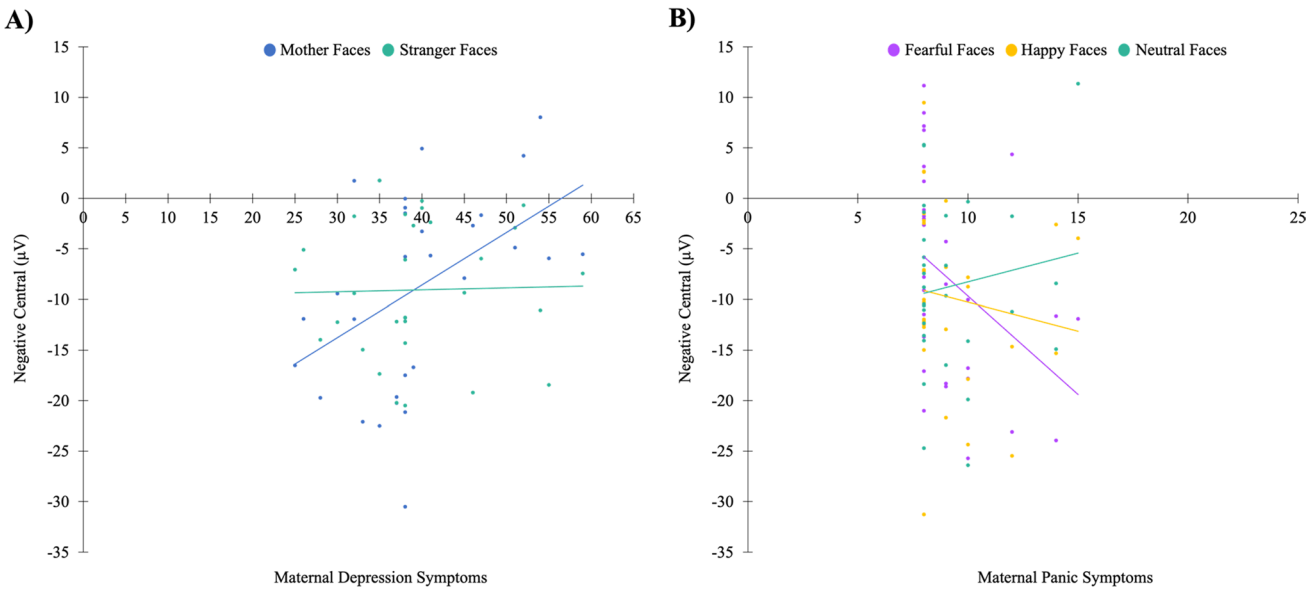

Fig. 2 **a** Scatter plot depicting associations between maternal symptoms of depression and the Negative Central in infants when they viewed their mother's and strangers faces. **b** Scatter plot depicting associations between maternal symptoms of panic and the Negative Central in infants when they viewed fearful, happy, and neutral faces. Negative Central (Nc) was scored at electrode FC2 between 465 and 466 ms. Because the Nc is a negative-going component, a smaller Nc is more positive

of mothers with increased symptoms of panic exhibited a larger Nc to fearful facial expressions posed by both their own mother and by female strangers. These data suggest that postnatal maternal symptoms of depression and anxiety have distinct effects on infants' neural responses to parent and stranger displays of emotion.

These results are consistent with theories which posit that mothers' symptoms of depression and anxiety may influence the functioning of neural systems that support attention to socioemotional information in infancy (Aktar & Bögels, 2017; Bowman et al., 2021; Porto et al., 2016) and extends prior behavioural work by using a direct measure of neural response in infants (Creswell et al., 2011; Diego et al., 2004; Forssman et al., 2014; Kataja et al., 2020; Morales et al., 2017). Moreover, our findings suggest that maternal symptoms of depression and anxiety are associated with specific abnormalities in the neural correlates of infants' attention to mother and/or stranger facial expressions, and these abnormalities may predispose infants to enduring social and emotional difficulties. In particular, among infants of more depressed mothers, we observed a blunted Nc to their mother's, but not to stranger faces, suggesting that exposure to maternal depression symptoms may specifically diminish infants' processing of mothers' facial expressions. Attending less to mothers' facial expressions may offer infants fewer opportunities to experience and learn from socioemotional cues, which could impair the development of downstream socioemotional abilities, including difficulties recognizing, responding to and regulating emotions, and might contribute to social disengagement and withdrawal (Apter-Levi et al., 2016; Feldman et al., 2009; Goodman & Tully, 2006; Joormann et al., 2010; Silk et al., 2006).

Conversely, among infants of mothers with increased panic symptoms, we found an enhanced Nc to both mothers' and strangers' fearful faces, suggesting that exposure to maternal symptoms of panic and physiological hyperarousal may specifically enhance infants' vigilance for and attention to aversive social signals. Increased attention to aversive faces may contribute to threat-related biases in developing socioemotional processes, such as misinterpreting innocuous social signals as threatening, and might heighten fearfulness and behavioural inhibition in novel and ambiguous social contexts (Aktar et al., 2014; Murray et al., 2008; Rosenbaum et al., 1988; Waters et al., 2008). However, future longitudinal work is needed to examine whether individual differences in the magnitude of the Nc to mother and/or stranger facial affect predicts emotional and social difficulties in infancy and beyond.

Importantly, our results are consistent with prior work in children, youth, and adults, suggesting that diminished processing of socioemotional information is a vulnerability marker for depression (Grunewald et al., 2019; Kujawa et al., 2011; Weinberg et al., 2016), whereas enhanced processing of aversive content is a vulnerability marker for anxiety (Kujawa et al., 2015; Moser et al., 2008; Nelson et al., 2015; Thomas et al., 2001). The present study extends this work by demonstrating that these patterns of neural response to socioemotional information are evident in infants at familial

risk for depression and anxiety, suggesting that these neural responses may be early life markers of risk for depression and anxiety that are observable long before the age of greatest risk for these disorders (Kessler et al., 2007). Use of neural markers may be particularly important given that subtle alterations in neural response to socioemotional information may not be observable with behavioural indices (MacNamara et al., 2013; Santerre & Allen, 2007; Weinberg & Sandre, 2018), and because identification of neural risk markers for depression and anxiety in infancy offers a larger window for early intervention or prevention.

Interestingly, mother's symptoms of depression and panic, but not her behaviour toward her infant, were significantly associated with infants' neural responses. One possibility is that our small infant sample did not provide adequate power to detect these effects. However, it is also the case that the parenting behaviours that we captured in the lab are not representative of all parenting behaviours, including more subtle and dynamic mother–infant interactions that may exert a stronger influence on neural indices of attention (e.g., reciprocal smiling; Leclère et al., 2014). In addition, the mother-infant interactions that we observed in the lab may not generalize to less artificial or more naturalistic settings. Nevertheless, we did observe significant associations between mothers' self-reported symptoms and parenting behaviours, suggesting that our ratings were capturing important sources of variance in parenting behaviours. Future research may therefore consider employing measures that tap more fine-grained parenting behaviours and in natural settings. Because maternal depression and anxiety are associated with other environmental factors that may compromise the postnatal environment beyond parenting (e.g., stress, marital conflict, poverty; Adrian & Hammen, 1993; Dawson et al., 2003; Gamliel et al., 2018; Goodman, 2007; Goodman & Gotlib, 1999; Wheatcroft & Creswell, 2007), future work would also benefit from simultaneously examining these inter-related factors and their independent or interactive effects on socioemotional processing in infancy (King et al., 2019; Salo et al., 2021).

Another possible interpretation of our data is that risk for depression and anxiety is transmitted from mother to child through blunted neural responses to socioemotional content and enhanced neural responses to aversive information (Ethridge et al., 2021; Freeman et al., 2022), respectively. Because we did not collect neural data from the mothers in our sample, our data are ill-suited to test this question. Transmission of depression and anxiety risk involves multiple complex pathways, involving genetic and environmental factors and/or their interaction, that are dynamic across development (Creswell & Waite, 2015; Ethridge et al., 2021; Gotlib et al., 2020). Indeed, neural responses to socioemotional information, including facial affect, are subject to both genetic and environmental influences (Anokhin et al., 2010; Javanbakht et al., 2015; Shackman et al., 2007; Weinberg et al., 2014), and it is possible that this biological liability (e.g., abnormal neural responses to socioemotional information) may lead to difficulty adapting to stressful environments, thereby heightening risk for depression and anxiety at different developmental stages (Dickey et al., 2021; Levinson et al., 2018; Sandre et al., 2019). Future research is needed to clarify if and how neural responses to facial affect might be transmitted from mother to child, and whether individual differences in these neural responses interact with the environment to enhance risk for depression and anxiety across development.

Strengths of the present study include the simultaneous examination of postnatal maternal symptoms of depression and anxiety as well as the use of observational measures of parenting, which may provide a more objective assessment of parenting that is not subject to some of the limitations of self-report measures (e.g., recall bias, desirability effects; Bornstein & Toole, 2010; Morsbach & Prinz, 2006). Additionally, the current study included emotional faces posed by the infants' own mother as stimuli, which may be more salient and ecologically valid socioemotional cues for infants compared to stranger faces. Finally, by capitalizing on the strengths of EEG, the current study extends prior behavioural work by using neural measures of attention to facial affect in infants at familial risk for depression and anxiety, providing new evidence that potential neural markers of depression and anxiety risk can be observed very early in development.

Aside from these strengths, the current study has several limitations that inform directions for future research. First, our sample size is relatively small, and so the present study cannot firmly establish the magnitude of effects for the within-subject analyses and between-subject associations we observed. Although our sample size is comparable to the sample sizes reported in many previous studies that have used the Nc as a within- and between-subject measure of socioemotional processing (de Haan et al., 2004; Hill et al., 2021; Hoehl et al., 2008; Hoehl & Striano, 2010; Krol et al., 2015; Leppänen et al., 2007; Peltola et al., 2009; Taylor-Colls & Pasco Fearon, 2015), our results are preliminary, and require replication using larger samples of mother-infant dyads.

Second, our faces task included a greater number of mother face trials compared to individual stranger face trials (i.e., 16 mother fearful trials vs. 8 fearful trials by each of the 3 female actors), meaning that each mother face stimulus was more frequent than each stranger face stimulus. Furthermore, the Nc appears to be more strongly modulated by stimulus salience and familiarity than probability (de Haan & Nelson, 1997; de Haan & Nelson, 1999; Nelson & Collins, 1991, 1992). In our study, therefore, mother faces were more salient, familiar, and probable than stranger faces, and so we might expect that mother faces would elicit a larger Nc in infants. Offsetting this concern somewhat is the fact that, in this study, stranger faces elicited a larger Nc than mother faces. Moreover, infants of mothers with increased depression symptoms demonstrated a *smaller* Nc to their mothers' but not strangers'

faces, suggesting that differences in presentation probabilities for mother and stranger face stimuli likely do not account for our results. However, it is also the case that our task included fewer mother trials than total stranger trials; thus, the signal-to-noise ratios may differ between these two conditions. For all of these reasons, future investigations should consider equating parent and stranger face stimulus frequency in infant ERP tasks without necessarily adding more trials to these tasks to reduce the potential for data loss (Hoehl & Wahl, 2012; Sandre et al., 2021). It is worth noting that even if these tasks include an equal number of mother and stranger face stimuli, the Nc may still be influenced by differences in stimulus familiarity and frequency (de Haan, 2013).

Third, there is some evidence that mothers with internalizing symptoms produce less intense facial expressions of emotion (Melfsen et al., 2000; Shackman et al., 2010), and so it is possible that infants of mothers with increased depression symptoms attended less to their mother's emotional expressions because these expressions were less affective or more neutral in nature. Consistent with this possibility, we observed a significant moderating effect of maternal depression symptoms on modulation of the Nc in infants to their own mother's faces, and not to strangers' faces. However, in our study, maternal symptoms of depression were also associated with a smaller infant Nc to mothers' *neutral* expressions, suggesting that decreased emotional expressivity in the mothers would not entirely explain the effects we observed. An important direction for future research will be to examine whether the affective intensity and accuracy of posed facial expressions differs between parents with and without internalizing symptoms, and if these differences influence infants' neural responses.

Fourth, our study used a relatively low trial cut-off for data inclusion (i.e., at least 5 artifact-free trials), which may impact the internal consistency reliability of the Nc and, consequently, the strength of the within- and between-subjects associations we observed (for further discussion, see Hajcak et al., 2017). We selected a five-trial cutoff to retain as many infants as possible in our analyses, and the average number of trials included in each condition across the sample ranged from 10 to 17, consistent with previous research (Grossmann et al., 2011; Hoehl & Striano, 2008; Leppänen et al., 2007). Using this cutoff, internal consistency (split-half) estimates of the Nc generally fell within moderate thresholds across mother's and strangers' faces, and these estimates are similar to some of those reported in other infant samples (e.g., rs = −0.04 to 0.53, Hill et al., 2021; rs = −0.40 to 0.71, Munsters et al., 2019). Prior work examining the Nc has used a wide range of trial cutoffs for data inclusion, ranging from 3 to 15 trials (Cicchetti & Curtis, 2005; de Haan et al., 2004; Kayhan et al., 2019; Missana et al., 2014; Taylor-Colls & Pasco Fearon, 2015), and these cutoffs are generally lower than those used in adult samples. These lower trial cutoffs are likely because infant ERP data include more noise and artifacts due to fussiness, fatigue, and movement, all of which can contribute to substantial data loss, as well as lower trial cutoffs for data inclusion (DeBoer et al., 2005; Hoehl & Wahl, 2012; Stets et al., 2012). Furthermore, to our knowledge, few studies have examined the number of trials needed to obtain a reliable Nc in infancy. Moving forward, future research will be needed to establish the number of trials required to obtain a reliable Nc as this will help to inform considerations about the selection of trial cutoffs for data inclusion. This work also will be necessary to support the Nc as a reliable and robust early life marker of risk for depression and anxiety in research and applied settings (Hill et al., 2021; Munsters et al., 2019; Shankman et al., 2020).

Fifth, maternal symptoms of depression and anxiety show high continuity across the prenatal and postnatal periods (Heron et al., 2004), making it difficult to determine whether the effects we observed in infants are due to prenatal or postnatal symptoms, or some combination of the two. Future longitudinal work in larger samples with dense sampling of maternal symptoms across the perinatal period will be needed to untangle the unique and/or interactive effects of prenatal and postnatal depression and anxiety symptoms on infants' neural responses to facial affect.

Sixth, the current study focused on postnatal maternal symptoms of panic and social anxiety given that these symptoms are common during the postpartum period (Fawcett et al., 2019; Goodman et al., 2016; Watson et al., 2007), and because prior work suggests that these symptoms are associated with distinct maternal parenting behaviours (Feldman et al., 2009; Murray et al., 2007; Warren et al., 2003) and risk for social and emotional difficulties in offspring (Kaitz et al., 2010; Murray et al., 2008; Schneider et al., 2002). Nonetheless, it is unclear whether the results we observed generalize to other types of anxiety symptoms that may be common during the postpartum period, such as generalized anxiety symptoms as well as postnatal-specific anxieties (e.g., anxiety about motherhood and parenting, as well as anxiety related to infant health and wellbeing; Dennis et al., 2017; Fallon et al., 2016; Ross & McLean, 2006). Moving forward, future research may consider incorporating measures that examine a broader range of anxiety symptoms, including postnatal-specific anxiety symptoms (Fallon et al., 2016) and to examine their associations with maternal parenting behaviours and infant neural responses.

Seventh, because maternal symptoms of depression and anxiety are more strongly related to depression and anxiety in offspring than paternal symptoms (Connell & Goodman, 2002), the current study focused only on mothers. Nonetheless, symptoms of depression and anxiety in fathers are also related to these symptoms in offspring (Dierker et al., 1999; Klein et al., 2005). Future studies also should examine associations between paternal depression and anxiety and infants' neural responses to facial affect.

Conclusions

The present study demonstrates that postnatal maternal symptoms of depression and panic show distinct associations with the magnitude of infants' Nc to their own mothers' and/or strangers' displays of emotion and provides new evidence for possible avenues of risk for depression and anxiety very early in development. These data also underscore the fact that, to identify viable neural markers of risk for internalizing psychopathologies, simultaneous examination of both parent depression and anxiety symptoms and associated parenting behaviours as well as the use of developmentally relevant stimuli (e.g., parent faces) are needed. Moving forward, it will be important not only to understand how neural vulnerabilities are passed from parent to child, but also to determine for whom, when in development, and under what environmental conditions these vulnerabilities are inherited (Gotlib et al., 2020). This work may better guide the development and implementation of interventions that target these vulnerabilities when it is most effective to do so, which ultimately may help us to interrupt the intergenerational transmission of depression and anxiety.

Appendix

Stranger faces used in the study:
01F_FE_C, 01F_HA_C, 01F_NE_C, 17F_FE_C, 17F_HA_C, 17F_NE_C, 11F_FE_C, 11F_HA_C, 11F_NE_C

Supplementary Information The online version contains supplementary material available at https://doi.org/10.3758/s13415-022-01022-y.

Authors' contributions AS and AW developed the study concept. AS, CF, and HR completed data collection and behavioural coding. AS completed data analysis, conducted the literature review, and drafted the manuscript. AW, CF, HR, and KLH edited the manuscript. All authors provided revisions and approved the final version of the manuscript for submission.

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Data availability The data that support the findings of this study are openly available in Mendeley Data at https://doi.org/10.17632/2xzz7sc3vp.1.

Code availability Code can be made available upon request.

Declarations

Conflicts of interest The authors have no conflicts of interest to declare.

Ethics approval This study was approved by the McGill University Research Ethics Board (Ethics approval number: 1-0617).

Consent to participate Mothers provided written informed consent for themselves and for their infant.

Consent for publication Mothers signed informed consent regarding publishing their data and their infant's data.

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Open practices statement The data for the experiment are openly available in Mendeley Data at https://doi.org/10.17632/2xzz7sc3vp.1. A list of all measures included in the experiment can be found at https://osf.io/kzpht/?view_only=99086c0054d2402fa8d9853e57017494. The experiment was not preregistered.