Distribution Agreement

In presenting this thesis as a partial fulfillment of the requirements for a degree from Emory University, I hereby grant to Emory University and its agents the non-exclusive license to archive, make accessible, and display my thesis in whole or in part in all forms of media, now or hereafter now, including display on the World Wide Web. I understand that I may select some access restrictions as part of the online submission of this thesis. I retain all ownership rights to the copyright of the thesis. I also retain the right to use in future works (such as articles or books) all or part of this thesis.

Binhong Huang April 2, 2019

Associations Between Maternal Affect, Infant Gaze Aversion and EEG Asymmetry in Infants of Mothers at Risk for Perinatal Depression

by

Binhong Huang

Dr. Sherryl H. Goodman
Adviser

Department of Psychology

Dr. Sherryl H. Goodman

Adviser

Dr. Patricia A. Brennan

Committee Member

Dr. James Rilling

Committee Member

2019

Associations Between Maternal Affect, Infant Gaze Aversion and EEG Asymmetry in Infants of Mothers at Risk for Perinatal Depression

By

Binhong Huang

Dr. Sherryl H. Goodman

Adviser

An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
of the requirements of the degree of
Bachelor of Arts with Honors

Department of Psychology

2019

Abstract

Associations Between Maternal Affect, Infant Gaze Aversion and EEG Asymmetry in Infants of Mothers at Risk for Perinatal Depression
By Binhong Huang

With researchers interpreting infants' gaze aversion as an emotion regulation strategy, we examined the association between maternal affect and infant gaze aversion to gain a better understanding of the development of emotion regulation. We hypothesized that infants were more likely to gaze away when the mothers showed flat or sad affect than positive affect. Additionally, because depression in mothers has been shown to be associated with a variety of adverse effects on children and infants' attentional biases to affective stimuli, we sampled mothers at elevated risk for perinatal depression and examined the association between postpartum depression in mothers and infant gaze aversion at 3- and 6-months of age. We hypothesized that mothers' depressive symptoms would be correlated to infant gaze aversion during mothers' flat or sad affect, and that the strength of such association would be stronger in the 6-month data than the 3-month data. Moreover, in order to further understand infant gaze aversion to mothers' emotion expressions, we also examined infants' EEG frontal asymmetry to infer their emotional valences. We hypothesized that there would be a positive association between infant gaze aversion and relative right frontal EEG asymmetry, and that depression in mothers would be a moderator in this relationship. The results showed that relative to mothers' positive affect, infants were significantly more likely to gaze away during mothers' flat affect, and significantly less likely to gaze away during mothers' sad affect. And mothers' depressive symptom levels were not significantly associated with infant gaze aversion during either mothers' flat or sad affect at either 3- or 6-months. In the 3-month group, EEG asymmetry was significantly correlated to infant gaze aversion during mothers' flat and sad affect combined, and flat affect alone, albeit not significant at 6-months. There was no significant association between EEG asymmetry and infant gaze aversion during mothers' sad affect at either time-point. And depression in mothers did not significantly moderate the relationship between EEG asymmetry and infant gaze aversion. Limitations, strengths and important future steps are discussed.

Associations Between Maternal Affect, Infant Gaze Aversion and EEG Asymmetry in Infants of Mothers at Risk for Perinatal Depression

By

Binhong Huang

Dr. Sherryl H. Goodman

Adviser

A thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
of the requirements of the degree of
Bachelor of Arts with Honors

Department of Psychology

2019

Acknowledgements

I would like to thank Dr. Sherryl Goodman and Meeka Maier for their support and guidance throughout this project. I would also like to thank Dr. Patricia Brennan and Dr. James Rilling for being a part of my committee. And I would like to thank Dr. Brandon Gibb for giving us feedback on an earlier draft. This research was supported by 1 P50 MH077928-01A1, Perinatal Stress and Gene Influences: Pathways to Infant Vulnerability.

Table of Contents

Associations Between Maternal Affect, Infant Gaze Aversion and EEG Asymmetry in Infants of Mothers at Risk for Perinatal Depression

Researchers have well documented that depression in mothers has a variety of adverse effects on children. Compared with offspring of non-depressed mothers, children of depressed mothers are at heightened risk for emotional and behavioral problems, as well as general psychopathology (as meta-analytically reviewed by Goodman et al., 2011). Moreover, researchers have found that problems associated with depression in mothers emerge in infancy (Goodman, 2015), and that the associations between depression in mothers and children's internalizing and externalizing problems, general psychopathology, and negative affect/behavior were all stronger when the mean age of children studied was younger (Goodman et al., 2011). In order to better understand the risks for development of psychopathology among infants of depressed mothers, some researchers have turned their attention to an effort to understand facial affective processing among infants of depressed mothers, consistent with knowledge of its importance to social development and emotion (Bistricky, Ingram, & Atchley, 2011).

One of the early tasks of infants is to process their caregivers' facial affect. The emotions expressed by caregivers are of fundamental significance to the infants' emotional states and behaviors (Tronick, 2003). The first step in infants' learning to process their caregivers' affect is to direct their gaze toward the mother's face. By around 3 months of age, infants are able to recognize faces, they preferentially attend to faces relative to other stimuli (Morton & Johnson, 1991), and they begin to be able to differentiate between facial expressions of emotion (Barrera & Maurer, 1981).

Another early task in infancy is to regulate emotions. Emotion regulation refers to the internal and external processes involved in the surveillance, evaluation, and modification of

affective responses (Cole, Martin, & Dennis, 2004). Although initially dependent on caregivers for emotion regulation, through interactions with caregivers, infants learn and shape their emotion regulation strategies. Moreover, because emotion regulation strategies learned in childhood are carried over into adulthood (Repetti, Taylor, & Seeman, 2002), suboptimal emotion regulation strategies might impose a vulnerability to the later development of internalizing problems.

In parallel with the emerging ability to visually attend to and explore faces at around 3 months of age, infants begin to be able to shift their gaze away from a stimulus (Hitzert et al., 2015). Gazing away is one of the earliest developing approaches to self-regulation in relation to external stimuli (Granat, Gadassi, Gilboa-Schechtman, & Feldman, 2017; Væver, Krogh, Smith-Nielsen, Christensen, & Tharner, 2015). It is also among the emotion-regulatory processes that Gross (1998) identified with regard to adults. Attention deployment, broadly speaking, is a strategy to change attentional focuses away from the immediate situation, for instance, shifts in gaze from the emotion-evoking stimulus (Gross, 1998). Although researchers often interpret gaze avoidance as an emotion regulation strategy (Bistricky et al., 2011), caution is warranted in that gaze aversion is likely to be an automatic process, which is subsequently negatively reinforced when it effectively regulates emotion.

During face-to-face interactions, infants show gaze aversion, as well as negative affect, when their mothers are instructed to suddenly be unresponsive, or still-faced (Adamson & Frick, 2003), and when their mothers show sad affect (Termine & Izard, 1988). These findings are particularly concerning because researchers have found maternal emotional unavailability, such as is studied in the still-face paradigm, and sad facial affect to be associated with depression in mothers. Depression in mothers is associated with disturbances in mother-infant interactions,

which could lead to suboptimal emotional regulation strategies in infants and the later development of psychopathology (Goodman & Gotlib, 1999). Based on a meta-analytic review of 46 observational studies (Lovejoy, Graczyk, O'Hare, & Neuman, 2000), depression in mothers was significantly associated with emotional unavailability or disengagement, with moderate effect size, and with mothers' higher negative and lower positive affect and behavior, with moderate and small effect sizes respectively; the latter association, in particular, was stronger in infancy relative to toddlerhood and preschool age.

There is some evidence that depression in mothers is associated with biases in 3- to 6-month old infants' attention, whether hypervigilance or avoidance of attention to certain facial affective stimuli. However, the specific form of these attentional biases remains unclear. For example, one study found that infants of mothers with elevated depression symptom levels, compared to a non-depressed control group, showed greater gaze aversion in general, regardless of maternal affect during mother-infant interactions (Boyd, Diamond, & Bourjolly, 2006). In contrast to this general gaze aversion, others found patterns of gaze aversion in infants of depressed mothers to vary depending on the specific affect expressed by the mothers, i.e. sad, flat/withdrawn, or positive affect. With regard to sad affect, relative to offspring of non-depressed mothers, infants of depressed mothers showed greater gaze avoidance (less time looking) to both their mothers' mock sad faces (mothers were instructed to display exaggerated sad facial expressions in a series of 15-s trials) (Diego et al., 2004) and sad face/voice stimuli (Field, Pickens, Fox, Gonzalez, & Nawrocki, 1998). In contrast, with regard to mothers' withdrawn/flat affect, typically studied with the Still-Face paradigm (Cohn & Tronick, 1983) in which mothers are instructed to be expressionless, two studies found that depression in mothers was associated with less gaze aversion in 4-month-old infants, albeit not in 2- or 6-month olds

(Moore, Cohn, & Campbell, 2001), as well as other distressed behaviors (Field et al., 2007). Finally, with regard to mothers' positive affect, researchers have found depression in mothers to be associated with infants' preferential attention to happy faces. When presented with happy facial expressions, infants of symptomatic mothers tended to look longer and needed longer time to habituate than those of non-depressed mothers (Hernandez-Reif, Field, Diego, Vera, & Pickens, 2006) and greater severity of maternal depressive symptoms was correlated with infants' longer duration of looking when their mothers were smiling (Striano, Brennan, & Vanman, 2002). Possible explanations for these different patterns include the extent to which the mothers' emotion expressions are aversive or novel to the infants, with more gaze aversion likely associated with both.

Although shifting attention away from a negative emotion-eliciting visual stimuli may aid regulation of negative emotion in the moment, attentional biases to facial affect stimuli might lead to problems with emotion regulation later in life, given that early facial affect attunements help shape the development of emotion regulation (Bistricky et al., 2011). Indeed, researchers studying children beyond infancy have shown that attentional avoidance of sad facial affective stimuli might have long-term consequences. Gibb, Uhrlass, Grassia, Benas, and McGeary (2009) found that attentional avoidance of sad faces interacts with 5-HTTLPR genotype, a genetic risk factors for depression, to increase children's depressive reactions to maternal depression. Furthermore, compared to never-depressed children, currently depressed children were found to exhibit attentional avoidance of sad facial stimuli and preferential attention to happy facial stimuli, which is consistent with findings on infants with depressed mothers (Harrison & Gibb, 2015). Given the functional significance of infant gaze aversion, and attentional biases to affective stimuli in infants of depressed mothers, it is important to further examine infant gaze

aversion as an emotion regulation strategy among infants of mothers at risk for perinatal depression.

In summary, depression in mothers is associated with (1) a range of adverse child outcomes; (2) mothers' more disengaged (uninvolved) and negative affect and behaviors and less positive affect and behaviors during mother-infant interactions; (3) infants showing more gaze aversion in general, greater gaze aversion when the mothers show emotional unavailability and sadness, and longer gazing time when the mothers show positive affect. In the present study, we build on this set of findings by examining mothers' affect and infants' gaze aversion in mother-infant free-play face-to-face interaction, testing the hypothesis that infants would be more likely to gaze away when the mothers showed flat or sad affect than when they showed positive affect.

We further test the idea that infants' attentional avoidance of their mothers' sad or withdrawn faces may serve as an emotion regulation strategy by examining infants' frontal EEG asymmetry. Researchers have commonly utilized electroencephalographic (EEG) asymmetry to infer emotional valences in infants. EEG asymmetry between the left and right frontal hemispheres has been associated with emotion processing and regulation, beginning in infancy (Fox, 1991). More specifically, relative right frontal EEG asymmetry is reliably correlated with negative, withdrawal-related emotions, which might be a biological marker of vulnerability to depression, and left frontal EEG asymmetry is consistently associated with positive, approach-related emotions (Davidson & Fox, 1982). For example, infants showed greater right frontal asymmetry when exposed to their mothers' or stranger's sad relative to happy facial expressions, along with more negative affect and less positive affect (Diego et al., 2004). As young as 3 months of age, compared to infants of non-depressed mothers, infants of mothers with

depression showed greater relative right frontal EEG asymmetry (Diego et al., 2004; Field, Fox, Pickens, & Nawrocki, 1995).

We found one study that examined infants' frontal EEG asymmetry in relation to their gaze patterns. Field et al. (1998) examined the association of affective stimuli, EEG asymmetry and visual fixation time in a small sample (n = 24) of 3-month-old infants of depressed and non-depressed mothers. They found that lower relative left frontal activation (the pattern typically associated with withdrawal) was associated with longer fixation time to video recorded facial expressions, although only for infants of non-depressed mother. However, conclusions from this finding are limited given the study's small sample size, the mothers having been adolescents or young adults, and use of a video recording of a female model depicting the facial expressions.

The Current Study

Given that infants show greater gaze aversion when their mothers exhibit flat affect in the still-face condition, and sad affect presented experimentally, examining infants' gaze aversion to mothers' naturally-occurring flat and sad affect could help shed light on the development of emotion regulation strategies in infants. Therefore, our first aim was to examine the associations between maternal withdrawn/flat and sad affect and infant gaze aversion in a face-to-face free play. Our first hypothesis was that infants would be more likely to gaze away when the mothers show withdrawn/flat or sad affect than when they show positive affect in mother-infant free-play.

Given that published studies on infants' gaze behaviors in relation to maternal affective stimuli examined infants at the ages of 3 months to 6 months, we planned to test our hypotheses on infants at ages 3 and 6 months. With our longitudinal design, we conducted exploratory analyses to examine potential development changes between ages 3- and 6-months.

To test this hypothesis, we sampled mothers at elevated risk for perinatal depression, with risk defined as the women's having met criteria for major depressive episodes prior to their pregnancy. Women's personal history of depression is one of the strongest predictors of depression in the postpartum period (O'Hara & Gorman, 2004). With this sampling strategy, we expected to enhance the proportion of the sample who experienced elevated depression symptom levels in the postpartum period, relative to a general population sample (Goodman & Tully, 2009). Thus, we tested our hypotheses in a sample for which depression in mothers is highly salient.

This sampling strategy further enabled us to examine the role of mothers' depression symptom levels in relation to our hypothesized association between mothers showing withdrawn/flat or sad affect and infants' gazing away. This is important given the well-established association of depression in mothers and infants' attentional biases to affective stimuli. Based on past findings on greater gaze avoidance in infants of depressed mothers (Diego et al., 2004; Field et al., 1998), our second hypothesis that there would be a positive association between mothers' cumulative depressive symptom levels and the proportion of time infants gazing away during mothers' sad affect. Further, because depression in mothers is associated with their greater likelihood of showing withdrawn/flat and sad affect (Lovejoy et al., 2000), infants whose mothers have been more depressed in the infants' lifetime might be more accustomed to maternal flat affect compared to infants whose mothers have been able to stay well, despite their history of depression. Thus, we hypothesized that mothers' more severe postpartum depressive symptoms would be negatively correlated to the likelihood of infants gazing away when the mothers show withdrawn/flat affect. Moreover, because more time of exposure to postpartum depression might make infants more accustomed to their mother's

withdrawn/flat and sad affect, our third hypothesis was that in terms of gaze aversion, the association with mothers' postpartum depression symptom levels in the 6-month-olds would be stronger than in the 3-month-olds.

In order to better understand the functional significance of infant gaze aversion when the mothers show flat/withdrawn or sad affect, we extended our first aim by examining the association between infant gaze aversion, maternal flat/withdrawn or sad affect and infant EEG asymmetry. Given that relative right EEG asymmetry is related to negative, withdrawn emotions (Davidson, 1992), and that infants' negative affect is associated with viewing flat/withdrawn or sad affect (Cohn & Tronick, 1983), our fourth hypothesis was that the proportion of time during which the infants gaze away when their mothers show flat or sad affect would be positively associated with the infants' relative right frontal EEG asymmetry during the play segment.

Finally, similar to our hypothesis of the role of mothers' postpartum depression symptom level in relation to infants' gazing away from their mothers' flat or sad affect, we examined the role of mothers' postpartum depression symptom level in relation to the association between infant gaze aversion when the mothers show flat or sad affect and infant right frontal EEG asymmetry. Compared to infants of non-depressed mothers, infants of mothers with depression tend to show relative right frontal EEG asymmetry, at least among infants whose mothers had elevated depression both prenatally and in the postpartum (Diego et al., 2004; Lusby, Goodman, Bell, & Newport, 2014). However, the more maternal depressive symptoms to which infants are exposed, the more maternal flat and sad affect infants are likely to experience, which in turn, might make them more accustomed to maternal flat and sad affect. Thus, our fifth hypothesis was that mothers' higher depressive symptom levels in the infants' lifetime would dampen the association between infants' relative right frontal EEG asymmetry and their gazing away during

the time their mothers show flat or sad affect. Accordingly, the severity of mothers' postpartum depressive symptoms would be negatively correlated to relative right frontal EEG asymmetry in infants during times when flat or sad affect.

Method

Participants

Pregnant women were recruited through a women's mental health program in the Emory University Department of Psychiatry and Behavioral Sciences. All women in the study met Diagnostic and Statistics Manual of Mental Disorders-Fourth Edition (DSM-IV) criteria for a previous major depressive episode. Many of the participants also met criteria for an anxiety disorder (Generalized Anxiety Disorder, Obsessive Compulsive Disorder, or Post Traumatic Stress Disorder). Being less than 16 weeks pregnant and between the age of 18 and 45 were additional inclusion criteria to participate in this study. Participants were excluded from the study for meeting any of the following exclusion criteria: bipolar disorder, schizophrenia, having psychotic symptoms, or currently active eating disorder, active substance use disorder within six months prior to last menstrual period or positive urine drug screen, active suicidality or homicidality, illness requiring treatment that can affect infant outcomes (autoimmune disorders, asthma, epilepsy), anemia, and/or abnormal thyroid stimulating hormone. A total number of 189 mother-infant dyads included in the current analyses participated in either or both of the lab visits at infant ages 3- and 6-months.

Procedure

The procedures in the current study are a subset of those from a larger longitudinal study: Perinatal Stress and Gene Influences: Pathways to Infant Vulnerability. This study was approved by the Emory University Institutional Review Board, and all women participated in informed

consent. Data were collected from the participants at multiple time points throughout pregnancy and the first 12 months postpartum. In order to confirm that participants had at least one previous major depressive episode, pregnant women were administered the Structured Clinical Interview for DSM-IV at their first visit (First, Spitzer, Gibbon, & Williams, 1995).

Mothers and their infants completed lab visits when the infants were at the ages of 3- and 6-months. At each visit, women completed the Beck Depression Inventory-Second Edition (BDI-II) (Beck, Steer, & Brown, 1996) to assess their depressive symptoms. Mothers and their infants were video-recorded during a 5-minute face-to-face free-play interaction, during which EEG was also collected. Prior to the segment, an EEG cap was attached to the infant's head while a research assistant manipulated toys aiming to distract the infant. Prior to the free-play segment, the mother was instructed to play with her child in any way that she liked and was provided a box of age-appropriate toys.

Measures

Depression in Mothers. The Structured Clinical Interview for DSM-IV Axis I Disorders-Patient Edition (First et al., 1995) was administered at each woman's initial visit to determine eligibility to participate in the study. All interviews were conducted by a psychiatric nurse, master's level psychologist, or social worker who had completed an established training procedure and attained and maintained high levels of inter-rater reliability based on audio recordings of the interviews. A licensed clinical psychologist listened to the recorded interviews and reviewed notes to make diagnoses.

To measure maternal depressive symptoms concurrent with the observed mother-infant interactions and EEG data, mothers completed the Beck Depression Inventory-Second Edition (BDI-II) (Beck et al., 1996). The BDI-II is a 21-item self-report measure of depressive symptom

severity with questions about the past two weeks, and has been found to be a valid and reliable measure (Dozois, Dobson, & Ahnberg, 1998). Higher depression scores indicate greater severity of depressive symptoms (Beck et al., 1996). Specifically, depression scores ranging from 14-19 indicate mild depression; 20-28 indicate moderate depression; and 29-63 suggest severe depression.

To determine the infants' overall (lifetime) exposure to mothers' depression symptoms at 3- and 6-months of age, at multiple times between birth and infant age 6 months, women also completed the Beck Depression Inventory (BDI; (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961). The original BDI is a self-report measure of depression symptom severity with 21 questions. Respondents are asked to answer the questions based on how they were feeling during the past week. Each item on this instrument is rated on a 4-point scale, ranging from 0 to 3. A total score is the sum of the ratings across items, with higher scores indicating greater severity of depressive symptoms. The BDI is a valid and reliable measure of depression severity, with a high degree of content validity and internal consistency reliability (Beck et al., 1961). In the present sample, women completed an average of 5.58 BDIs, ranging from 2 to 15 times (*SD* = 2.37), between birth and 6 months. Analyses were conducted using area under the curve (AUC) scores calculated to estimate the time-averaged total score across the duration of birth to 3-months and birth to 6-months. The AUC score was calculated by generating a piecewise linear curve, with the scores obtained between the infant's birth date and 3- or 6-months postpartum. Area is calculated under this curve. AUC scores are preferred as summaries of the cumulative burden of depression severity, relative to alternatives such as the mean or peak scores), given the episodic nature of depression (Fekedulegn et al., 2007; Lydick, Epstein, Himmelberger, & White, 1995).

Infant Gaze. From the 5-minute video recordings of the mother-infant face-to-face free-play segment during the 3- and 6-month laboratory visits, infants' gaze was coded continuously in mutually exclusive categories of infants' gaze to mother's face, gaze to mother's body, gaze to object, joint attention, or gaze away. A team of undergraduate research assistants coded infants' observed moment-to-moment gaze using Mangold International's Interact Video Coding Software (Mangold, 2010). Coders underwent a training process in which they practiced coding and discussed disagreement with a graduate student and principal investigator, and were deemed trained once inter-rater reliability was demonstrated by a kappa greater than .80 on four consecutive coded segments. In order to maintain reliability, we conducted weekly meetings involving discussion of segments that had been randomly selected for reliability checks. For infant gaze coding, inter-rater reliability, computed for a randomly selected 20% of the segments that were coded by two individuals who were not aware of which segments were selected for reliability, yielded a kappa of .79.

Mother Affect. Maternal flat and sad affect scores were calculated from observational coding of mothers' affect from the 5-minute video recordings of the mother-infant face-to-face free-play segment during the 3-, and 6-month laboratory visits. A separate team of coders, independent of infant gaze team, coded mothers' observed moment-to-moment affect using Mangold International's Interact Video Coding Software (Mangold, 2010). Much like infant gaze coders, mother affect coders were also undergraduate research assistant who underwent the same training process and deemed trained once the same criterion was met.

Mothers' moment-to-moment expressions were coded as different valences of negative (tension/negative interest, brief distress/frown/protest/fuss, and marked distress/cry), withdrawn/flat, or positive (positive interest, smile/excitement, and laughter/squeal) affect, with

codes modified from Dawson et al. (1999). We then computed scores for the proportion of time that mothers showed withdrawn/flat and negative affect out of the total duration of the segment. Inter-rater reliability, computed for a randomly selected 19% of segments that were coded by two individuals who were not aware of which segments were selected for reliability, yielded a kappa of .90.

Gaze aversion. Within the Mangold system, we aligned the second-by-second infant gaze codes with the mothers' affect codes. Because past literature considered infant gazing away from mother's face as gaze aversion, we combined all infant gaze behaviors except gaze to mother's face as gaze aversion. Next, we computed infant gaze aversion to mothers' withdrawn/flat and sad affect separately as the proportion of time infants gazed away given that their mothers were in withdrawn/flat and similarly for when mothers were in sad affect, out of the total duration of maternal withdrawn/flat (sad) affect in the segment.

EEG. The play EEG recordings were made from 16 left and right scalp sites: frontal pole (Fp1, Fp2), medial frontal (F3, F4), lateral frontal (F7, F8), central (C3, C4), anterior temporal (T3, T4), posterior temporal (T7, T8), parietal (P3, P4), and occipital (O1, O2), referenced to Cz. EEG was recorded using a stretch cap (Electro-Cap, Inc., Eaton, OH) with electrodes in the 10/20 system pattern and recommended procedures regarding EEG data collection with infants and young children were followed (Pivik et al., 1993). After the cap was placed on the infant's head, conductive gel provided by the cap manufacturer was placed in each site using a blunt tip syringe and the edge of a Q-tip. Electrode impedances were measured and accepted if they were below 5K ohms. The electrical activity from each lead was amplified using separate SA Instrumentation Bioamps (San Diego, CA) and band passed from 1 to 100 Hz. Activity for each lead was displayed on-line at 512 samples per second for each channel so that the data were not

affected by aliasing. The acquisition software was Snapshot-Snapstream (HEM Data Corp.), and the raw data were stored for later analysis.

Infant EEG data were examined and analyzed using EEG Analysis System software developed by James Long Company (Caroga Lake, NY). First, the data were re-referenced via software to an average reference configuration, with 16 electrode sites in the 10/20 configuration to satisfy the requirement of even scalp distribution (Hagemann, Naumann, & Thayer, 2001). Then, the average reference EEG data were artifact scored for eye movements and gross motor movements. These artifact-scored epochs were eliminated from all subsequent analyses. The data were then analyzed with a discrete Fourier transform (DFT) using a Hanning window of one-second width and 50% overlap. Power was computed for the 6 to 9 Hz frequency band. Infants and young children have a dominant frequency between 6 to 9 Hz (Bell & Fox, 1994; Marshall, Bar-Haim, & Fox, 2002), and this particular frequency band has been correlated with patterns of emotion reactivity and emotion regulation during infancy (Bell & Fox, 1994; Buss et al., 2003; Dawson, 1994) and early childhood (Fox, Henderson, Rubin, Calkins, & Schmidt, 2001). The power was expressed as mean square microvolts and the data transformed using the natural log to normalize the distribution (Tottenham et al., 2010).

For 3-month infant play EEG data, 156 infants (92.9%) had usable data, data for 11 infants (6.5%) were unable to be edited due to too much artifact, data for 7 infants (4.2%) were excluded for an insufficient quantity (less than 10 seconds) of good data, data for 2 infants (1.2%) were excluded as outliers (+/- 3 standard deviations from the mean), and 1 infant (0.6%) had no EEG data collected. For 6-month infant play EEG data, 158 infants (94.0%) had usable data, data for 4 infants (2.4%) were unable to be edited due to too much artifact, data for 3 infants (1.8%) were excluded for an insufficient quantity (less than 10 seconds) of good data,

data for 4 infants (2.4%) were excluded as outliers (+/- 3 standard deviations from the mean), and 6 infant (3.6%) had no EEG data collected.

Frontal EEG asymmetry values were computed by subtracting ln power at left frontal (F3) from ln power at right frontal (F4). In infants and young children, power in the 6 to 9 Hz band has been shown to be inversely related to cortical activation during emotion reactivity and regulation (Bell & Fox, 1994). Thus, a negative asymmetry reflects greater relative right frontal activation, whereas a positive asymmetry score reflects greater relative left frontal activation.

Data Analytic Strategy

Preliminary analyses. We conducted frequency analyses to examine the distributions of scores for sociodemographic variables, including gender of infant, order of infant, race of infant, age of mother at delivery, education level of mother, marital status, and socioeconomic status. See Table 1 for descriptive sociodemographic characteristics of participants.

Hypothesis testing. To test our hypothesis that infants would be more likely to gaze away when the mothers showed flat or sad affect than when they showed positive affect in mother-infant free-play, we ran paired-sample t-tests to compare the proportion of time infants gazed away during mothers' flat affect and sad affect with the infants' rate of gazing away during mothers' positive affect. We ran these separately for the 3- and 6-month data. In future work, we will consider a linear mixed model (LMM) approach as an alternative to ANOVA.

To test our hypothesis that if the mothers' postpartum depressive symptoms are more severe, their infants would be less likely to gaze away when they show flat affect, and more likely to gaze away when they show sad affect, we ran Pearson correlation analyses between mothers' cumulative depressive symptom levels (BDI AUC) and the proportion of time infants gazed away when the mothers showed flat or sad affect. We ran these separately for the 3-month

and 6-month group, which enabled us to test our hypothesis that the association between infant gaze aversion to mothers' flat or sad affect and mothers' postpartum depression symptom levels would be stronger in the 6-month-olds than in the 3-month-olds. In future work, we will consider a linear mixed model (LMM) approach as an alternative to this correlational approach.

With Aim 2, we hypothesized that the proportion of time during which the infants gazed away when their mothers showed flat or sad affect would be positively associated with relative right frontal EEG asymmetry. We examined this hypothesis by running Pearson correlational analyses among these three variables, separately for data obtained at 3- and 6-months. We further hypothesized that mothers' higher depressive symptom levels would dampen the association between infants' relative right frontal EEG asymmetry and their gazing away during their mothers' flat or sad affect. To test this, we ran moderation analyses examining mothers' postpartum depressive symptoms as a moderator to the relationship between infant gaze aversion and EEG frontal asymmetry, separately for data obtained at 3- and 6-months.

Results

Preliminary Analyses and Descriptive Statistics

Among the 168 mother-infant dyads who completed the 3-month lab visit, 163 (97.0%) had infant gaze and mother affect data, 156 (92.9%) had usable EEG data, and 152 (90.5%) had data for all three variables. Among the 168 mother-infant dyads that completed the 6-month lab visit, 154 (91.7%) had infant gaze and mother affect data, 158 (94.0%) had usable EEG data, and 146 (86.9%) had data for all three variables. This yielded 189 mother-infant dyads that participated in the 3-month and/or 6-month lab visit as the final sample for our study. We ran one-way ANOVA and Chi-square tests of independence to compare those who participated in the 3-month and the 6-month lab visits, separately who had usable data for all three variables and

those excluded in terms of the three primary variables and all demographic variables. There were no significant differences between included and excluded participants. See Table 2 and Table 3 for descriptive characteristics of infant gaze and mother affect variables. See Table 4, and Table 5 for descriptive statistics of mothers' postpartum depressive symptoms.

Associations among three primary study variables. We ran Pearson's correlations to investigate the associations between mothers' postpartum depressive symptoms, infant gaze aversion during mothers' flat or sad affect, and relative right EEG frontal asymmetry (See Table 6 and Table 7).

Hypothesis Testing

Mother affect and infant gaze aversion. Consistent with the first hypothesis, that infants would be more likely to gaze away when the mothers showed flat or sad affect than when they showed positive affect during mother-infant free-play, paired-samples t-tests revealed that the proportion of time infants gazing away when the mothers were in flat or sad affect (M = 73.1, SD = 27.9; M = 83.6, SD = 19.8, for 3-, and 6-months, respectively) was significantly higher than that when the mothers were in positive affect (M = 68.9, SD = 22.9; M = 71.2, SD = 17.8, for 3-, and 6-months, respectively), t(156) = 2.27, p = .024, d = 0.18; and t(139) = 8.74, p = .000, d = 0.74, for 3-, and 6-months, respectively.

Given that the previous analyses considered mothers' flat and sad affect together, we next took several steps to consider the two negative affects separately. In order to see if there were differences in gaze aversion between mothers' flat and sad affect, we ran additional paired-samples t-tests and found that infants were significantly more likely to gaze away when their mothers show flat rather than sad affect (see Table 2 and 3 for means and standard deviations, and Tables 8 and 9 for the t-tests). Therefore, we ran paired-samples t-tests to test our hypothesis

separately for mothers' flat and sad affect. The results showed that the proportion of time infants gazed away when the mothers were in flat affect was significantly higher than that when the mothers were in positive affect for both infants at 3- and 6-months of age. Contrary to our expectation, 3-month old infants were significantly less likely to gaze away during mothers' sad affect compared to positive affect, albeit not significant at 6-months of age. See Table 2 for means and standard deviations and Table 8 and Table 9 for t-tests results of the comparisons between infant gaze aversion during mothers' positive, flat and sad affect.

Maternal depression and infant gaze aversion. The second hypothesis stated that if mothers' postpartum depressive symptoms are more severe, their infants would be less likely to gaze away when they show flat affect, and more likely to gaze away when they show sad affect. We ran a bivariate Pearson's correlation analysis for mothers' cumulative depression severity scores (AUC) and proportion of time infants gazing away when mothers were in flat or sad affect, separately for data obtained at 3- and 6-months. The results revealed that mothers' depressive symptom levels were not significantly associated with infant gaze aversion during either mothers' flat (r = .05, p = .28; and r = -.05, p = .29, for 3-, and 6-months respectively) or sad (r = -.11, p = .16; and r = .14, p = .15, for 3-, and 6-months respectively) affect at either 3- or 6-months.

To test our third hypothesis, that due to longer exposure to postpartum depression, such gaze aversion would have a stronger association with mothers' depressive symptoms in the 6-month-olds than in the 3-month-olds, we performed Fisher z-transformations to get z values to assess the significance of difference between the 3-month and 6-month correlation coefficients. Contrary to our prediction, the strength of relationship between maternal depressive symptoms

and infant gaze aversion during mothers' sad or flat affect was not significantly stronger in the 6-month data compared to the 3-month data (see Table 10).

Infant gaze aversion and relative right frontal EEG asymmetry. To test the fourth hypothesis, that the proportion of time during which the infants gaze away when their mothers show flat or sad affect would be positively associated with relative right frontal EEG asymmetry, we conducted a bivariate Pearson's correlation, separately for the 3-, and 6-month data. Consistent with our hypothesis, we observed a significant correlation between infant time in gaze aversion when their mothers show flat or sad affect and relative right frontal EEG asymmetry in the 3-month data, albeit not significant in the 6-month data(r = -.20, p = .008; r = .07, p = .22, for 3-, and 6-months respectively).

Next, additional bivariate Pearson's correlation analyses separating infants' gaze aversion during mothers' flat and sad affect revealed that relative right frontal EEG asymmetry was significantly correlated to 3-month old infants' gaze aversion during mothers' flat affect (r = -.17, p = .02), although it was not significantly correlated to 6-month old infants' gaze aversion during mothers' flat affect (r = .09, p = .14). And no significant association was found between relative right frontal EEG asymmetry and the proportion of time infants gazed away when the mothers were in sad affect, at either the 3-month or 6-months of age (r = -.09, p = .19; r = -.08, p = .26, for 3-, and 6-months respectively).

Maternal depression, infant gaze aversion and relative right frontal EEG asymmetry. Our fifth hypothesis stated that mothers' higher depressive symptom levels in the infants' lifetime would dampen the association between infants' relative right frontal EEG asymmetry and their gazing away during the time their mothers show flat or sad affect, and that this difference would be more significant in the 6-month group relative to the 3-month group. In

order to test this hypothesis, we ran a moderation analysis, separately for 3-month data and 6-month data, using Process v3.0 for SPSS model 1 (Hayes, 2018). As shown in Table 11 and Table 12, there was no significant interaction effect of infant gaze aversion during mothers' flat or sad affect by postpartum depressive symptoms in predicting relative right frontal EEG asymmetry in either group (β = .00, 95% CI [0.00, 0.00], t = .26, p = .80; β = .00, 95% CI [0.00, 0.00], t = -.77, p = .44, for 3-, and 6-months respectively).

In addition, we examined depression in mothers as a moderator between EEG relative right frontal asymmetry and infant gaze aversion, separately for mothers' flat and sad affect. The results revealed that for both the 3-month group and the 6-month group, mothers' depressive symptoms did not significantly moderate the relationship between relative right frontal EEG asymmetry and infants gazing away either when the mothers showed flat affect or sad affect (see Table 13).

Discussion

With researchers interpreting infants' gaze aversion as an emotion regulation strategy, an increasing amount of studies focus on infant gaze aversion and its correlates to gain a better understanding of the development of emotion regulation. Because of the association between depression in mothers and a variety of adverse effects on children, we sampled mothers at elevated risk for perinatal depression and their infants, with risk defined as having at least one major depressive episode prior to their pregnancy. In an effort to better understand infant gaze aversion as an emotion regulation strategy, the present study was conducted to examine the associations between infant gaze aversion when mothers show flat/withdrawn or sad affect and EEG frontal asymmetry. Our hypothesis that infants would be more likely to gaze away during mothers' flat or sad affect compared to positive affect was supported, consistent with the idea of

looking away from flat or sad affect as an emotion regulation strategy. But we did not find significant correlations between mothers' cumulative postpartum depressive symptoms and infant gaze aversion during mothers' flat/withdrawn or sad affect, and such associations were not stronger in the 6-month group compared to the 3-month group. There was significant association between relative right EEG frontal asymmetry and infant gaze aversion when the mothers exhibit flat or sad affect for the 3-month data, albeit not for the 6-month data. Postpartum depression did not significantly moderate those relationships.

In addition, due to the significant difference in infant gaze aversion when mothers show flat and sad affect, we tested our hypotheses separating mothers' flat and sad affect. We found that 3-month old infants were significantly less likely to gaze away when their mothers exhibit sad affect than positive affect, again consistent with the idea of looking away from an aversive affect (specifically sad) as an emotion regulation strategy. We further found a significant correlation between EEG relative right frontal asymmetry and infant gaze aversion during mothers' flat affect for the 3-month data.

Built on findings on infant gaze aversion during the still-face paradigm (Adamson & Frick, 2003), and when their mothers show sad affect (Termine & Izard, 1988), we investigated infant aversion during mothers' naturally-occurring flat/withdrawn or sad affect in mother-infant free-play. Consistent with our hypothesis, infants were significantly more likely to gaze away when their mothers exhibited flat or sad affect than positive affect. The greater infant gaze avoidance when exposed to mothers' flat or sad affect, relative to positive affect, supports the notion of gaze aversion as an emotion regulation strategy, consistent with an understanding of facial affect processing and depression susceptibility (Bistricky et al., 2011).

When we examined the difference in infant gaze aversion between when the mothers show flat versus sad affect, we found the proportion of time infant gazed away during mothers' sad affect was significantly lower than during mothers' flat affect. Therefore, we tested the hypothesis separating these two affects. The results for flat affect alone were still consistent with the results for two affects combined. However, opposite of what we expected, infants were significantly less likely to gaze away during mothers' sad affect than positive affect for the 3-month group, albeit not significant for the 6-month group. Even though the difference was not in the direction that we predicted, it was supported by similar findings of infants spending more time looking at sad other than happy facial expressions in previous literature (Field et al., 1998; Hernandez-Reif et al., 2006). These studies interpreted this finding as infants' novel experience to sad affect. Moreover, another possible explanation for this result could be that mother's sad affect was in response to her infant's sad affect, which the infant in turn showed empathy by looking at mother's face. However, findings on the proportion of time infants gazed away during their mother's sad affect should be interpreted with caution given the very small amount and proportion of time during which mothers exhibited sad affect in these play segments.

In light of the well-established association between depression in mothers and infants' attentional biases to affective stimuli, we followed up on this line of research by examining the relationship between mothers' depressive symptoms and infant gaze aversion during mothers' naturally-occurring flat or sad affect. Based on Lovejoy et al. (2000)'s finding of the correlation between depression in mothers and their heightened likelihood of showing flat affect, and past literature on increased gaze aversion during mothers' sad affect among infants of depressed mothers (Diego et al., 2004), we hypothesized that the severity of mothers' cumulative postpartum depressive symptoms would be correlated to higher likelihood of infants gazing away

during mothers' flat affect, and lower likelihood of infants gazing away during mothers' sad affect. In addition, we further hypothesized that such associations would be stronger in the 6-month group compared to the 3-month group. The results showed that the association was not significant for either group, and there was no significant difference in strength of the correlation between the two groups.

There are several possible explanations for the lack of significance in our findings. Even though women who participated in the current study varied in terms of their postpartum depressive symptoms, they all had a history of at least one major depressive episode. We might have failed to detect the hypothesized correlations due to the sampling strategy. Furthermore, about three quarters of women in the current study fell into the minimal depression category. Therefore, insufficient number of participants with elevated postpartum depressive symptoms could potentially help explain the null findings. In addition, because the current study examined infant gaze aversion within the mother-infant free-play setting, infants' attention was often drawn to the toys, albeit frequently with joint attention with their mother, in contrast to the common setting from past literature, in which the only stimulus was mothers' facial expressions (Diego et al., 2004; Hernandez-Reif et al., 2006). Thus, infants were not always attending to their mothers' faces and reacting to facial expressions in this study.

In an effort to further understand infant gaze aversion to mothers' emotion expressions, we examined infants' EEG frontal asymmetry to infer their emotional valences. The results showed that our hypothesis was partially supported. There was a significant and positive correlation between relative right EEG asymmetry and infant gaze aversion during mothers' flat and sad affect combined, and during mothers' flat affect alone, at 3-months of age, albeit not significant during mothers' sad affect alone. That is, at 3-months of age, infants' greater relative

right EEG asymmetry, consistent with negative affect, was associated with their greater gaze aversion when mothers were expressing flat and sad affect combined or expressing flat affect alone. Even though we did not find published studies examining such association, this result is in line with our rationale for the predicted directionality in the correlation, which is that infants may find mothers' sad affect aversive, which might be reflected in their greater relative right frontal EEG asymmetry, consistent with negative affect, and in their gaze aversion.

Contrary to our hypotheses, for the 6-month lab visit, there was no significant correlation between infants' relative right frontal EEG asymmetry and the proportion of time infant gazed away during mothers' flat and sad affect, combined or alone. This finding might be explained by the fact that we used an average EEG asymmetry score of the entire free-play segment. In order to understand the extent to which infant gaze aversion during mothers' flat/withdrawn or sad affect is associated with their experience of negative affect, EEG asymmetry scores exclusively from those moments could potentially reflect changes in infants' emotion more accurately. Moreover, it is crucial to bear in mind that the results were correlational, which could be affected by confounding variables.

Mothers' postpartum depressive symptoms did not significantly moderate the relationship between infant gaze aversion during mothers' flat/withdrawn or sad affect and EEG frontal asymmetry at either 3- or 6-months of age. These findings are incongruous with our rationale for depression in mothers as a moderator, since past literature found significant correlations between either two out of the three study variables (Diego et al., 2004; Field et al., 1995; Field et al., 1998).

Limitations & Strengths

The study had several limitations that should be taken into account when interpreting our findings. First, all of the women participated in this study had at least one previous major depressive episode. Therefore, our findings cannot be generalized to women without a history of depression. However, consistent with findings that depression prior to pregnancy is one of the strongest risk factors for depression during pregnancy and the postpartum, this sampling strategy did enhance the proportion of women with elevated postpartum depressive symptom levels, relative to a general population sample. Second, the generalizability of our results was limited by the restricted demographic diversity, since the majority of our sample was composed of European American women who were married, relatively high in education level and socioeconomic status. Additionally, because past literature considered infants gazing away from mother's face as gaze aversion, we also counted all infant gaze behaviors, except for gazing to mother's face, as gaze aversion. Therefore, despite the fact that joint attention is commonly considered as a positive and beneficial gaze behavior for infants (Scaife & Bruner, 1975), it was treated as gaze aversion in the current study. Last but not least, we did not account for other postnatal influences that might moderate the relationship between the three primary study variables, such as the presence and quality of involvement of infants' fathers or other caregivers. Nor did we test the specificity of our findings to infants' interactions with their mothers relative to infants' interactions with others.

There were several notable strengths in the study, in spite of these limitations. First, we sampled a population at elevated risk for perinatal depression who are, thus, very important to understand. Second, mothers' depressive symptoms were measured at multiple time points between infants' birth date and 6-months postpartum, allowing us to calculate AUC scores to determine infants' overall exposure to their mothers' depressive symptoms at 3-, and 6-months

of age. Third, in an effort to understand the idea of infant gaze aversion during mothers' flat or sad affect as potentially an emotion regulation strategy, the present study explored the possibility of depression in mothers as a moderator in the relationship between infant gaze aversion and EEG asymmetry. Moreover, our study was among the first to investigate infants' gaze aversion to their mothers' naturally-occurring flat or sad affect during mother-infant free-play.

Future directions

Despite the limitations and failure to find significant correlations between infant gaze aversion, maternal depression, and relative right frontal EEG asymmetry, the current study does provide suggestions for future exploration in this field of research. Four such future explorations planned for the dataset used in the current study are: First, because of infants' significantly lower likelihood to gaze away during mothers' sad affect than positive affect in the current study, we will look into a possible explanation that infants' visual fixation on mothers' sad facial expressions could be related to mothers' sad affect being an empathetic response. Second, we plan to address one of the limitations discussed in the present study by separating joint attention from gaze aversion. Third, since we focused on the influence of infants' overall exposure to mothers' postpartum depressive symptoms in this study, an interesting future step would be to take mothers' depressive symptoms during pregnancy into consideration. Fourth, while one of the aims in the current study was to understand the infants' emotional experience that might be associated with their infant gaze aversion during mothers' naturally occurring sad or flat affect during face-to-face mother-infant interactions, we examined infants' average fontal asymmetry scores of the entire free-play segment. We plan to continue exploring the intercorrelations between study variables utilizing infant frontal asymmetry scores exclusively from moments when infants gaze away during mothers' flat or sad affect, and during mothers' positive affect.

References

Adamson, L. B., & Frick, J. E. (2003). The Still Face: A History of a Shared Experimental Paradigm. *Infancy, 4*(4), 451-473. doi:10.1207/S15327078IN0404_01

Barrera, M. E., & Maurer, D. (1981). The Perception of Facial Expressions by the Three-Month-Old. *Child Development, 52*(1), 203-206. doi:10.2307/1129231

Beck, A. T., Steer, R. A., & Brown, G. (1996). Beck Depression Inventory–II. In: Pearson.

Beck, A. T., Ward, C. H., Mendelson, M., Mock, J., & Erbaugh, J. (1961). An inventory for measuring depression. *4*(6), 561-571.

Bell, M. A., & Fox, N. A. (1994). Brain development over the first year of life: Relations between electroencephalographic frequency and coherence and cognitive and affective behaviors. In G. Dawson & K. W. Fischer (Eds.), *Human behavior and the developing brain* (pp. 314-345). New York: Guilford.

Bistricky, S. L., Ingram, R. E., & Atchley, R. A. (2011). Facial affect processing and depression susceptibility: Cognitive biases and cognitive neuroscience. *Psychological Bulletin, 137*(6), 998-1028. doi:10.1037/a0025348

Boyd, R. C., Diamond, G. S., & Bourjolly, J. N. (2006). Developing a family-based depression prevention program in urban community mental health clinics: A qualitative investigation. *Family Process, 45*(2), 187-203.

Buss, K. A., Schumacher, J. R. M., Dolski, I., Kalin, N. H., Goldsmith, H. H., & Davidson, R. J. (2003). Right frontal brain activity, cortisol, and withdrawal behavior in 6-month-old infants. *Behavioral Neuroscience, 117*(1), 11.

Cohn, J. F., & Tronick, E. Z. (1983). Three-month-old infants' reaction to simulated maternal depression. *Child Development, 54*, 185-190.

Cole, P. M., Martin, S. E., & Dennis, T. A. (2004). Emotion regulation as a scientific construct: Methodological challenges and directions for child development research. *Child Development, 75*, 317-333.

Davidson, R. J. (1992). Anterior cerebral asymmetry and the nature of emotion. *Brain and Cognition, 20*(1), 125-151. doi:10.1016/0278-2626(92)90065-T

Davidson, R. J., & Fox, N. A. (1982). Asymmetrical brain activity discriminates between positive and negative affective stimuli in human infants. *Science, 218*(4578), 1235-1237. doi:10.1126/science.7146906

Dawson, G. (1994). Frontal electroencephalographic correlates of individual differences in emotion expression in infants: A brain systems perspective on emotion. *Monographs of the Society for Research in Child Development, 59*(2-3), 135-151.

Dawson, G., Frey, K., Self, J., Panagiotides, H., Hessl, D., Yamada, E., & Rinaldi, J. (1999). Frontal brain electrical activity in infants of depressed and nondepressed mothers: Relation to variations in infant behavior. *Development & Psychopathology, 11*, 589-605.

Diego, M. A., Field, T., Jones, N. A., Hernandez-Reif, M., Cullen, C., Schanberg, S., & Kuhn, C. (2004). EEG responses to mock facial expressions by infants of depressed mothers. *Infant Behavior & Development, 27*(2), 150-162.

Dozois, D. J. A., Dobson, K. S., & Ahnberg, J. L. (1998). A psychometric evaluation of the Beck Depression Inventory–II. *Psychological Assessment, 10*(2), 83-89. doi:10.1037/1040-3590.10.2.83

Fekedulegn, D. B., Andrew, M. E., Burchfiel, C. M., Violanti, J. M., Hartley, T. A., Charles, L. E., & Miller, D. B. (2007). Area under the curve and other summary indicators of

repeated waking cortisol measurements. *Psychosom Med, 69*(7), 651-659. doi:10.1097/PSY.0b013e31814c405c

Field, T. M., Fox, N. A., Pickens, J., & Nawrocki, T. (1995). Relative right frontal EEG activation in 3-to 6-month-old infants of" depressed" mothers. *Developmental Psychology, 31*(3), 358.

Field, T. M., Hernandez-Reif, M., Diego, M., Feijo, L., Vera, Y., Gil, K., & Sanders, C. (2007). Still-face and separation effects on depressed mother-infant interactions. *Infant Mental Health Journal, 28*(3), 314-323. doi:10.1002/imhj.20138

Field, T. M., Pickens, J., Fox, N. A., Gonzalez, J., & Nawrocki, T. (1998). Facial expression and EEG responses to happy and sad faces/voices by 3-month-old infants of depressed mothers. *British Journal of Developmental Psychology, 16*(4), 485-494. doi:10.1111/j.2044-835X.1998.tb00766.x

First, M. B., Spitzer, R. L., Gibbon, M., & Williams, J. B. (1995). *Structured clinical interview for DSM-IV axis I disorders*. New York: New York State Psychiatric Institute.

Fox, N. A. (1991). If it's not left, it's right: Electroencephalograph asymmetry and the development of emotion. *American Psychologist, 46*(8), 863.

Fox, N. A., Henderson, H. A., Rubin, K. H., Calkins, S. D., & Schmidt, L. A. (2001). Continuity and discontinuity of behavioral inhibition and exuberance: Psychophysiological and behavioral influences across the first four years of life. *Child Development Vol 72(1) Jan-Feb 2001, 1-21*.

Gibb, B. E., Uhrlass, D. J., Grassia, M., Benas, J. S., & McGeary, J. (2009). Children's inferential styles, 5-HTTLPR genotype, and maternal expressed emotion-criticism: An

integrated model for the intergenerational transmission of depression. *Journal of Abnormal Psychology, 118*(4), 734-745. doi:10.1037/a0016765

Goodman, S. H. (2015). Infant Vulnerability to Psychopathology. In S. D. Calkins (Ed.), *Handbook of Infant Biopsychosocial Development* (pp. 392-424): Guilford Press.

Goodman, S. H., & Gotlib, I. H. (1999). Risk for psychopathology in the children of depressed mothers: A developmental model for understanding mechanisms of transmission. *Psychological Review, 106*, 458-490.

Goodman, S. H., Rouse, M. H., Connell, A., Broth, M., Hall, C., & Heyward, D. (2011). Maternal Depression and Child Psychopathology: A Meta-Analytic Review. *Clinical Child and Family Psychology Review, 14*, 1-27. doi:10.1007/s10567-010-0080-1

Goodman, S. H., & Tully, E. C. (2009). Recurrence of depression during pregnancy: Psychosocial and personal functioning correlates. *Depression and Anxiety, 26*(6), 557-567.

Granat, A., Gadassi, R., Gilboa-Schechtman, E., & Feldman, R. (2017). Maternal depression and anxiety, social synchrony, and infant regulation of negative and positive emotions. *Emotion, 17*(1), 11-27. doi:10.1037/emo0000204

Gross, J. J. (1998). The emerging field of emotion regulation: An integrative review. *Review of General Psychology, 2*(3), 271-299. doi:10.1037/1089-2680.2.3.271

Hagemann, D., Naumann, E., & Thayer, J. F. (2001). The quest for the EEG reference revisited: A glance from brain asymmetry research. *Psychophysiology, 38*(5), 847-857. doi:10.1017/S0048577201001081

Harrison, A. J., & Gibb, B. E. (2015). Attentional biases in currently depressed children: An eye-tracking study of biases in sustained attention to emotional stimuli. *Journal of Clinical*

Child and Adolescent Psychology, 44(6), 1008-1014. doi:10.1080/15374416.2014.930688

Hayes, A. F. (2018). *Introduction to mediation, moderation, and conditional process analysis. (2nd Ed.)*. New York: The Guilford Press.

Hernandez-Reif, M., Field, T., Diego, M., Vera, Y., & Pickens, J. (2006). Brief report: Happy faces are habituated more slowly by infants of depressed mothers. *Infant Behavior & Development, 29*(1), 131-135. doi:10.1016/j.infbeh.2005.07.003

Hitzert, M. M., van Geert, P. L., Hunnius, S., Van Braeckel, K. N., Bos, A. F., & Geuze, R. H. (2015). Associations between developmental trajectories of movement variety and visual attention in fullterm and preterm infants during the first six months postterm. *Early Human Development, 91*(1), 89-96.

Hollingshead, A. B. (1975). *Four factor index of social status*. New Haven, CT: Yale University.

Lovejoy, M. C., Graczyk, P. A., O'Hare, E., & Neuman, G. (2000). Maternal depression and parenting behavior: A meta-analytic review. *Clinical Psychology Review, 20*(5), 561-592.

Lusby, C. M., Goodman, S. H., Bell, M. A., & Newport, D. J. (2014). Electroencephalogram patterns in infants of depressed mothers. *Developmental Psychobiology, 56*(3), 459-473. doi:10.1002/dev.21112

Lydick, E., Epstein, R. S., Himmelberger, D., & White, C. J. (1995). Area under the curve: a metric for patient subjective responses in episodic diseases. *Qual Life Res, 4*(1), 41-45.

Mangold. (2010). INTERACT Quick Start Manual V2.4. Mangold International BfbH (Ed.). In. http://www.mangold-international.com/.

Marshall, P. J., Bar-Haim, Y., & Fox, N. A. (2002). Development of the EEG from 5 months to 4 years of age. *Clinical Neurophysiology, 113*(8), 1199-1208.

Moore, G. A., Cohn, J. F., & Campbell, S. B. (2001). Infant affective response to mother's still-face at 6 months differentially predict externalizing and internalizing behaviors at 18 months. *Developmental Psychology, 37*, 706-714.

Morton, J., & Johnson, M. H. (1991). CONSPEC and CONLERN: A two-process theory of infant face recognition. *Psychological Review, 98*(2), 164-181. doi:10.1037/0033-295X.98.2.164

O'Hara, M., & Gorman, L. L. (2004). Can postpartum depression be predicted? *Primary Psychiatry, 11*(3), 42-47.

Pivik, R. T., Broughton, R. J., Coppola, R., Davidson, R. J., Fox, N., & Nuwer, M. R. (1993). Guidelines for the recording and quantitative analysis of electroencephalographic activity in research contexts. *Psychophysiology, 30*(6), 547-558.

Scaife, M., & Bruner, J. S. (1975). The capacity for joint visual attention in the infant. *Nature, 253*(5489), 265-266. doi:10.1038/253265a0

Striano, T., Brennan, P. A., & Vanman, E. J. (2002). Maternal depressive symptoms and 6-month-old infants' sensitivity to facial expressions. *Infancy, 3*(1), 115-126.

Termine, N. T., & Izard, C. E. (1988). Infants' responses to their mothers' expressions of joy and sadness. *Developmental Psychology, 24*(2), 223-229. doi:10.1037/0012-1649.24.2.223

Tottenham, N., Hare, T. A., Quinn, B. T., McCarry, T. W., Nurse, M., Gilhooly, T., . . . Eigsti, I. M. (2010). Prolonged institutional rearing is associated with atypically large amygdala volume and difficulties in emotion regulation. *Developmental Science, 13*(1), 46-61.

Tronick, E. Z. (2003). Emotions and emotional communication in infants. In J. Raphael-Leff (Ed.), *Parent-infant psychodynamics: Wild things, mirrors and ghosts.* (pp. 35-53). Philadelphia, PA: Whurr Publishers.

Væver, M. S., Krogh, M. T., Smith‐Nielsen, J., Christensen, T. T., & Tharner, A. (2015). Infants of depressed mothers show reduced gaze activity during mother–infant interaction at 4 months. *Infancy, 20*(4), 445-454.

Table 1

Participant Demographics

Variable	*Mean*	*SD*	*%*
Mothers' Age at Delivery (years)	33.8	4.5	
Socioeconomic Status (Hollingshead Score)	50.5	9.1	
Marital Status (%)			
Married			87.8
Mothers' Education (%)			
Some high school			0.5
Completed high school			2.7
Some college			18.5
Completed college			36.0
Some post-college			42.3
Infant's Race (%)			
European American			87.3
African American			7.4
Multiple			5.3
Sex of Infant: Female (%)			48.7
Order of Infant: First-born (%)			43.9

Note. $N = 189$ for the study sample.

For interpretation of Hollingshead Score:
8-19: Unskilled laborers, menial service workers
20-29: Machine operators, semi-skilled workers
30-39: Skilled craftsman, clerical and sales workers
40-54: Medium business and minor professional, technical
55-66: Major business and professional (Hollingshead, 1975).

Table 2

Descriptive Statistics for Infant Gaze and Maternal Affect Variables at 3 Months

Variable	*M*	*SD*	*min*	*max*
Infant Gaze				
% time gaze to mother's face	19.3	15.6	0	75.0
% time gaze away	80.7	22.5	0	100
% time joint attention	40.7	22.2	0	87.5
% time gaze to object	26.1	17.7	0	80.3
% time gaze away	10.3	11.7	0	77.6
% time gaze to mother's body	3.6	3.2	0	25.5
Mother Affect				
% time in positive affect	79.0	20.2	3.6	100
% time in flat affect	18.9	17.5	0	79.4
% time in sad affect	2.1	4.5	0	35.5
Infant Gaze Aversion & Mother Positive Affect				
Duration (in seconds)	163.0	69.0	0	306.4
% time out of total segment	54.2	22.0	0	99.9
% time out of time mother in positive affect	68.9	22.9	0	99.9
Infant Gaze Aversion & Mother Flat Affect				
Duration (in seconds)	43.7	47.0	0	240.1
% time out of total segment	14.1	14.8	0	74.1
% time out of time mother in flat affect	76.4	27.8	0	100
Infant Gaze Aversion & Mother Sad Affect				
Duration (in seconds)	2.5	5.5	0	44.4
% time out of total segment	0.8	1.9	0	14.6
% time out of time mother in sad affect	49.3	40.1	0	100

Table 3

Descriptive Statistics for Infant Gaze and Maternal Affect Variables at 6 Months

Variable	*M*	*SD*	*min*	*max*
Infant Gaze				
% time gaze to mother's face	20.9	13.7	0.25	68.6
% time gaze away	79.1	15.9	10.3	99.6
% time joint attention	37.8	14.3	1.2	74.0
% time gaze to object	28.4	13.7	1.4	62.0
% time gaze away	9.2	7.4	0	45.1
% time gaze to mother's body	3.7	3.5	0	19.0
Mother Affect				
% time in positive affect	80.9	21.0	17.1	100
% time in flat affect	18.2	18.4	0	82.9
% time in sad affect	0.9	2.1	0	15.6
Infant Gaze Aversion & Mother Positive Affect				
Duration (seconds)	179.8	60.1	31.2	311.1
% time out of total segment	56.2	19.2	5.1	97.9
% time out of time mother in positive affect	71.2	17.8	9.5	99.3
Infant Gaze Aversion & Mother Flat Affect				
Duration (in seconds)	49.3	51.5	0	230.8
% time out of total segment	15.7	16.4	0	71.0
% time out of time mother in flat affect	84.9	19.6	0	100
Infant Gaze Aversion & Mother Sad Affect				
Duration (in seconds)	1.9	4.5	0	41.5
% time out of total segment	0.6	1.4	0	12.9
% time out of time mother in sad affect	63.5	36.2	0	100

Table 4
Postpartum Depressive Symptom (BDI-II) at 3 Months

Variable	*Mean*	*SD*	*N*	*%*
BDI-II Score	8.9	7.6	164	100
Minimal			129	78.7
Mild			17	10.4
Moderate			13	7.9
Severe			5	3.0

Note. BDI-II = Beck Depression Inventory-Second Edition.

Table 5
Postpartum Depressive Symptom (BDI-II) at 6 Months

Variable	*Mean*	*SD*	*N*	*%*
BDI-II Score	9.2	8.2	159	100
Minimal			120	75.5
Mild			18	11.3
Moderate			17	10.7
Severe			4	2.5

Note. BDI-II = Beck Depression Inventory-Second Edition.

Table 6

Intercorrelations Among Primary Study Variables at Infant Age 3 Months

Variable	1	2a	2b	3	*M*	*SD*
1.Postpartum Depression (BDI) AUC	—				115.59	86.35
2.% time infant gaze away during mothers' flat or sad affect out of time mother in flat or sad affect		—		-.20**	73.10	27.91
a. flat affect alone	.05				76.37	27.81
b. sad affect alone	-.11	.48**	—		49.29	40.05
3.EEG Frontal Asymmetry	.03	-.17*	-.09	—	0.06	0.69

** p < .01 level (2-tailed). * p < .05 level (2-tailed).

Note. BDI = Beck depression inventory; AUC = area under the curve score for mother's depression from infant's birth through infant age 3 months.

Table 7

Intercorrelations Among Primary Study Variables at Infant Age 6 Months

Variable	1	2a	2b	3	*M*	*SD*
1.Postpartum Depression (BDI) AUC	—				234.11	165.94
2.% time infant gaze away during mothers' flat or sad affect out of time mother in flat or sad affect		—		.07	83.61	19.81
a. flat affect alone	-.05				84.94	19.65
b. sad affect alone	.14	.37**	—		63.51	36.23
3.EEG Frontal Asymmetry	-.06	.09	-.08	—	0.11	0.55

** p < .01 level (2-tailed). * p < .05 level (2-tailed).

Note. BDI = Beck depression inventory; AUC = area under the curve score for mother's depression from infant's birth through infant age 6 months.

Table 8

T-test Results for Infant Gaze Aversion During Mothers' Positive, Flat, and Sad Affect at 3 Months

Pair	*N*	95% CI	*r*	*t*	*df*	*p*
Flat vs. Sad	91	12.89, 28.28	.48**	5.3	90	.000
Flat vs. Positive	156	3.80, 11.05	.61**	4.1	155	.000
Sad vs. Positive	92	-22.80, -7.53	.43**	-3.9	91	.000

** p < .01 level (2-tailed). * p < .05 level (2-tailed).

Table 9

T-test Results for Infant Gaze Aversion During Mothers' Positive, Flat, and Sad Affect at 6 Months

Pair	*N*	95% CI	*r*	*t*	*df*	*p*
Flat vs. Sad	66	12.48, 29.31	.37**	5.0	65	.000
Flat vs. Positive	140	10.97, 16.60	.60**	9.7	139	.000
Sad vs. Positive	66	-15.28, .78	.44**	-1.8	65	.08

** p < .01 level (2-tailed). * p < .05 level (2-tailed).

Table 10

Difference in Strength of Correlations Between Maternal Depressive Symptoms and Infant Gaze Aversion Between the 3-Month and 6-Month Data

Correlation	*r* (3M)	*N* (3M)	*r* (6M)	*N* (6M)	*z*	*p*
Depression & Infant Gaze Aversion During Mothers' Flat or Sad Affect	-.006	145	-.03	131	.20	.42
Flat Affect	.05	144	-.05	131	.82	.21
Sad Affect	-.11	86	.14	62	-1.48	.07

Table 11

Moderation Models of Postpartum Depression Severity Predicting EEG Frontal Asymmetry at 3 Months

	EEG Frontal Asymmetry	
Predictor	ΔR^2	β
Step 1	.003	
Infant Gaze Aversion		-.0006
Postpartum Depression		.0002
Infant gaze Aversion x Postpartum Depression		.0000

Table 12

Moderation Models of Postpartum Depression Severity Predicting EEG Frontal Asymmetry at 6 Months

	EEG Frontal Asymmetry	
Predictor	ΔR^2	β
Step 1	.009	
Infant Gaze Aversion		.0012
Postpartum Depression		-.0002
Infant gaze Aversion x Postpartum Depression		.0000

Table 13

Postpartum Depression Severity as Moderator Between Infant Gaze Aversion During Mothers' Flat or Sad Affect and EEG Asymmetry

Interaction	β	95% CI	*t*	*p*
3 Months				
Depression x Infant gaze aversion during mothers' flat affect	.00	[.00, .00]	.79	.43
Depression x Infant gaze aversion during mothers' sad affect	.00	[.00, .00]	-.50	.62
6 Months				
Depression x Infant gaze aversion during mothers' flat affect	.00	[.00, .00]	-.75	.46
Depression x Infant gaze aversion during mothers' sad affect	.00	[.00, .00]	-.71	.48