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Associations Between Mother-Infant Affect Synchrony and Infants' Frontal EEG Asymmetry in Infants of Mothers at Risk for Perinatal Depression

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a thesis submitted to the Faculty of Emory College of Arts and Sciences
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Abstract

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Positive affect synchrony during mother-infant interactions is crucial for infants' development of emotional self-regulation. Frontal electroencephalogram (EEG) asymmetry indexes infant orientation toward either greater withdrawal and negative emotions or greater approach and positive emotions. Taking these two considerations into account, we hypothesized that mother-infant positive affect synchrony would be associated with individual differences in infant EEG frontal asymmetry patterns. Therefore, we examined the relationship between proportion of mother-infant positive affective synchrony and infant frontal EEG asymmetry scores during a mother-infant play activity at 3-, 6-, and 12-months of age. Additionally, given that depression in mothers has been shown to be associated with both lower mother-infant positive affect synchrony and infants' greater relative right frontal EEG asymmetry, we sampled mothers at risk for perinatal depression and examined the extent to which the association between mother-infant positive affect synchrony and infants' frontal EEG asymmetry varied by mothers' postnatal depression status. Contrary to our hypothesis, for the sample as a whole, proportion of time in mother-infant positive affect synchrony was not significantly associated with infant frontal EEG asymmetry, regardless of infant age. Consistent with our hypothesis, for mothers with recent major depressive episodes, in contrast to those with no recent episodes, there was a significant and moderate negative correlation when the infant was 6-months of age and a non-significant, yet moderate negative correlation when the infant was 12-months of age. Our findings suggest that

there is an association between proportion of time spent in positive affect synchrony and infant frontal EEG asymmetry for infants of mothers who experience a major depressive episode between the second and fourth quartiles postpartum.

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Associations between Mother-Infant Affect Synchrony and Infants' Frontal EEG Asymmetry in Infants of Mothers at Risk for Perinatal Depression

Mother-infant face-to-face interaction is reliably associated with infants' development of emotion expression, inhibition, and reactivity. During these interactions, both the mother and infant can show a range of emotions, to which the other has the opportunity to respond. These emotions are conveyed through facial expression, vocal tone, and nonverbal gestures. When the emotional expressions of the infant are matched by the emotional expressions of the mother, the dyad is described as being in affect synchrony (Delaherche et al., 2012). Affect synchrony is one of several forms of synchrony (e.g. motor, gaze, or physiological synchrony) and, more broadly, is considered one aspect of parenting sensitivity, the adaptive ability of the mother to accurately perceive, interpret, and respond to the cues of the infant (Bernieri, Reznick, & Rosenthal, 1988; Wen et al., 2017). Parenting behaviors have been found to be associated with infant neural functions (Taylor-Colls & Pasco Fearon, 2015), consistent with knowledge that infancy is a sensitive period during which the brain undergoes significant modification and is particularly susceptible to environmental influence (Johnson, 2001). Thus, in the current study, we focused on infants and sampled them at three points in time through the first year of life.

Positive affect synchrony refers to instances in which the mother and infant are sharing positive emotion expressions as shown by smiling, laughing, and mutual interest in play activities. Evidence for the importance of mother-infant positive affect synchrony comes from studies that examined its correlates, both concurrently and prospectively. Positive affect synchrony has been shown to help infants learn how to moderate emotional expression (Zentall, Boker, & Braungart-Rieker, 2006) and extend or heighten a positive emotional state (Feldman, 2003). In these ways, mother-infant positive affect synchrony may influence infant outcomes, such as emotion regulation, cognitive processing, and social relationships (Bernier, Calkins, & Bell, 2016). Greater positive affect synchrony is related to more positive infant outcomes, such as superior cognitive processing during infancy (Feldman, 2007) and more secure attachment with the mother (Lundy, 2003). Additionally, a systematic review of 63 studies concluded that positive affect synchrony is associated with fewer symptoms of maternal psychopathology and more positive child outcomes, including less development of psychopathology through adolescence (Leclère et al., 2014). Given the range and public health significance of the aspects of child functioning that have been associated with positive affect synchrony, it is important to better understand positive affect synchrony and its correlates.

Frontal EEG Asymmetry

Broadly speaking, mother-infant positive affect synchrony is related to brain and behavior development across the infant's first year of life, a period of extensive neurological change (Bernier et al., 2016). Frontal asymmetry, typically measured using electroencephalography (EEG), is one particular neurological component that indexes infant affectivity and is shown to be associated with parenting behaviors.

EEG measures cortical electrical brain activity resulting from excitatory and inhibitory potentials in the superficial cortex (Greenfield, Geyer, & Carney, 2009). Asymmetry between the left and right frontal hemispheres is repeatedly shown to be a reliable measure of brain activity associated with affective behaviors, including in infants. Evidence supports the approach/withdraw motivational model of emotion, which proposes that left frontal asymmetry is associated with approach behavior and positive affect, while right frontal asymmetry is associated with withdrawal and negative emotional expression (Coan & Allen, 2004; Davidson, 1993). Researchers studying the stability of frontal asymmetry over infants' first year found moderate correlations of EEG asymmetry scores from 1 to 3 months (Jones, Field, Fox, Lundy, & Davalos, 1997) and from 7 to 12 months (Bell & Fox, 1994). Furthermore, an additional study showed that 7 out of 8 infants who showed frontal asymmetry in infancy had the same patterns at 3 years of age (Jones, Field, Davalos, & Pickens, 1997). These findings provide support for the stability of frontal asymmetry throughout infancy and into the preschool years. Infant frontal asymmetry is a reliable indicator of infant emotionality in a variety of contexts. For example, 10-month old infants who cry when separated from their mothers show increased relative right frontal activation, while 10-month old infants who do not cry when separated from their mothers show increased relative left frontal activation (Davidson & Fox, 1989).

Infant frontal asymmetry is also related to parenting behavior. Infants of mothers who have a more understimulating interactive style during play have greater relative right frontal asymmetry, while infants of mothers who have a more overstimulating interactive style during play have greater relative left frontal asymmetry (Jones, Field, Fox, Davalos, et al., 1997). This same study also showed that the infants of the more withdrawn mothers have less adaptive interaction styles one year later. Although still correlational, which precludes assumptions about causality, these findings may indicate that mothers' behavior during interactions with her infant can impact infant frontal asymmetry. We followed up on this line of evidence by examining mother-infant positive affect synchrony and infants' frontal EEG asymmetry during face-to-face play in infants of mothers at risk for perinatal depression .

Depression in Mothers

Mothers with depression and their infants are an important group to study in regards to both frontal EEG asymmetry and positive affect synchrony. First, in terms of frontal EEG asymmetry, depression in mothers has been associated with infants' lower relative left frontal EEG asymmetry (Dawson, Frey, Panagiotides, Osterling, & HessI, 1997; Wen et al., 2017). Results from one study show that this association was specific to infants who spent more than half of daytime hours with the mother (Wen et al., 2017), and another study showed that this association was specific to infants who were exposed to their mothers' prenatal and postnatal depression (Lusby, Goodman, Bell, & Newport, 2014). Further, researchers have found that depression in mothers was associated with infants' lower relative left frontal EEG asymmetry only when the infants were expressing negative but not positive emotions (Dawson, Panagiotides, Klinger, & Spieker, 1997).

Frontal EEG asymmetry in infants of depressed mothers has been measured during situations designed to elicit positive or negative affect. In positive and negative emotion eliciting situations, frontal asymmetry in infants of mothers with depressive symptoms was significantly different than that of infants of mothers without symptoms of depression (Dawson, Klinger, Panagiotides, Hill, & Spieker, 1992). During a playful interaction, infants of symptomatic mothers did not show increased relative left frontal activation, and during maternal separation, these same infants did not show the expected increased right frontal activation. Similarly, another study showed that when viewing a happy video clip designed to induce positive affect, infants of depressed mothers had significantly higher right frontal asymmetry than infants of mothers without depression (Jones, Field, Fox, Davalos, & Gomez, 2001).

A second important reason to study mothers with depression and their infants, in terms of mother-infant positive affect synchrony, is that depression in mothers is associated with lower mother-infant positive affect synchrony. In a meta-analytic review, more severe depression in mothers was associated with their lower levels of positive behavior during interactions with their children (Lovejoy, Graczyk, O'Hare, & Neuman, 2000). Moreover, the effect sizes were larger for mother-infant interactions than for mother-toddler interactions, implying that maternal depression is more salient during mother-infant interactions. Depression in mothers may impede mothers' ability to quickly and accurately detect and respond to shifts in infants' affect expression (Feldman, 2007). Consistent with these ideas, a review by T. Field, Healy, and LeBlanc (1989) found that depression in mothers is associated with a lower frequency of moments of positive affect synchrony with their infants.

The Current Study

Greater mother-infant positive affect synchrony is associated with a number of positive outcomes for infants, including infants' development of emotion regulation capabilities (Leclère et al., 2014). Elevated depression symptoms in mothers are associated with lower levels of mother-infant positive affect synchrony and with infants' greater emotional dysregulation (Manian & Bornstein, 2009) and more relative right frontal asymmetry that is stable throughout the first year (T. Field, 1998). We build on these findings by testing the hypothesis that, among infants of mothers at risk for perinatal depression, the proportion of time the dyad spend in positive affect synchrony will be positively associated with infants' greater relative left frontal asymmetry. Furthermore, although history of depression is a strong predictor of perinatal depression, justifying our recruitment strategy, not all mothers at risk for perinatal depression experience a recurrence of depression (Goodman & Tully, 2009). Thus, we examine that association separately for those with postnatal depression occurrence relative to those who stay well. We hypothesize that the association would be stronger for those who have a recurrence of depression concurrent with the time of the observed interaction and measurement of infant EEG. Although we had no specific hypothesis about changes in the association between mother-infant positive affect synchrony and infant frontal EEG asymmetry, we tested the association at three points in time across infants' first year of life.

Method

Participants

The data for this study were originally collected as part of the longitudinal study *Perinatal Stress and Gene Influences: Pathways to Infant Vulnerability.* Pregnant women were recruited from a number of sources, including the Women's Mental Health Program (WMHP) of the Department of Psychiatry and Behavioral Sciences at Emory University, Emory Mood and Anxiety Disorders Program, and the Grady Satellite Clinic. Women were also recruited through methods such as advertisements, annual mailing, postings at the WMHP and other obstetrics practices in Atlanta, Georgia, and through education of Emory University staff members about ongoing research studies.

All participants included in this study met Diagnostic and Statistics Manual of Mental Disorders- Fourth Edition (DSM-IV) criteria for a previous Major Depressive

Episode (MDE), and many of the women also met criteria for obsessive compulsive disorder, generalized anxiety disorder, or post-traumatic stress disorder. Additional inclusion criteria were attending at least one laboratory visit when the infant was aged 3-, 6-, or 12-months, being less than 16 weeks pregnant measured from last menstrual period, being between ages 18 and 45, being fluent in both written and verbal English, and being able to give informed consent and abide by study procedures. Participants were not included in the study if they met any of the following exclusion criteria: active suicidality or homicidality, having psychotic symptoms, meeting DSM-IV criteria for bipolar disorder, schizophrenia, and/or currently active eating disorder, having an active substance use disorder within six months prior to last menstrual period and/or positive urine drug screen, illness requiring treatment that can influence outcomes such as epilepsy, asthma, autoimmune disorders, and having abnormal thyroid stimulating hormone or anemia. To assess for these criteria, potential participants in the study responded to questionnaires and were administered the full structured Clinical Interview for the Diagnostic and Statistical Manual- IV Axis I Disorders – Patient Edition (SCID) (First, Spitzer, Gibbon, & Williams, 1995).

Procedure

This study was approved by the Emory Institutional Review Board, and all women were engaged in informed consent. The study utilized a longitudinal design, and data was collected from the mothers at different time points throughout pregnancy and postpartum. The data from 1 week through 52 weeks postpartum were the focus of this study. Mothers completed SCID interviews a number of times throughout the first year postpartum. Data for the mother-infant interactions and infant EEG were collected at three laboratory visits that occurred when the infants were 3-, 6-, and 12-months of age. At each lab visit, mothers and their infants were video-recorded and infants' EEG was recorded during a 3-minute baseline, 5-minute feeding, and 5-minute free play segment. Prior to the baseline segment, an EEG cap was fastened to the infant's head while a research assistant manipulated toys to distract the infant. The 3-minute baseline segment, in which the infants sat on their mothers' laps and watched a research assistant blow bubbles, was designed to calm and quiet the infants while keeping them alert and minimizing eye and body movements. The 5-minute feeding segment was a time for the mother to breast- or bottle-feed her infant. For the final 5-minute play segment, mothers were instructed to play with her infant any way she would like using a box of toys provided by the laboratory. Only the play segment is included in the current study, as justified by the reviewed literature.

Measures

Positive Affect Synchrony. Positive affect scores were calculated from observational coding of mothers' and infants' affect from the video recordings of the mother-infant 5-minute face-to-face play interaction during the 3-, 6-, and 12-month laboratory visits. Two independent teams separately coded mothers' and infants' observed moment-to-moment affect using Mangold International's Interact Video Coding Software (Mangold, 2010). The teams consisted of undergraduate research assistants who underwent a training process in which they practiced coding and discussed disagreements with a graduate student and principal investigator. Coders were deemed trained when inter-rater reliability was demonstrated by a kappa greater than .80 on four consecutive coded segments. Inter-rater reliability was 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. Inter-rater reliability yielded a kappa of .90 for maternal affect and .60 for infant affect.

Affect was coded based on mothers' and infants' moment-to-moment expressions. The expressions were classified into different valences of negative (tension/negative interest, brief distress/frown/protest/fuss, and marked distress/cry), neutral, or positive (positive interest, smile/excitement, and laughter/squeal) affect, with codes modified from Dawson et al. (1999). Using the separately coded affect scores for the mothers and infants, following Feldman, Magori-Cohen, Galili, Singer, and Louzoun (2011) and Goodman, Bakeman, McCallum, Rouse, and Thompson (2017), we computed a score for positive affect synchrony as the proportion of time that mothers matched their infants' positive affect (given that their infants were in positive affective states).

EEG (Bell, personal communication, November 18, 2009). The baseline 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.) 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 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 the 16 electrode sites evenly distributed across the head (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 then were 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) and early childhood (Fox, Henderson, Rubin, Calkins, & Schmidt, 2001). The power was expressed as mean square microvolts and the data transformed using the log (ln) to normalize the distribution.

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 score reflects greater right frontal activation, whereas a positive asymmetry score reflects greater left frontal activation.

Depression in Mothers. The Structured Clinical Interview for DSM-IV Axis I disorders (SCID) is a semi-structured diagnostic interview designed to assess for any past history or current diagnostic status of any Axis I disorders based on the DSM-IV (American Psychiatric Association, 1994; First et al., 1995). The SCID was administered by trained research assistants during the initial screening and following visits, with reliability determined by a senior psychiatric nurse who listened to the audiotapes of each interview and independently assigned diagnoses. The initial SCID was used both to determine eligibility for the study such that all women met criteria for at least one prior or current major depressive episode (MDE). Follow up SCIDs provided data on MDEs that may have occurred during the first year post-partum. For the purposes of this study, we classified women as having met diagnostic criteria for at least one MDE or not during the three months prior to the 3- and 6-month data collection visits and during the six months prior to the 12-month data collection visit.

Data Analytic Strategy

To determine the characteristics of the participants, we ran frequency analyses for socio-demographic variables, including gender of infant, race of infant, race of mother, age of mother at delivery, education level of mother, marital status, and socioeconomic status.

Next, we determined the normality and variance for our variables at each time point. For the overall sample at each laboratory visit, we had sample sizes large and equal enough to assess normality based on visual observation of histograms and skew. We additionally ran a Kolmogorov-Smirnov test and a Shapiro-Wilk test for positive affect synchrony and frontal asymmetry for each laboratory visit to assess for normality.

Then, we compared mother-infant positive affect synchrony data and infants' frontal asymmetry data separately for mothers who had experienced an MDE in the time period before each laboratory visit or not. For both the synchrony and asymmetry variables at each time point, we ran a Levene's test to assess for homogeneity in variance and a Kolmogorov-Smirnov test and Shapiro-Wilk test to assess normality of distribution. Bearing in mind that the number of women in the MDE group at each age was expected to be smaller than those in the no MDE group, we used the higher powered and preferred Shapiro-Wilk test in addition to visual observation of histograms and box plots to assess for normality (Ghasemi & Zahediasl, 2012). Comparing the skews between the two groups would be less informative and possibly misleading due to the difference in sample sizes and the presence of outliers.

Upon finding that all of our variables had statistically equal variances, but several of our variables had distributions that differed from normal distribution, we considered the possibility of using a square root or log transformation to correct for the not normal distribution. However, due to the possible different implications of what a transformation would mean for different sample sizes (A. Field, 2009), we decided against a transformation and to run the analyses with the raw data.

To test the primary hypothesis, we ran three bivariate Pearson's correlations between proportion of time in mother-infant positive affect synchrony and infant frontal asymmetry, one for each infant age (3-, 6-, and 12-months). To take into consideration dyads that included mothers who had experienced recent MDE or not, we ran three additional bivariate Pearson's correlations for positive affect synchrony and infant frontal asymmetry for the MDE mother group and no MDE mother group separately.

Results

Preliminary Analyses and Descriptive Statistics

Of the 224 mother-infant dyads that participated in the 3-month lab visit, 62 (27.7%) were excluded, 162 (72.3%) had positive affect data, 157 (70.1%) had EEG data, and 151 (67.4%) had both positive affect data and EEG data. Of the 212 mother infant dyads that participated in the 6-month lab visit, 51 (24.1%) were excluded, 161 (75.9%) had positive affect data, 158 (74.5%) had EEG data, and 151 (71.2%) had both positive affect data and EEG data. Of the 161 mother infant dyads that participated in the 12-month lab visit, 36 (22.4%) were excluded, 125 (77.6%) had positive affect data, 109 (67.7%) had EEG data, and 107 (66.5%) had both positive affect data and EEG data. This resulted in our final sample of 192 mother-infant dyads that had both usable positive affect data and usable EEG data for at least one of the three lab visits. See Table 1 for descriptive demographic characteristics of participants and Table 2 for the number and percentage of women who met criteria for MDE in the months prior to each data collection time period.

Next, we looked at the descriptive statistics and measures of normality of proportion of time in positive affect synchrony and frontal asymmetry scores for the three age points. Refer to Table 3, Table 4, and Table 5 for descriptive statistics of duration of mother and infant positive affect, proportion of time in mother-infant positive affect synchrony, and infant frontal EEG asymmetry at each time point. Descriptions of skew, kurtosis, and the results of the normality tests are shown in Table 6. All of the positive affect synchrony distributions display some degree of skew, as reported in Table 6. However, contrary to the reported statistics in Table 6, frontal asymmetry scores are normally distributed for all three groups at all three laboratory visits. This finding is based off of observations of box plots and histograms that show a clear normal distribution. The frontal asymmetry statistics reported in Table 6, suggest possible influence by the presence of a small number of strong outliers in frontal asymmetry scores.

Hypothesis Testing

Our first hypothesis states that infant relative left frontal asymmetry will be positively associated with the proportion of time spent in positive affect synchrony with their mothers during a 5 minute play interaction among women at elevated risk for perinatal depression associated with their history of depression. For this first hypothesis, we ran a bivariate Pearson's correlation analysis for proportion of time mothers and infants spent in positive affect synchrony and frontal asymmetry scores at each of the three time points for the sample as a whole. Contrary to the hypothesis, at all three ages, we observed a nonsignificant correlation between positive affect synchrony and frontal asymmetry, $r = -.15$, $p = .06$; $r = -.05$, $p = .564$; and $r = -.05$, $p = .609$, for 3-, 6-, and 12-months respectively.

Our second hypothesis states that infants of mothers with current or recent depression will have a negative association between proportion of time spent in positive affect synchrony and left frontal asymmetry. For this second hypothesis, we ran a bivariate Pearson's correlations for each follow-up time-point (3-, 6-, and 12-months postpartum) to assess the strength of the association between proportion of time spent in positive affect synchrony and infant frontal asymmetry scores separately for mothers who had experienced MDE in the preceding quartile (or the preceding half year, for the 12-

month data) and mothers who had not experienced MDE in the preceding quartile. As shown in Figure 1 and Figure 2, at the 3-month time point, contrary to the hypothesis, and similar to the findings for the first hypothesis with the sample as a whole, there were no significant associations at any time-point between proportion of time spent in positive affect synchrony and infant frontal asymmetry either among dyads with depressed mothers and dyads with non-depressed mothers. However, as shown in Figure 4, for the 6-month time point, consistent with our hypothesis, we see a significant negative association between proportion of time spent in positive affect synchrony and infant frontal asymmetry among dyads with depressed mothers. As shown in Figure 3, we do not see a significant association at this time point for dyads with non-depressed mothers, and the effect size is very weak. Similarly, as shown in Figure 6, at the 12-month time point, we see a non-significant association with a moderate effect size between proportion of time spent in positive affect synchrony and infant frontal asymmetry among dyads with depressed mothers. For dyads with non-depressed mothers, there is not a significant association and a very weak effect size, as shown in Figure 5. See Table 7, Table 8, and Table 9 for intercorrelations at the three time-points.

Discussion

Overall, our first hypothesis that dyads with mothers at risk for perinatal depression will show a positive association between proportion of time spent in positive affect synchrony and infants' greater relative left frontal symmetry was not supported. We first looked at the proportion of time mothers and infants spent in positive affect synchrony during play in relation to infant frontal asymmetry scores during play at 3-, 6-, and 12-months of age for the sample as a whole, i.e. among women with history of depression episodes. It is widely held that during the first year of life, infants rapidly acquire social and emotional regulation skills, with much of that acquisition possibly facilitated by sensitive interactions with their mothers. Infants begin life dependent on their caregivers to co-regulate their arousal, and over the course of the first year gradually increase the extent to which they can engage in self-regulation (Calkins, 2015). Maternal sensitivity is conceptualized as one mechanism by which infants learn self-regulation. Sensitive mothers tend to mitigate affect extremes in infants by increasing or decreasing their stimulation during play (Zentall et al., 2006). Additionally, sensitive mothers can help teach their child how to regulate emotion by modeling appropriate emotion regulation behaviors themselves. We studied mother-infant positive affect synchrony because it has been proposed as an important aspect of sensitive parenting that promotes infants' development of emotion regulation strategies (Leclère et al., 2014). During moments of positive affect synchrony, mothers are sensitive and responsive to the cues of their infant in order to heightened and maintain infants' positive affective state (Feldman, 2003). Thus, mother-infant positive affect synchrony is an adaptive mechanism by which mothers teach and infants learn emotion regulation strategies.

In addition to positive affect synchrony, we studied infants' EEG frontal asymmetry as a neurological index of infant emotionality. Researchers have shown that left frontal asymmetry is indicative of approach motivation and positive affect and right frontal asymmetry is indicative of withdraw motivation and negative affect, including during infancy (Coan & Allen, 2004; Davidson, 1993). Greater relative right frontal asymmetry is associated with depression in mothers (Jones et al., 2001).

Given the reviewed findings on the importance of sensitive parenting for infants' development of emotion regulation and associations between depression in mothers and both less mother-infant positive affect synchrony and greater right frontal asymmetry, we hypothesized that higher proportion of time spent in positive affect synchrony would be related to increased relative left frontal asymmetry. Contrary to our hypothesis, for the sample as a whole, our results show no significant associations between proportion of time spent in positive affect synchrony during play and infant frontal asymmetry scores. Interestingly, the five dyads that show the most positive affect synchrony are not the same five dyads that had the most relative left frontal asymmetry, which provides further evidence that more positive affect synchrony is not related to frontal asymmetry in infants at 3-months. On the other hand, at the 6- and 12-month laboratory visits, the distribution looked quite different with the majority of dyads spending the majority of time in positive affect synchrony during the play activity. The frontal asymmetry scores have roughly the same distribution at all three time points. Like with the 3-month scores, at 6- and 12-months, the five dyads that show the highest and lowest proportion of positive affect synchrony are not the same five dyads that show the most relative left or right asymmetry.

We sampled mothers at risk for perinatal depression, with risk defined as mothers having met diagnostic criteria for a major depressive episode at least once in their lifetimes. Given this sampling strategy, we were able to examine associations between mother-infant positive affect synchrony and infant frontal EEG asymmetry separately for women who did or did not have a recurrence of depression during the postpartum year. We expected the association between proportion of time spent in positive affect synchrony and left frontal asymmetry to be negative for the former group. This hypothesis was based on findings that elevated depression symptoms in mothers are associated with less positive affect synchrony, as reviewed by T. Field (1987) and that depression in mothers is associated with infant frontal asymmetry.

Our results show that our hypothesis was partially supported. For mothers who had experienced a recent MDE, at the 6-month and 12-month time points, we found moderate effect sizes for the association between left frontal asymmetry and positive affect synchrony. Interestingly, for dyads with mothers who experienced an MDE in the second quartile postpartum, at the 6-month time point, we see that most of the infants exhibit greater relative left frontal activation, and the few infants that exhibit greater relative right frontal activation are the infants that have the highest proportion of positive affect synchrony. This finding is supported by Dawson, Frey, et al. (1997), which showed that infants of mothers with depression have lower relative left frontal asymmetry. On the other hand, for dyads with mothers who experienced an MDE in the third or fourth quartile postpartum, at the 12-month time point, we see that most of the infants exhibit greater relative right frontal asymmetry. This finding is supported by T. Field (1998), which showed that infants of mothers with depression have greater relative right frontal asymmetry. Given the moderate effect sizes for these associations for mothers with recent depressive episodes, our results show that for infants of mothers with depressive episodes between the second and fourth quartile postpartum, there is an association between proportion of time spent in positive affect synchrony and infant frontal EEG asymmetry.

Our failure to find significant associations between positive affect synchrony and frontal asymmetry scores for either infants of mothers with current depression or infants of mothers without depression at 3-months cannot be explained by the distribution of scores. That is, as for the sample as a whole we looked at the dyads with the highest and lowest proportion of positive affect synchrony in each group and found that they did not match up with the dyads that showed the most relative left or right frontal asymmetry. Additionally, it is important to note that these findings are correlational and could still be influenced by possible third variables, such as infant temperament or other physiological indices.

Limitations

There are several limitations that are important to bear in mind when interpreting the results of our study. First, we sampled women all of whom had a history of at least one MDE, so the results cannot be generalized to women without a history of depression. Yet in considering this limitation, it should be noted that postnatal depression is often preceded by pre-pregnancy or prenatal depression, suggesting that our sampling strategy is highly justified. Another limitation with our sample was that it was fairly homogenous in terms of race and socioeconomic status, so the results cannot be generalized to more racially diverse or disadvantaged populations.

We should also use caution in interpreting the findings from our second hypothesis in that the sample sizes for the groups who met criteria for MDE were relatively small. Larger sample sizes allow for a higher probability of outliers than smaller sample sizes. Thus, we encourage attempts to replicate this finding.

Future Directions

Mother-infant positive affect synchrony is an important construct to study due to the implications on advantageous aspects of infant development. We were also interested in researching negative affect synchrony and its associations with parenting behaviors, infant emotional development, and infant neurological correlates. However, due to a very small amount of observed negative affect synchrony during the play interactions, we could not use negative affect synchrony as a construct in our study. An interesting next step for future studies would be to induce negative affect in mothers and/or infants, enabling examination of proportion of negative affect synchrony in relation to infant frontal asymmetry and postpartum depression in mothers. We are familiar with studies on infant negative affectivity and negative affect toward mothers, but we have yet to see a study that assesses negative affect synchrony in relation to infant emotional development and maternal depressive status.

Additionally, we are following up on studies on adults comparing frontal asymmetry at rest and frontal asymmetry during emotion induction paradigms, which have yielded interesting results that support that frontal asymmetry scores during emotional challenge is a better predictor for symptoms of depression than frontal asymmetry scores at rest (Stewart, Coan, Towers, & Allen, 2014). Given this finding, we propose that a better test of our hypotheses might be to examine infants' frontal asymmetry averaged exclusively across the moments of positive affect synchrony rather than for the full duration of the play segment. Furthermore, we will compare infant frontal asymmetry scores during moments of positive affect synchrony to frontal asymmetry scores during moments of positive infant affect that is not matched by the mothers. We hope that this research will build on the growing body of evidence that supports positive affect synchrony as an important experience for the development of infant emotion regulation capabilities.

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Table 1
Participant Demographics

Variable	*Mean*	*SD*	%
Mothers' Age at Delivery (years)	33.8	4.5	
Socioeconomic Status (Hollingshead Score)	50.35	9.2	
Marital Status (%)			
Married			88
Mother's Race (%)			
European American			88.5
African American			8.9
Asian American			1
Native American			1
Multiple			0.5
Infant's Race (%)			
European American			87
African American			7.8
Multiple			5.2
Infant's gender (female)			48.4

Note. *N* = 192 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

Depression Status by Quartile Postpartum

Variable	*N*	%
First Quartile (0 – 13.0 weeks postpartum)	151	100
MDE	22	14.6
No MDE	120	79.4
Unreported	9	6
Second Quartile (13.1 – 26.0 weeks postpartum)	151	100
MDE	17	11.3
No MDE	109	72.2
Unreported	25	16.5
Third and Fourth Quartile (26.1 – 52 weeks postpartum)	107	100
MDE	16	15
No MDE	87	81.3
Unreported	4	3.7

Note. MDE = Major Depressive Episode

Table 3
Descriptive Statistics for Positive Affect (PA) and Frontal Asymmetry Variables at 3 Months

Variable	*M*	*SD*	*min*	*max*
Total Sample (N=151)				
Duration infant in PA (seconds)	72.9	70.1	0	292.1
Duration mother in PA (seconds)	234.9	68.6	0	364
% time PA synchrony	70.3	37.6	0	100
Frontal asymmetry score	0.06	0.69	-4.46	5.81
MDE in First Quartile (N = 22)				
Duration infant in PA (seconds)	65.3	67.1	0	265.1
Duration mother in PA (seconds)	215.7	67	65.1	306.1
% time PA synchrony	57.4	42.9	0	100
Frontal asymmetry score	0.12	0.30	-0.59	0.66
No MDE in First Quartile (N = 120)				
Duration infant in PA (seconds)	72.8	67.1	0	265.1
Duration mother in PA (seconds)	236.2	70.8	0	364
% time PA synchrony	72.2	36.8	0	100
Frontal asymmetry score	0.02	0.53	-4.46	2.1

Note. PA = Positive Affect

Table 4

Descriptive Statistics for Positive Affect (PA) and Frontal Asymmetry Variables at 6 Months

Variable	*M*	*SD*	*min*	*max*
Total Sample (N=151)				
Duration infant in PA (seconds)	264.3	50.5	88	340.2
Duration mother in PA (seconds)	248.1	61.9	55.1	360.1
% time PA synchrony	80.3	19.5	16	100
Frontal asymmetry score	0.10	0.56	-3.08	4.02
MDE in Second Quartile (N = 17)				
Duration infant in PA (seconds)	280.3	30.6	209	340.2
Duration mother in PA (seconds)	250.2	70.2	76.1	321.2
% time PA synchrony	80.3	21.8	21	100
Frontal asymmetry score	0.13	0.28	-0.33	0.57
No MDE in Second Quartile (N = 109)				
Duration infant in PA (seconds)	265.6	50.9	88	334.1
Duration mother in PA (seconds)	250.4	61	55.1	360.1
% time PA synchrony	81.1	18.8	16	100
Frontal asymmetry score	0.14	0.56	-1.18	4.02

Note. PA = Positive Affect

Table 5

Descriptive Statistics for Positive Affect (PA) and Frontal Asymmetry Variables at 12 Months

Variable	*M*	*SD*	*min*	*max*
Total Sample (N=107)				
Duration infant in PA (seconds)	252.6	58	20.1	314.2
Duration mother in PA (seconds)	220.4	55.5	53.2	310
% time PA synchrony	72.6	18.7	17	100
Frontal asymmetry score	0.03	0.71	-5.73	3.31
MDE in Third or Fourth Quartile (N = 16)				
Duration infant in PA (seconds)	261.4	32.7	194	299.1
Duration mother in PA (seconds)	211.6	62.1	61.2	290
% time PA synchrony	69.1	20.2	19	93
Frontal asymmetry score	-0.02	0.23	-0.49	0.47
No MDE in Third or Fourth Quartile (N = 87)				
Duration infant in PA (seconds)	250.5	62.5	20.1	314.2
Duration mother in PA (seconds)	222.7	54.5	53.2	310
% time PA synchrony	73.3	18.3	17	100
Frontal asymmetry score	0.03	0.78	-5.73	3.31

Note. PA = Positive Affect

Table 6

Skewness, Kurtosis and Normality Tests

								Shapiro-Wilk		*Levene's Test of Homogeneity of Variance*		
Variable	*Sample Size*	*Skewness*	$SE_{skewness}$	$Z_{skewness}$	*Kurtosis*	$SE_{kurtosis}$	$Z_{kurtosis}$	*Statistics*	*p-value*	*Sample Size*	*Statistic*	*p-value*
3 Month												
% time PA synchrony - total	151	-1.04	0.20	-5.20	-0.54	0.39	-1.38	.74	.000	140	2.24	.137
% time PA synchrony - MDE	22	-0.46	0.49	-0.94	-1.64	0.95	-1.72	.78	.000			
% time PA synchrony - No MDE	120	-4.65	0.22	-21.14	-0.29	0.44	-0.66	.72	.000			
Frontal asymmetry score - total	151	2.20	0.20	11.16	44.84	0.39	114.39	.51	.000	140	0.07	.787
Frontal asymmetry score - MDE	22	-0.25	0.49	-0.51	0.43	0.95	0.45	.98	.900			
Frontal asymmetry score - No MDE	120	-4.65	0.22	-21.06	46.13	0.44	105.32	.56	.000			
6 Month												
% time PA synchrony out of total segment - total	151	-1.30	0.20	-6.50	1.19	0.39	3.04	.86	.000	124	0.21	.652
% time PA synchrony out of total segment - MDE	17	-1.64	0.55	-2.98	2.44	1.06	2.30	.81	.003			
% time PA synchrony out of total segment - No MDE	109	-1.27	0.23	-5.52	1.07	0.46	2.33	.86	.000			
Frontal asymmetry score - total	151	1.88	0.20	9.55	24.55	0.39	62.62	.62	.000	124	0.39	.533
Frontal asymmetry score - MDE	17	0.08	0.55	0.15	-1.05	1.06	-0.99	.94	.292			
Frontal asymmetry score - No MDE	109	4.08	0.23	17.67	23.79	0.46	51.83	.61	.000			
12 Month												
% time PA synchrony out of total segment - total	107	-0.73	0.23	-3.12	0.24	0.46	0.52	.95	.001	101	0.36	.551
% time PA synchrony out of total segment - MDE	16	-0.93	0.56	-1.66	0.85	1.09	0.78	.92	.160			
% time PA synchrony out of total segment - No MDE	87	-0.70	0.26	-2.69	0.26	0.51	0.51	.96	.006			
Frontal asymmetry score - total	107	-4.12	0.23	-17.60	46.19	0.46	99.76	.45	.000	101	0.38	.540
Frontal asymmetry score - MDE	16	0.23	0.56	0.40	0.65	1.09	0.59	.98	.955			
Frontal asymmetry score - No MDE	87	-3.84	0.26	-14.88	38.86	0.51	76.05	.46	.000			

Note. PA = Positive Affect

Note. MDE = Major Depressive Episode

Table 7

Intercorrelations among Proportion of Time Spent in Positive Affect Synchrony and Infant EEG Asymmetry Scores at Infant Age 3 Months

	1	2	M	SD
1. Proportion of PA Synchrony	__	.07	0.57	0.43
2. Frontal Asymmetry Score	-.06	__	0.12	0.3
M	0.72	0.02		
SD	0.37	0.53		

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

Note. PA = Positive Affect Synchrony

Note. MDE = Major Depressive Episode

Note. Intercorrelations for MDE mothers (n=120) are displayed above the diagonal, and intercorrelations for no MDE mothers (n=22) are displayed below the diagonal. Means and standard deviations for MDE mothers are displayed in the vertical columns, and means and standard deviations for no MDE mothers are displayed in the horizontal rows.

Table 8

Intercorrelations among Proportion of Time Spent in Positive Affect Synchrony and Infant EEG Asymmetry Scores at Infant Age 6 Months

	1	2	M	SD
1. Proportion of PA Synchrony	__	-.48*	0.8	0.22
2. Frontal Asymmetry Score	-.02	__	0.13	0.28
M	0.81	0.14		
SD	0.19	0.56		

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

Note. PA = Positive Affect Synchrony

Note. MDE = Major Depressive Episode

Note. Intercorrelations for MDE mothers (n=109) are displayed above the diagonal, and intercorrelations for no MDE mothers (n=17) are displayed below the diagonal. Means and standard deviations for MDE mothers are displayed in the vertical columns, and means and standard deviations for no MDE mothers are displayed in the horizontal rows.

Table 9

Intercorrelations among Proportion of Time Spent in Positive Affect Synchrony and Infant EEG Asymmetry Scores at Infant Age 12 Months

	1	2	M	SD
1. Proportion of PA Synchrony	__	-.49	0.69	0.2
2. Frontal Asymmetry Score	-.03	__	-0.02	0.23
M	0.73	0.03		
SD	0.18	0.78		

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

Note. PA = Positive Affect Synchrony

Note. MDE = Major Depressive Episode

Note. Intercorrelations for MDE mothers (n=87) are displayed above the diagonal, and intercorrelations for no MDE mothers (n=16) are displayed below the diagonal. Means and standard deviations for MDE mothers are displayed in the vertical columns, and means and standard deviations for no MDE mothers are displayed in the horizontal rows.

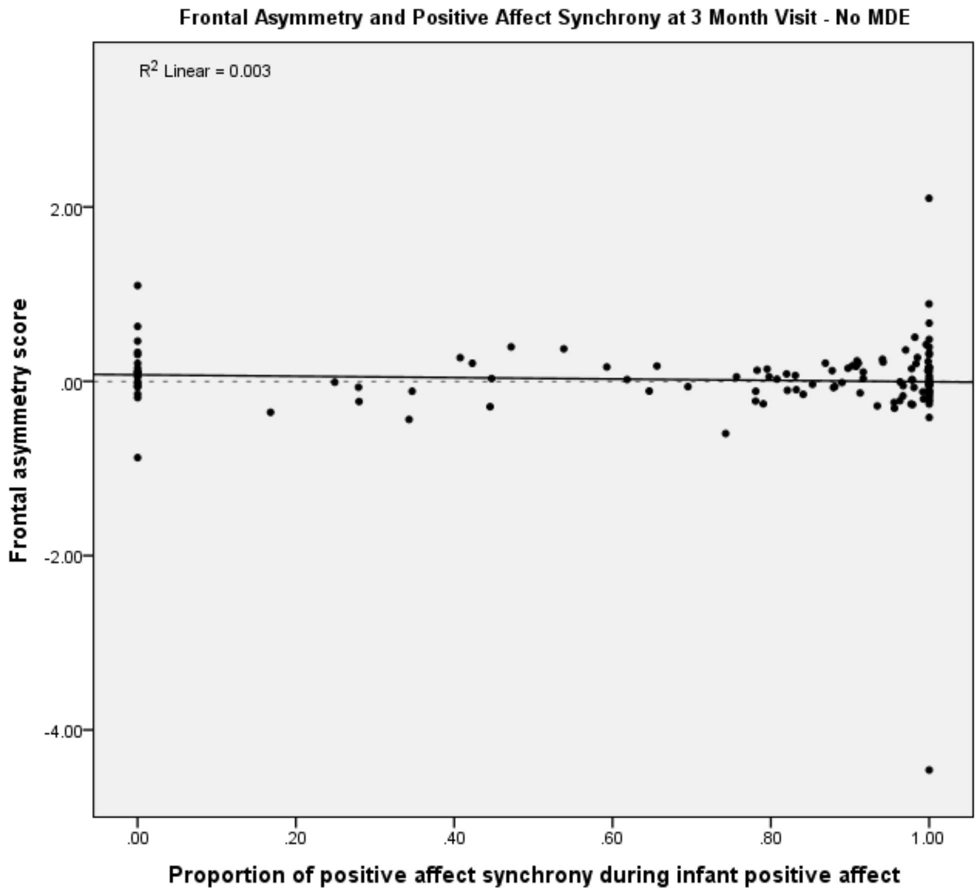

Figure 1. The relationship between infant frontal EEG asymmetry score and proportion of time infants and mothers spend in positive affect synchrony during a 5-minute play activity when the infant age is 3-months and the mothers had not experienced a major depressive episode (MDE) in the first quartile postpartum. Positive asymmetry scores indicate greater relative left frontal activation, which is related to approach motivation. Negative asymmetry scores indicate greater relative right frontal activation, which is related to withdraw motivation. There is little to no correlation between frontal asymmetry score and positive affect synchrony for dyads with mothers who did not have an MDE in the first quartile postpartum.

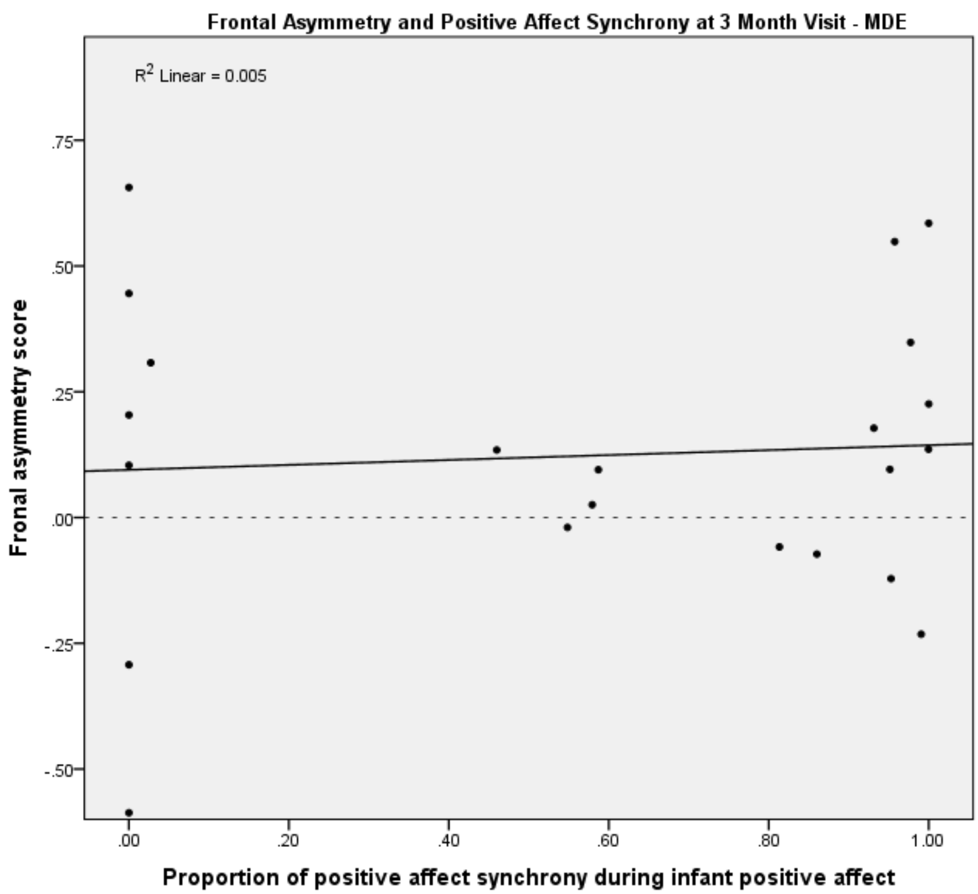

Figure 2. The relationship between infant frontal EEG asymmetry score and proportion of time infants and mothers spend in positive affect synchrony during a 5-minute play activity when the infant age is 3-months and the mothers experienced a major depressive episode (MDE) in the first quartile postpartum. Positive asymmetry scores indicate greater relative left frontal activation, which is related to approach motivation. Negative asymmetry scores indicate greater relative right frontal activation, which is related to withdraw motivation. There is little to no correlation between frontal asymmetry score and positive affect synchrony for dyads with mothers who experienced an MDE in the first quartile postpartum.

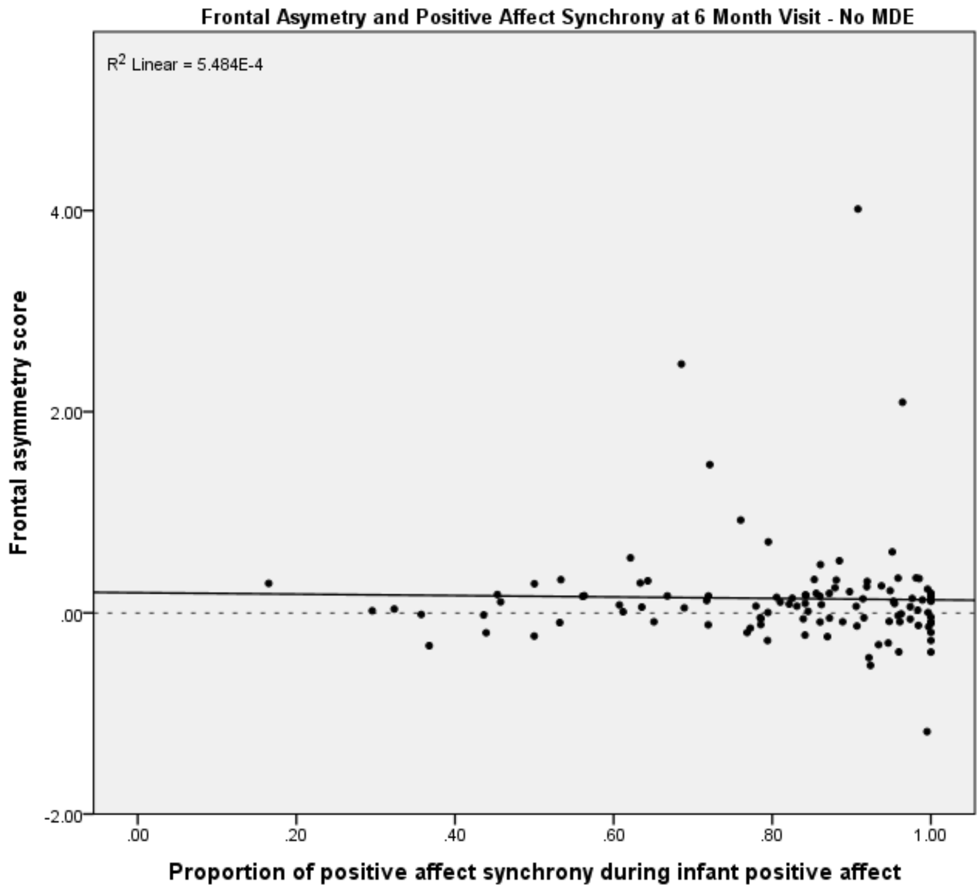

Figure 3. The relationship between infant frontal EEG asymmetry score and proportion of time infants and mothers spend in positive affect synchrony during a 5-minute play activity when the infant age is 6-months and the mothers had not experienced a major depressive episode (MDE) in the second quartile postpartum. Positive asymmetry scores indicate greater relative left frontal activation, which is related to approach motivation. Negative asymmetry scores indicate greater relative right frontal activation, which is related to withdraw motivation. There is little to no correlation between frontal asymmetry score and positive affect synchrony for dyads with mothers who did not have an MDE in the second quartile postpartum.

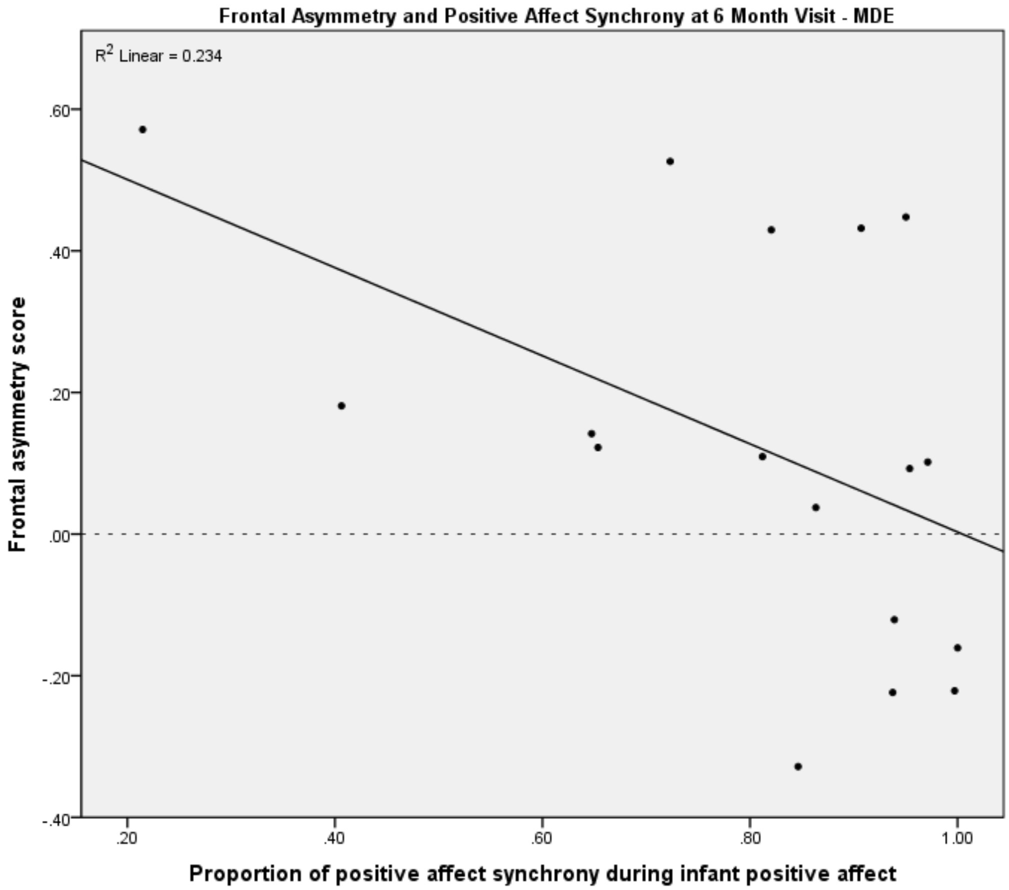

Figure 4. The relationship between infant frontal EEG asymmetry score and proportion of time infants and mothers spend in positive affect synchrony during a 5-minute play activity when the infant age is 6-months and the mothers experienced a major depressive episode (MDE) in the second quartile postpartum. Positive asymmetry scores indicate greater relative left frontal activation, which is related to approach motivation. Negative asymmetry scores indicate greater relative right frontal activation, which is related to withdraw motivation. There is a significant and moderate negative correlation between frontal asymmetry score and positive affect synchrony for dyads with mothers who experienced an MDE in the second quartile postpartum.

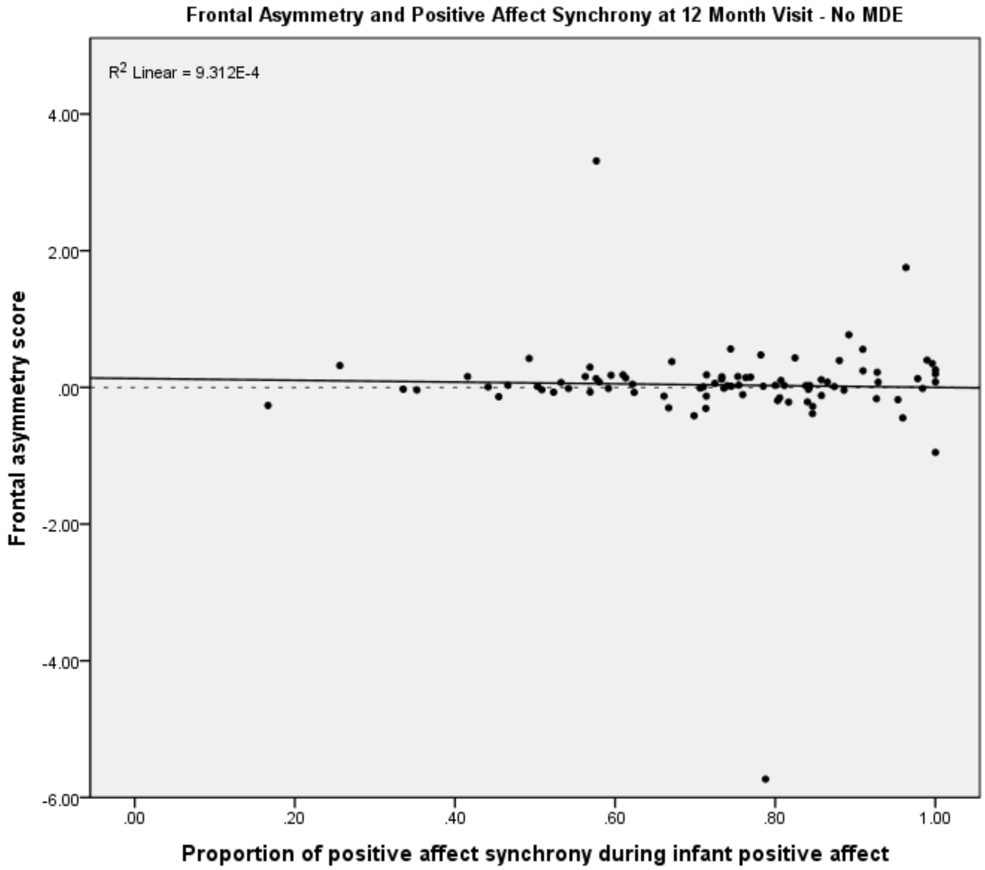

Figure 5. The relationship between infant frontal EEG asymmetry score and proportion of time infants and mothers spend in positive affect synchrony during a 5-minute play activity when the infant age is 12-months and the mothers had not experienced a major depressive episode (MDE) in the third or fourth quartiles postpartum. Positive asymmetry scores indicate greater relative left frontal activation, which is related to approach motivation. Negative asymmetry scores indicate greater relative right frontal activation, which is related to withdraw motivation. There is little to no correlation between frontal asymmetry score and positive affect synchrony for dyads with mothers who did not have an MDE in the third or fourth quartiles postpartum.

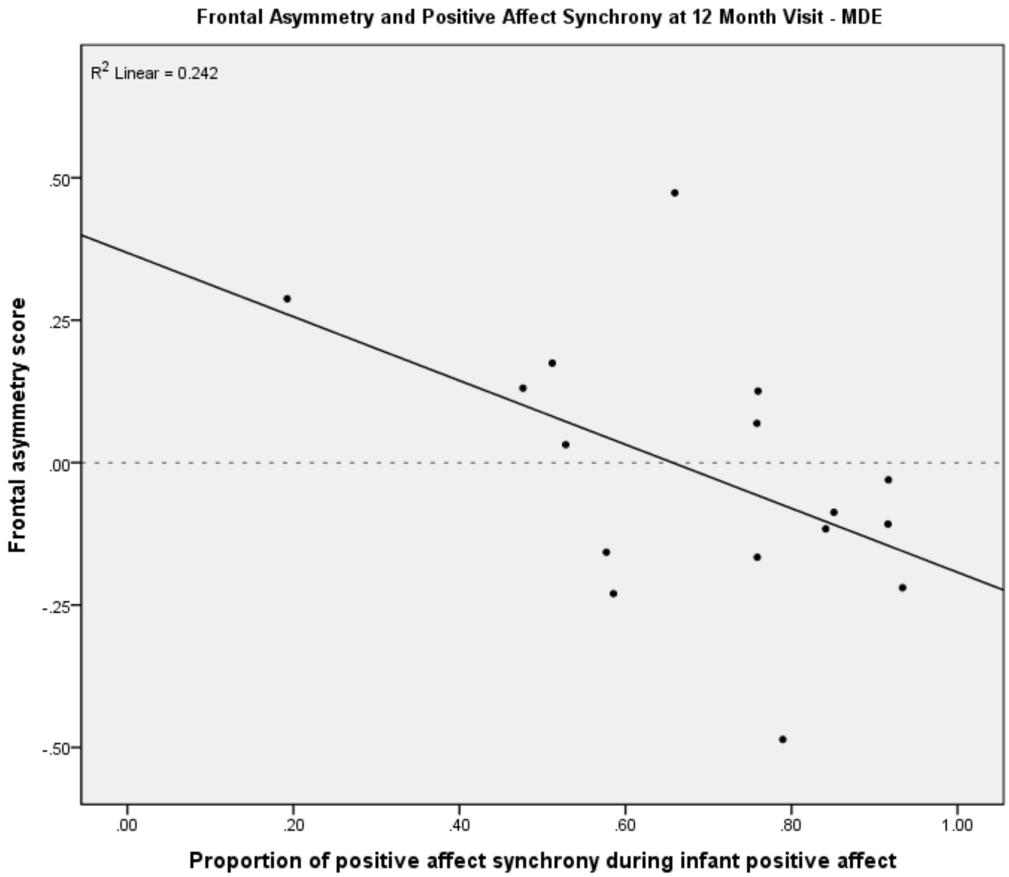

Figure 6. The relationship between infant frontal EEG asymmetry score and proportion of time infants and mothers spend in positive affect synchrony during a 5-minute play activity when the infant age is 12-months and the mothers experienced a major depressive episode (MDE) in the third or fourth quartiles postpartum. Positive asymmetry scores indicate greater relative left frontal activation, which is related to approach motivation. Negative asymmetry scores indicate greater relative right frontal activation, which is related to withdraw motivation. There is a non-significant, yet moderate negative correlation between frontal asymmetry score and positive affect synchrony for dyads with mothers who experienced an MDE in the third or fourth quartiles postpartum.