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Association between theta power in 6-month old infants at rest and maternal PTSD severity: A pilot study

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Abstract

Compared to infants born to mothers without PTSD, infants born to mothers with active PTSD develop poorer behavioral reactivity and emotional regulation. However, the association between perinatal maternal PTSD and infant neural activation remains largely unknown. This pilot study ($N=14$) examined the association between perinatal PTSD severity and infant frontal neural activity, as measured by MEG theta power during rest. Results indicated that resting left anterior temporal/frontal theta power was correlated with perinatal PTSD severity ($p=0.004$). These findings suggest delayed cortical maturation in infants whose mothers had higher perinatal PTSD severity and generate questions regarding perinatal PTSD severity and infant neurophysiological consequences.

Keywords

posttraumatic stress disorder; theta power; magnetoencephalography; perinatal; infant; left anterior temporal

1. Introduction

Approximately 8% of first-time pregnant women in the United States experience prenatal posttraumatic stress disorder (PTSD) during pregnancy [1] from traumatic events that

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Conflict of interest

The authors declare that there are no conflicts of interest.

occurred either prior to or during pregnancy. Perinatal PTSD might affect infant development through impairment of prenatal bonding, disturbed prenatal care, and postnatal maternal-infant attachment. Interpersonal trauma history [2] or poor psychological functioning [3] are associated with disturbed prenatal bonding and poor mother-infant attachment [4]. Poor prenatal bonding is, in turn, associated with prenatal alcohol exposure [5], poor prenatal health practices [6], and postpartum depression [5] - mechanisms that can impact fetal neural development.

Perinatal PTSD affects emotional and physiological development of infants [7,8], perhaps via maternal corticolimbic dysregulation [9] or impaired responsiveness [10]. Relative to infants born to mothers without PTSD, infants born to mothers with perinatal PTSD face poorer emotional regulation and behavioral reactivity [7] and increased symptom severity if they develop PTSD later [8]. Prenatal anxiety and depression (disorders with PTSD symptom overlap [11]) predict negative behavioral reactivity in infants [12] and neurophysiological differences: infants born to depressed mothers exhibit abnormal frontal electroencephalography (EEG) asymmetry [13]. Perinatal PTSD may have similar effects on developing infant neurophysiology.

Resting neural oscillations reflect local and global brain activity and connectivity [14]. Microstructural changes alter brain function [15], thus assessment of resting oscillations using EEG or magnetoencephalography (MEG) provides an indicator of brain health. In infancy, there is a developmental transition in relative EEG resting spectral power [16] with a reduction in low frequency power (delta and theta bands) and an increase of high frequency power (alpha, beta and gamma) with increasing age [17–19]. Evoked theta oscillations (emerging in response to stimuli) relate to emotional and social processing, and resting theta power may also play such a role.

To the extent that perinatal PTSD interferes with infant development, prenatal identification and treatment of PTSD should improve developmental outcomes. However, it is unknown whether perinatal PTSD translates into neurophysiological changes in the infant brain. A gap in neuroimaging literature exists for infants born to mothers with perinatal PTSD. In this pilot study we examined the association between maternal perinatal PTSD severity and 6-month infant oscillations measured by MEG. We hypothesized that perinatal PTSD severity would be associated with altered infant frontal spectral power.

2. Method

2.1 Participants

Participants were recruited from the Preterm Infants Mu Rhythm Evaluation study (PrIMES). Parents who participated in the PrIMES study were re-contacted by telephone and completed consents and perinatal PTSD questionnaires. The University of New Mexico IRB approved this study.

For the PrIMES study, preterm (N=18) and term infants (N=22) were recruited from a local university-affiliated hospital. Preterm infants were 28 6/7 weeks or less gestational age (GA) at birth and were between the 10th and 90th percentile weight for GA. Full term infants were

>37 weeks GA at birth, with appropriate weight/size and no complications or indications of atypical development. Preterm infants were excluded for Grade II, III or IV intraventricular hemorrhage, periventricular leukomalacia, or neuroimaging abnormality prior to discharge. Additional exclusion criteria included: seizures, intracranial congenital anomalies, microcephaly, chromosomal, or major genetic abnormality. Sixteen mothers were successfully re-contacted for PTSD assessments. Two infants lacked sufficient rest periods for reliable power spectrum estimates (noisy data and movement) and were excluded from analyses, leaving a sample of 14 (5 pre-term, 9 full-term).

2.2 Behavioral Assessment

Neurocognitive functioning was assessed using the Bayley Scales of Infant Development – III [20] at 6 months of age (adjusted for GA). Socioeconomic status was estimated using the Barratt Simplified Measure of Social Status (BSMSS [21]). The Lifetime Events Checklist for DSM5 (LEC-5 [22]) was used to determine number of traumatic events and number of traumatic birth experiences and to identify an index trauma for PTSD assessment. The LEC-5 assesses exposure to 16 index traumas. It was modified to ask whether each event occurred prior to, during, or after becoming pregnant with the study infant. Additionally, we asked about traumatic birth experiences (e.g., miscarriage, fetal demise, still birth). Few psychometric differences are expected for the new LEC-5 from the original LEC reliable version (kappa mean=0.47, range=0.29-0.66) [23], as revisions were minimal [22,23]. Following the LEC-5, the Modified PTSD Symptoms Scale (MPSS [24]) was administered (symptom time period modified to “the time since you found out you were pregnant with this baby”). DSM-IV PTSD symptom severity was calculated by summing frequency and severity scores for all symptoms. The MPSS has good psychometric properties with a sensitivity of 89% [25]. A score of 46 or greater is indicative of PTSD in community samples [24].

2.3 Sensorimotor Mu Rhythm Task

The MEG infant task included three conditions: 1) rest: infant rests quietly during data acquisition, 2) infant squeeze: to identify sensorimotor activation, 3) investigator squeeze: infant observes squeeze. The infant/investigator squeezed a soft pipette connected through water-filled plastic tubing to a pressure transducer, which was connected to the MEG A/D channels marking infant and investigator squeezes. The investigator heard tones every 4 seconds through an ear insert to cue squeezing to minimize the phenomenon of increased frequency with self-paced squeezing. A second investigator outside the shielded room monitored infant rest, infant squeezes, and investigator squeezes to ensure sufficient numbers of epochs for each component (30 epochs/component). Parents engaged with infants as needed. Data collection time ranged from 10-20 minutes depending on infant behavior. The MEG session was video-taped and the video was synchronized to MEG data.

2.4 MEG data collection

MEG data were collected using the Elekta Neuromag 306 channel biomagnetometer and sampled at 1000 Hz with online 0.1-300 Hz anti-aliasing filters. Bipolar EEG channels were attached to each clavicle to assess electrocardiogram (ECG). Electromyogram (EMG) bipolar leads were attached to the left and right infant forearms to capture squeezing (one on

the elbow and one on the forearm muscle). EMG channels captured additional squeezing, as infants may squeeze without the pipette. Finally, forearm EMG placed on the investigator's arm tracked investigator squeezes. A Polhemus 3D tracking device was used to identify infant fiducial points (nasion, left and right preauricular points), MEG HPI coil locations, and EEG sensor array positioning in addition to extra points to outline infant head shape.

Infants were measured in supine position with the left hemisphere positioned close to the sensors to optimize signal strength from left hemisphere [26]. Investigator and parent were seated on either side of the bed. Video-recording and physiological monitoring channels (infant EMG and investigator EMG) characterized behavior during MEG data collection.

2.5 MEG data processing

MEG data were preprocessed and transformed to a standard head position to allow for inter-subject comparisons with a standard head position relative to the sensor array using Maxfilter 2.1. The default head position was determined based on average head position across subjects to minimize the distance that head position was transformed for each infant and avoid noise amplification. After Maxfilter, a cardiac signal space projector (SSP) was generated using Graph [27], because Maxfilter does not reliably remove cardiac artifacts from infant MEG signals.

Video coding of behavior occurred in conjunction with the MEG coding of conditions. Coding identified periods of rest (infant resting arms/hands quietly), periods of infant squeezing (monitor infant arm EMGs and video), and periods of infant attending the investigator while resting quietly (investigator squeezing while infant observed). By monitoring MEG data, infant EMGs, investigator EMGs, pipette pressure signals, and synchronized videos, we reliably identified 2-second intervals of noise-free MEG activity for each condition. Examples are shown in Figure 1.

Coded, 2-second epochs for each condition were extracted from the continuous MEG files using MNE software [28]. Mean spectra were calculated for 12 regions (left and right, frontal, anterior/posterior temporal, central, parietal, and occipital) based on the sensor array (see Figure 2). Because we biased the head position of the infants to improve sensitivity over the left hemisphere, we limited our analysis to left hemisphere. Normalized amplitude spectrum was obtained in the 5 physiological frequency bands (delta: 1-4 Hz, theta: 4-7 Hz, alpha: 8-14 Hz, beta: 15-28 Hz, and gamma: 32-50 Hz) using the FFT function with a 2048 window providing a frequency resolution of 0.488 Hz using custom Matlab scripts. Normalized spectral amplitude was obtained by dividing spectral amplitude at each frequency by total amplitude across the 1-50 Hz range. Due to the relevance of frontal theta to emotional reactivity, our primary interest was examining frontal lobe power. Parietal lobe was a control region. Thus, values from three regions (frontal, left anterior temporal: LAT, and parietal) were compared to PTSD severity in SPSS.

2.6 Statistical analysis

There was no significant PTSD severity difference between preterm infant and full term infant mothers ($t=-1.617$, $p=0.18$). In the PrIMES sample ($N=27$) there were no significant differences between preterm and full term infants on theta power ($p>0.1$). Since no

differences in PTSD or MEG theta power were observed between infant groups, the two groups were combined to evaluate perinatal PTSD severity and infant neurophysiological activity.

We performed a Spearman's correlation to test for an association between maternal PTSD and infant brain dynamics during rest. Multiple comparisons were corrected for using the false discovery rate method of Benjamini and Hochberg [29] with $q=0.1$. Despite concerns about over fitting the data, a post-hoc linear regression was performed with two ordered sets of predictors to analyze the combined association between theta power and PTSD severity controlling for GA.

3. Results

On average 17.7 (SD=8.7) epochs of rest were identified per infant (number of trials did not differ between term/preterm $p=0.5$). (See Table 1.) BSMSS scores (range=12-21) indicated mothers and their family members had high school to graduate school educations and low-middle to upper level occupational status (range=13-42.5). Socioeconomic status was not significantly correlated with PTSD severity, nor was infant GA, birth weight, age at 6-month scanning, or BSID developmental scores (See Table 1). One participant reported no exposure to traumatic events and a PTSD score of zero. See Table 1 for the distribution of traumatic events reported. Number of traumatic events reported was not significantly correlated with PTSD severity, but number of traumatic pregnancies was ($r=0.56$, $p=0.021$).

Accounting for multiple comparisons (delta, theta, alpha and beta bands), only one of the three regions showed a significant correlation with PTSD severity. LAT theta power during rest was significantly correlated with perinatal PTSD severity ($r=0.72$, $p=0.004$, $N=14$, see Figure 3). A multiple regression with infant LAT theta power and infant GA did not increase predictive power of PTSD severity significantly over the first model, R^2 change=0.013, $F(1,11)=0.306$, $p=0.59$. Thus GA offered little additional predictive power beyond infant LAT theta power. Finally, examination of PTSD symptom clusters revealed that all three sub-scales correlated with infant LAT theta power (Reexperiencing $r=0.55$, $p=0.041$; Avoidance $r=0.75$, $p=0.002$; Arousal $r=0.68$, $p=0.008$). Only two mothers had PTSD symptom severity above the screening threshold for PTSD, thus we experimentally removed these two infants from the analysis, and the correlation remained, but was weaker ($r=.26$).

4. Discussion

We found a strong correlation between perinatal PTSD symptom severity and 6-month infant LAT theta power concurrent with prior studies where a developmental shift in resting frontal theta power occurs with increasing age [30], a pattern that emerges pre-birth [31]. Notably, elevated *resting* theta power in young adults born preterm is interpreted as delayed maturation [32]. In our results, greater perinatal PTSD severity similarly corresponded to higher resting theta power, potentially indicating delayed brain maturation in these infants. The LAT sensor region associated with this relationship corresponds with theta power originating from the vicinity of the frontal cortex (Figure 2), consistent with the developmental pattern described previously. Current understanding of low and high

frequency oscillations [14] suggests this emergence may be related to the establishment of long-range connectivity (the role of lower frequency oscillations), which evolves into further development of cognitive capabilities (the role of higher frequency oscillations) as executive function capabilities emerge.

In contrast to resting theta oscillations, *evoked* frontal theta oscillations in adults are associated with social and emotional processing and internally motivated attention processes. Whether spectral power in the same frequency band is associated with similar behavior in infants is an emerging field of study [33]. Recently theta power has been associated with social and emotional processing and attention in infants [34]. Orekhova et al. [35] determined that theta oscillations were modulated by a peek-a-boo game at 9-10 months of age. In 11-month old infants [36] increased theta power during object exploration was related to recognition of the object during a follow-up preferential looking paradigm. Our paradigm assessed resting theta power rather than evoked theta oscillations. The relationship between resting neural oscillations and evoked oscillations is still unknown, however resting oscillations do influence stimulus-evoked neural oscillations [37]. This suggests that future studies are needed to determine if alterations in resting theta oscillations interfere with performance of social/emotional tasks.

To the best of our knowledge, no published studies have assessed infant EEG or MEG measures in association with perinatal PTSD symptoms. An understanding of maternal/infant interactions and implications for infant brain development is also currently emerging. Our results contribute evidence that perinatal maternal mental health (perinatal PTSD) contributes to infant brain development. Further research will determine the role of anterior theta activity in brain development and whether it is associated with risk for development of anxiety or other poor outcomes, including intergenerational transmission of PTSD risk. The correlation between infant resting LAT theta power and perinatal PTSD was weakened with the removal of the two participants above the probable PTSD threshold. This raises intriguing questions about whether PTSD symptom severity must cross a threshold for a strong relationship to emerge.

4.1 Limitations

The primary limitation of this study is the small sample. This retrospective pilot was an addition to a study, and ability to collect data from the full sample was limited. A further limitation is reliance on sensor level analysis for the MEG data. MEG datasets were transformed to a common head position, allowing for valid sensor level comparisons similar to EEG. The current study did not obtain infant MRIs and therefore full source localization was not performed, justifying a follow-up to estimate the cortical location of theta oscillations during rest. Theta in this study was defined as 4-7 Hz minimizing the theta/alpha overlap due to immaturity as discussed by Orekhova [35]. Additionally, the parent study focused on premature birth, thus our sample included 5 premature infants, but this pilot was underpowered to rule out an interaction between perinatal PTSD severity and preterm birth status on theta power. We also cannot rule out overlap between PTSD severity and current maternal depression, as we had no maternal depression scale. Future directions include a full assessment of perinatal anxiety and depression in combination with PTSD diagnosis.

Finally, to reduce participant burden, we used a questionnaire administered via telephone interview to assess PTSD instead of using a more comprehensive diagnostic PTSD interview. This may have reduced the clinical accuracy of PTSD severity.

5. Conclusions

Increased resting LAT theta oscillations are associated with slower cortical maturation in infants. In the present study, a positive association between infant anterior theta power and maternal perinatal PTSD severity suggests delayed cortical maturation in infants with mothers with substantial PTSD severity.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights

- Perinatal PTSD severity is correlated with infant left anterior temporal theta power.
- Perinatal PTSD in mothers may be a risk for delayed infant cortical maturation.
- There may be a threshold perinatal PTSD severity must pass to affect fetal brains.

Figure 1. MEG and video data

MEG and video data were coded as rest, infant squeezing, and investigator squeezing. (a)

Investigator and infant resting (flat top three red EMG channels). EMG061=infant right forearm, MEG062=infant left forearm, and EMG064=investigator forearm.

MSC008=pipette pressure transducer. (b) Deviations in both EMG061 and EMG062 correspond to left and right arm squeezing by infant. (c) Investigator squeeze (infant rest and infant squeeze).

Figure 2. Average head position within the sensor helmet

(a) The template head size is an adult head. However, one can see that the head position is biased to the left hemisphere with anterior temporal/frontal activity measured in left anterior temporal channels. (b) Each region contained an equivalent number of channels and spectral power was measured for each epoch then averaged across epochs. A regional estimate of spectral power was obtained using these channel groups.

Figure 3. Infant LAT theta correlation with maternal perinatal PTSD

The infant regional theta power (in normalized arbitrary units) from the left anterior temporal (LAT) sensor region (shown in Figure 2) is plotted relative to the perinatal PTSD severity score.

Table 1

Sample Demographics and Characteristics

	Sample (N=14)	Correlation with Perinatal PTSD Severity
Mothers	Mean (SD, Range)	
PTSD Severity (MPSS)	17.1 (26.23, 0-87)	
Socioeconomic status (N= 13)	41.6 (10.96, 25.3-63.5)	-.52
Number of Reported Traumas	5.0 (2.83, 0-9)	.51
Number of Traumatic Birth Experiences	0.9 (0.95, 0-3)	.56 *
Infants		
Gestational Age at Birth (weeks)	35.5 (5.76, 26.4-40)	-.49
Birth weight (grams, N=11)	2498 (1181.9, 700-3600)	-.58
Age at 6-month MEG scan (months)	6.3 (0.32, 5.9-6.9)	.42
BSID Cognition Scaled Score	10.7 (2.02, 8-14)	-.32
BSID Language Scaled Score	17.9 (2.85, 13-22)	-.43
BSID Motor Scaled Score	19.6 (5.47, 10-33)	-.51
Types of Traumas Experienced by Mothers	% (N)	
Natural Disaster	37.5 (5)	
Fire or Explosion	21.4 (3)	
Transportation Accident	71.4 (10)	
Other Serious Accident	21.4 (3)	
Toxic Exposure	14.2 (2)	
Physical Assault	37.5 (5)	
Assault with a Weapon	7.1 (1)	
Sexual Assault	37.5 (5)	
Other Aversive Sexual Experience	28.5 (4)	
Combat or Exposure to War	21.4 (3)	
Captivity	7.1 (1)	
Life-threatening Illness or Injury	28.5 (4)	
Severe Human Suffering	37.5 (5)	
Sudden Violent Death	37.5 (5)	
Sudden Accidental Death	42.9 (6)	
Serious Injury, Harm, or Death Caused by You	7.1 (1)	
Other	21.4 (3)	
Traumatic Pregnancy	50.0 (7)	

Note: PTSD = posttraumatic stress disorder, MPSS = Modified PTSD Symptom Scale, BSID = Bayley Scales of Infant Development, N= sample size, SD= Standard Deviation. Traumatic Events Experienced by Mothers includes 4 categories of type of exposure (happened to me, witnessed it, learned about it, and part of my job) on the Life Events Checklist. Traumatic Birth Experience was an item added to the LEC for our study and included preterm birth, fetal demise, miscarriage, and other traumatic pregnancy event.

* $p < 0.05$