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Disrupted Visual Cortex Neurophysiology Following Very Preterm Birth

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ABSTRACT

BACKGROUND: Visual regions develop rapidly in utero and throughout early childhood, but very preterm (VPT) birth can disrupt the typical maturation of primary cortices, with VPT children exhibiting mild visual impairments in early life and throughout development. This is thought to be due to dysfunctional maturation of occipital cortices. A way to readily index brain function is to examine neural oscillations; these mechanisms play a central role in the modeling and pruning of connections, providing an intrinsic temporal structure that refines the precise alignment of spiking, processing information in the brain, and coordinating networks.

METHODS: Using magnetoencephalography, we examined regional oscillatory patterns and functional coupling in VPT and full-term children. Five minutes of eyes-open resting-state data were acquired from 27 VPT and 32 full-term children at 8 years of age.

RESULTS: As hypothesized, the VPT group, when compared with control children, had elevated theta-band power, while alpha amplitude envelope coupling, a marker of connectivity, was found to be decreased.

CONCLUSIONS: These results support the hypothesis of spectral slowing in VPT children and more broadly suggest that the developmental arc of visual neurophysiology is disrupted by VPT birth. We conclude that these deficits underlie difficulties in complex visual perceptual processing evident during childhood and beyond.

Keywords: Children, Functional connectivity, Magnetoencephalography (MEG), Neurodevelopment, Neuronal oscillations, Preterm birth, Resting state

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Out of every hundred births, at least one baby is born 2 to 4 months too early, or very preterm (VPT: 24–32/40 weeks gestational age [GA]) (1). Owing to huge advances in neonatal intensive care, these infants now have an excellent survival rate (2), yet most VPT children still experience difficulties at school age (3–5). These problems include academic underachievement (6,7), social and cognitive dysfunction (8–11), and a greatly increased risk of psychiatric disturbances (12). If it were possible, from an early age, to identify which children will develop such difficulties and which children will follow a typical maturational trajectory, it would be possible to allocate interventional resources precisely to those children who stand to benefit most. The first step toward this goal is to identify the neural markers associated with preterm birth that provide robust measures of VPT children's cognitive development and how it may differ from their full-term (FT) peers.

The challenge is that children born VPT often exhibit selective problems with perceptual and cognitive development (13–15) that often occur even in the absence of individual (i.e., single-subject) structural brain abnormalities (16,17). Subtle difficulties in areas such as visual perception can manifest and interfere with typical functioning (18–24), although the biological bases of these issues remain poorly understood. A proposed explanation for the visuoperceptual impairments found in children born VPT is that preterm birth alters the typical maturational trajectories of visual cortex development (25), and group-level studies using magnetic resonance imaging (MRI) have revealed structural changes associated with problems in perceptual function (16,26,27), including alterations to white matter, indicative of atypical structural connectome development among regions in this population (27).

Preterm birth has also been associated with altered functional circuitry in the brain, as indexed by functional MRI (fMRI) blood oxygen level–dependent interregional correlations (28). Known as functional connectivity (29,30), these measures are abnormal during the neonatal period (31) and remain abnormal into adolescence, suggesting maladaptive reorganization of functional brain circuits during early developmental periods. We know that intrinsic network physiology matures rapidly through the early life span (32); however, relatively little is known about developmental neurophysiology in preterm birth. Because neural oscillations have been shown to be a key mechanism of brain function, neurophysiological exploration of VPT birth is warranted.

Neural oscillations are cyclic regular fluctuations in neuronal excitability that allow groups (or ensembles) of neurons to process and coordinate information in the brain, playing a central role in cognition, perception, and behavior (33–37).

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They are readily imaged noninvasively in humans using electrophysiological techniques such as electroencephalography and magnetoencephalography (MEG). While these techniques capture information about the same underlying neural processes—that is, summated primary currents from the mass action of synchronous neural firing—they differ in the physical properties of the signals they record and in their spatial and frequency resolution (38).

Neural oscillations coordinate local and large-scale communication in the brain, from microcircuits within individual regions to brain-wide networks. Neural rhythms can be characterized in a number of ways, and each property of a wave tells us something different about the nature of these circuits; measurements include frequency, defined by cycles per second (or Hertz), the amplitude of a wave, and the phase angle. All three properties of neural waves are known to be complementary in terms of their functional significance and can be modulated independently of one another for use as a multiplexing mechanism (39).

Both spontaneous neural oscillations and their task-dependent dynamics develop dramatically throughout infancy [including the developmental window corresponding to very premature birth (40)], childhood, and adolescence (34,41) and well into middle age (42). These developmental dynamics reflect the maturational trajectories of functional brain circuits (34,42). Neural oscillations exhibit a distinct characteristic peak in the alpha band (8–14 Hz) that dominates in the occipital lobe, and this is driven by strong and reciprocal thalamocortical connections (43). As the brain matures, it exhibits simultaneous and progressive decreases and increases in the peak frequency and amplitude of neural oscillations (34,42), and these are reliable markers of neurodevelopment in infants and school-age children (44). A number of studies have found differences in regional spectral power at rest in children born VPT, particularly decreases associated with aspects of visual function, dominant in slower frequency bands (45,46).

It has been previously demonstrated that low-frequency alpha oscillations (~8–13 Hz) in school-age children born VPT are slowed and/or decreased in power (45), with a concomitant increase in power in the theta band (4–7 Hz). Persistent dysfunctional brain activity, indexed by oscillations, may explain some of the lifelong perceptual and cognitive difficulties this group faces, given that adults born VPT also express altered low-frequency oscillations (47). Building on this, dysfunction in the dynamic coordination of information has also been identified in VPT children during working memory tasks, and these alterations were associated with visuospatial outcome measures (45).

While local spectral power is linked to regional functional specialization, the statistical interdependencies of fluctuations between brain regions captures the degree to which brain areas are communicating with one another. Dysfunctional patterns in neurophysiological coupling within and across networks is thought to underlie the primary symptoms in a number of conditions that include psychiatric symptoms such as multiple sclerosis (48), autism spectrum disorder (49), and posttraumatic stress disorder (50). MEG has revealed dysfunctional cortical responses in preterm children (51) and altered neural synchrony in preterm-born children and adolescents (45,52,53). However, amplitude envelope connectivity (AEC), a measure that correlates highly with blood oxygen level–dependent fMRI functional connectivity, has not been used in cohorts born VPT, to the authors' knowledge. AEC is a mechanism that can operate independently of interregional neural phase synchrony and is known to correlate highly with the underlying structural pathways in the brain (39,54,55). This function–structure relationship may elucidate structural abnormalities that are beyond the resolution of in vivo structural imaging methods by assessing interregional communication directly. Moreover, AEC has been found to exhibit the greatest test–retest reliability of all electrophysiological functional connectivity methods at both the group and individual levels (56,57).

In the current study, we investigated the proposed slowing of alpha oscillations or increased magnitude of low-frequency theta oscillations through examination of the regional power spectral density in the theta and alpha frequency ranges in VPT children. We recorded eyes-open resting-state MEG activity from a group of school-age children born VPT and a cohort of age-matched FT control children. We hypothesized that children born VPT would exhibit increases in theta power and/or reductions in alpha power, consistent with spectral slowing. Furthermore, we extend existing literature with our analysis of AEC—a reliable and robust measure of circuitry in the brain—and hypothesized that children born VPT would exhibit reduced amplitude envelope coupling in the occipital lobes, where the spectral shift in power is most prominent. Together, these indices of neurophysiological function would indicate disrupted neural circuits that control visual perception brought about by preterm birth.

METHODS AND MATERIALS

Participants

A total of 62 8-year-old children were recruited for this study. Three children born VPT were excluded for motion artifacts in the scanner. The final sample consisted of 27 children born VPT and 32 FT children (see Table 1 for sample demographics; see Supplemental Table S1 for further characterization of the VPT cohort). Children who were born VPT were recruited through the Hospital for Sick Children neonatal intensive care unit (Toronto, Ontario, Canada) at birth and then were followed longitudinally every 2 years. The current data were obtained at their 8-year follow-up. All children provided verbal assent and parents gave written informed consent. This study was approved by the research ethics board at the Hospital for Sick Children. FT children were recruited through advertisements placed in the community, in local schools, and at the hospital. Exclusion criteria included a history of neurodevelopmental disorders, an IQ $\leq$ 70, and any language issues (e.g., non-English speakers) preventing successful completion of tasks as well as standard MEG/MRI exclusions such as metallic dental work.

Neuropsychological Assessments

All participants completed the vocabulary and matrix reasoning subtests of the Wechsler Abbreviated Scale of Intelligence as an estimate of their full-scale IQ (58) and the Beery Test of Visual–Motor Integration (59). Parents completed

Table 1. Demographics of Children Born VPT and FT

	VPT (n = 27)	FT (n = 32)	Test Statistic
Age, Years	8.63 ± 0.55	8.53 ± 0.44	$t_{57} = 0.87$, $p = .39$
Sex, Male:Female	17:10	14:18	χ^2_1 ($N = 59$) = 2.17, $p > .05$
Birthweight, Grams	1220.90 ± 217.10	3538.60 ± 574.80	$t_{57} = 19.60$, $p < .001$
Gestational Age, Weeks	29.07 ± 2.11	≥37 (39.04 ± 1.48)	$t_{57} = 20.30$, $p < .001$
Trial Number	21.11 ± 6.67	21.59 ± 5.67	$t_{57} = 0.30$, $p > .05$
Head Movement, mm	4.99 ± 2.50	5.51 ± 2.28	$t_{57} = 0.84$, $p = .40$
WASI Matrix Score	51.78 ± 10.66	59.50 ± 4.20	$t_{57} = 3.77$, $p < .001$
Visual–Motor Integration Score	95.56 ± 11.22	104.88 ± 11.60	$t_{57} = 3.12$, $p < .01$
BRIEF Global Function Score	47.70 ± 9.65	45.69 ± 7.88	$t_{57} = 0.88$, $p = .38$

Values are mean ± SD or n.
BRIEF, Behavior Rating Inventory of Executive Function; FT, full term; VPT, very preterm; WASI, Wechsler Abbreviated Scale of Intelligence.

the Behavior Rating Inventory of Executive Function (BRIEF), Global Function (60).

MEG and MRI Data Acquisition

Participants were tested in a magnetically shielded room in the MEG laboratory at the Hospital for Sick Children using a 151-channel MEG system (CTF Omega; CTF MEG International, Coquitlam, British Columbia, Canada). Three fiducial coils were placed on each participant's nasion and left and right preauricular points to measure head position continuously while in the scanner. Five minutes of resting-state MEG data (600-Hz sampling rate, third-order spatial gradient noise cancellation, with continuous head position recording) were acquired in the supine position with eyes open. Participants were instructed to try to minimize eye movements and to maintain fixation on a plus sign (+) within a circle, presented on a black background. The fixation stimulus was projected into the magnetically shielded room onto a back-projection screen positioned at a viewing distance of 80 cm.

After the MEG recording, the fiducial coils were replaced with MRI contrast markers for coregistration of MEG with MRI data. A 3T structural MRI (T1-weighted, sagittal three-dimensional magnetization prepared rapid acquisition gradient-echo, field of view/resolution = 240 × 256, 0.8 mm isovoxels, repetition time/echo time/inversion time = 1870/3.14/945 ms, flip angle = 9°) was acquired in all participants on a Siemens scanner (Magnetom PrismaFIT, Siemens AG, Erlangen, Germany) with a 20-channel head coil. MEG data were coregistered to the MRIs using the fiducial coils as reference.

MEG Preprocessing

An overview of our MEG processing pipeline is presented in Supplemental Figure S1. MEG data were bandpass filtered offline using a high-pass filter of 1 Hz and a low-pass filter of 150 Hz with a 60-Hz notch filter and were subsequently analyzed in FieldTrip (61). Artifacts related to cardiac activity, eye blinks, and eye movements were removed using the independent component analysis function (fastica) in FieldTrip. Components were visually inspected and rejected by an experienced MEG analyst. As many epochs of 10 seconds as possible were selected from the 5-minute recording such that the head position during each epoch 1) deviated less than 8 mm from the recording median and 2) excluded portions of data that contained SQUID (superconducting quantum interference device) resets or exceeding a threshold of ±2 pT after independent component analysis component rejection.

Subject-specific single shell head models were created from each subject's T1-weighted MRI. The brain was parcellated using the automated anatomical labeling (AAL) atlas (62), and individual MRIs were warped using a nonlinear transformation from template Montreal Neurological Institute coordinates into subject-specific MEG coordinates. The centroid of each AAL parcel was used to define the node location for the beamformer reconstruction. The FieldTrip implementation of the linearly constrained minimum variance vector beamformer (63) was used to reconstruct the neural time series at each location defined by the AAL centroid with 5% Tikhonov regularization. Lead fields were computed from the subject single-shell head model for a unit current dipole in three dimensions at each node. The beamformer weights for the activity at each node were computed by projecting the sensor weights along the axis with the highest singular value decomposition variance, resulting in a one-dimensional activity time series for each node. The time series for each node were then z-scored (converted to zero mean and unit standard deviation), and the regional power spectrum density (PSD) was estimated using Welch's method (pwelch function in MATLAB [The MathWorks, Inc., Natick, MA]) on each epoch and then averaged over epochs. The resultant values were portioned into two low-frequency bands of interest, theta (4−7 Hz) and alpha (8−14 Hz), and for each the trial-mean PSD in the frequency domain was derived. Regional PSD maps were plotted using BrainNet Viewer (64).

Functional Connectivity: AEC

The broadband regional time course for each node location was filtered into theta and alpha frequency ranges, and before computing functional connectivity a symmetric orthogonalization procedure (65) was applied to the filtered regional time series to attenuate artificial connectivity that might be the result of signal leakage. The Hilbert transform was applied to the resultant time course to derive instantaneous estimates of the amplitude envelope, which was then downsampled to 1 Hz by averaging the amplitude over 1-second intervals (66). Pearson correlations between all node pairs were calculated to index functional connectivity. AEC was chosen over other measures of synchrony (e.g., phase lag index, phase locking

value) because it has been shown to be the most reliable measure of connectivity across sessions and over individuals, pointing to the greatest replicability as well as the lowest susceptibility to coregistration-related errors (56).

Statistical Analyses

For the demographics and neuropsychological data, normality was assessed using the Shapiro-Wilk test, and given the directionality of our hypotheses, we used one-tailed *t* tests to evaluate for group mean differences in all tests except for sex ratios, which used a χ^2 test.

For the neuroimaging data, owing to the previous literature on power differences between FT children and children born VPT (45,52), we assessed normality using the Shapiro-Wilk test and tested our hypotheses using one-tailed *t* tests to evaluate for group differences. All tests were corrected, on a whole-brain level, using a false discovery rate correction implemented using the Benjamini-Hochberg procedure (67). Our novel analysis of functional connectivity could not be strongly informed from prior literature; as such, we used two-tailed statistics and contrasted between groups by using nonparametric permutation testing with 10,000 permutations and alpha criterion set at .05. Permutation testing does not require data to be normally distributed. Again, false discovery rate was used to control for multiple comparisons across the whole-brain functional connectome space (90 AAL regions).

RESULTS

Group Characteristics

There were no significant differences in age or sex between groups or in the number of trials that passed data quality assurance; the VPT group did, of course, have lower birthweight and GA (Table 1). For the neuropsychological tests, the Wechsler Abbreviated Scale of Intelligence and Visual–Motor Integration were found to be significantly lower in the VPT group compared with the control group, although still within normal limits, while the Behavior Rating Inventory of Executive Function rating was not significantly different.

Elevated Theta Oscillations in Visual Cortex in Children Born VPT

The resting-state group-averaged power spectrum density plots for each lobe in the VPT and FT children are presented in Figure 1. We observed the characteristic 1/*f* PSD with a defined alpha peak at approximately 10 Hz, which was dominant in the visual cortex (green trace). When comparing these PSD curves between groups, we saw a reduction in children born VPT, in line with previous reports (Figure 1, left). In terms of the regional power distribution of band-limited theta and alpha within each group, theta power appeared to be relatively evenly distributed throughout the cortical seeds (middle row), while alpha power dominated in the occipital cortex, as expected.

PSD from occipital seeds showed a trend for reduction in peak alpha power in the bilateral lateral occipitotemporal seeds (Figure 2A). When contrasting regional power maps using a one-tailed *t* test between groups, we found elevated theta power in the ventromedial prefrontal cortex, orbitofrontal cortex, and occipital regions in VPT ($p_{corr} < .05$), which would be consistent with a slowing of alpha frequencies (Figure 2B; regions listed and further statistical details provided in Supplemental Table S2). For alpha, there were no significant regional differences ($p_{corr} > .05$).

Reduced Alpha Envelope Coupling in Visual Cortex of Children Born VPT

Functional coupling via AEC was used as a measure of integrative function where, given previous findings and hypotheses, we tested contrasts in the theta and alpha bands. Theta AEC trended toward greater connectivity in VPT frontal lobes (the upper left quadrant of the connectivity matrix), and when considered globally a greater number of increased connection weights were seen, with some decreases that do not show any specific spatial organization (Figure 3). For alpha AEC, the characteristic visual network structure was evident within the groups (red squares with black bounding boxes in the center of the connectivity matrices in Figure 3). Contrasting VPT with FT using a two-tailed permutation procedure similar to theta AEC, there were a number of connections showing increased and reduced connectivity. However, the majority of occipital seeds were shown to have reduced AEC in the VPT group compared with the FT group ($p_{corr} < .05$). This network is plotted on the glass brain for interpretative ease and shows a mix of intra- and interhemispheric connections. Assessing the average connection strength within this network, we found there to be a significant positive correlation with GA, whereby higher GA was accompanied by greater connection strength within this occipital network (Supplemental Figure S2).

DISCUSSION

VPT birth occurs during the late prenatal stage of brain development in the third trimester (gestational weeks 24–32) when thalamocortical brain circuits develop rapidly (68), laying the foundation for long-range thalamocortical and corticocortical connectivity (69). While analyses of hemodynamic recruitment have shown neurovascular coupling dysfunction in VPT cohorts, electrophysiological analyses that capture neuronal processes offer a direct window into neural (dys)function. Here, we extended previous electrophysiological studies assessing the neurophysiological impact of VPT birth.

Our PSD analyses revealed that both VPT and FT children exhibit the classic alpha-band peak within the occipital lobes. However, the VPT group alpha peak was reduced, at the lobular level, compared with FT children. Exploring this effect on a region-by-region basis indicated a trending group difference most apparent in the inferior occipitotemporal region, a region critical for detailed processing of complex visual stimuli, including faces, numbers, and letters (70). Assessing power across the cortex, we found theta-band PSD to be increased in VPT children compared with FT children in several frontal and occipital regions. This is consistent with the previously observed spectral slowing following premature birth, where oscillatory phenomena that would typically be localized to the alpha band (~8–14 Hz) shift into the canonically defined theta band (~4–7 Hz). This notion is also supported by our cortex-wide assessment of alpha power, where the FT cohort exhibited greater occipital power than children born VPT.

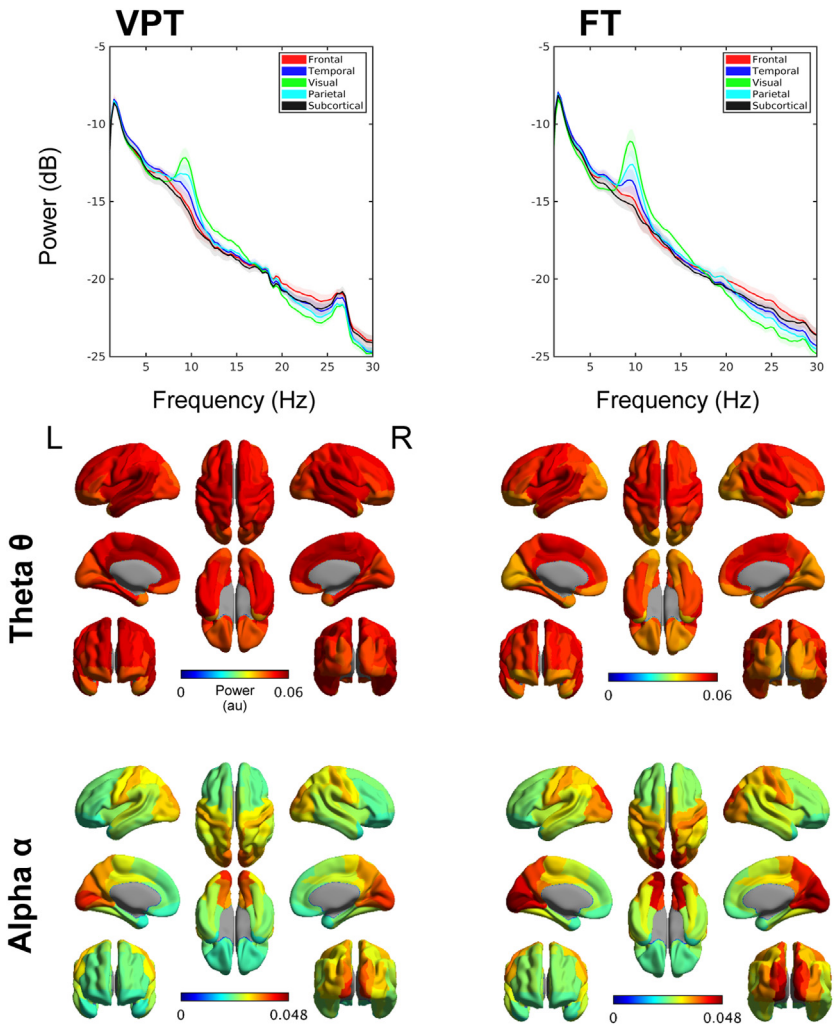

Figure 1. Group mean power spectrum density by lobe (top row) and regional power in the theta and alpha range (middle and bottom rows, respectively) for very preterm (VPT) (left column) and full-term (FT) (right column) children. For the power spectrum density curves, automated anatomical labeling seeds from each lobe were averaged to make a lobe-mean power curve for frontal (red), temporal (blue), visual (green), parietal (light blue), and subcortical (black). For regional oscillatory power in the theta and alpha bands, band-limited power spectrum density was averaged over participants and plotted on a template mesh. L, left; R, right.

Our observation of an occipital power difference in the VPT group is extended by our novel functional connectivity analysis assessing AEC at the whole-brain level (Figure 3). Here, we found children born VPT to exhibit significantly reduced functional coupling within a subset of occipital regions in the alpha band.

The children born VPT were born during critical developmental stages, on average 3 months before their FT peers. Our study suggests that the adverse experience of preterm birth disrupted aspects of the developmental process, such that neural circuits with oscillatory profiles that dominate in the theta and alpha bands were selectively affected and that functional coupling within the visual cortex was particularly susceptible. Low-frequency oscillations are generated by thalamocortical loops and are of greater power in the visual cortex. In terms of their functional significance, they reflect local inhibitory processes through selective activation and phasic blocking of information processing in task-irrelevant regions (71–73). These develop during the differentiation of the cortical layers from the cortical plate; because VPT birth occurs during this important phase of brain development, it can cause disruptions to the maturation of typical cytoarchitecture and arcs of synaptogenesis (74).

Given prior studies and the role of oscillations in thalamocortical coupling, we replicated the findings reporting reduced low-frequency regional power and extended them by examining AEC, a measure of the temporal correlation between the envelopes of neural oscillations. This measure was used because AEC is the most similar conceptual analog of connectivity computed in resting-state fMRI, and therefore our results can be compared to and extend the fMRI literature (75,76). Structural MRI has revealed dysmaturation in VPT children associated with problems in perceptual function (16,26,27), including alterations to white matter, indicating that structural connections among brain regions do not develop typically in this population (27). This has been attributed to reduced myelination and delayed neuronal maturation (77,78) as a result of oligodendrocyte progenitor cells being adversely affected by stressful neonatal experience (79–81). Prior work has found that cortical myelin correlates with low-frequency

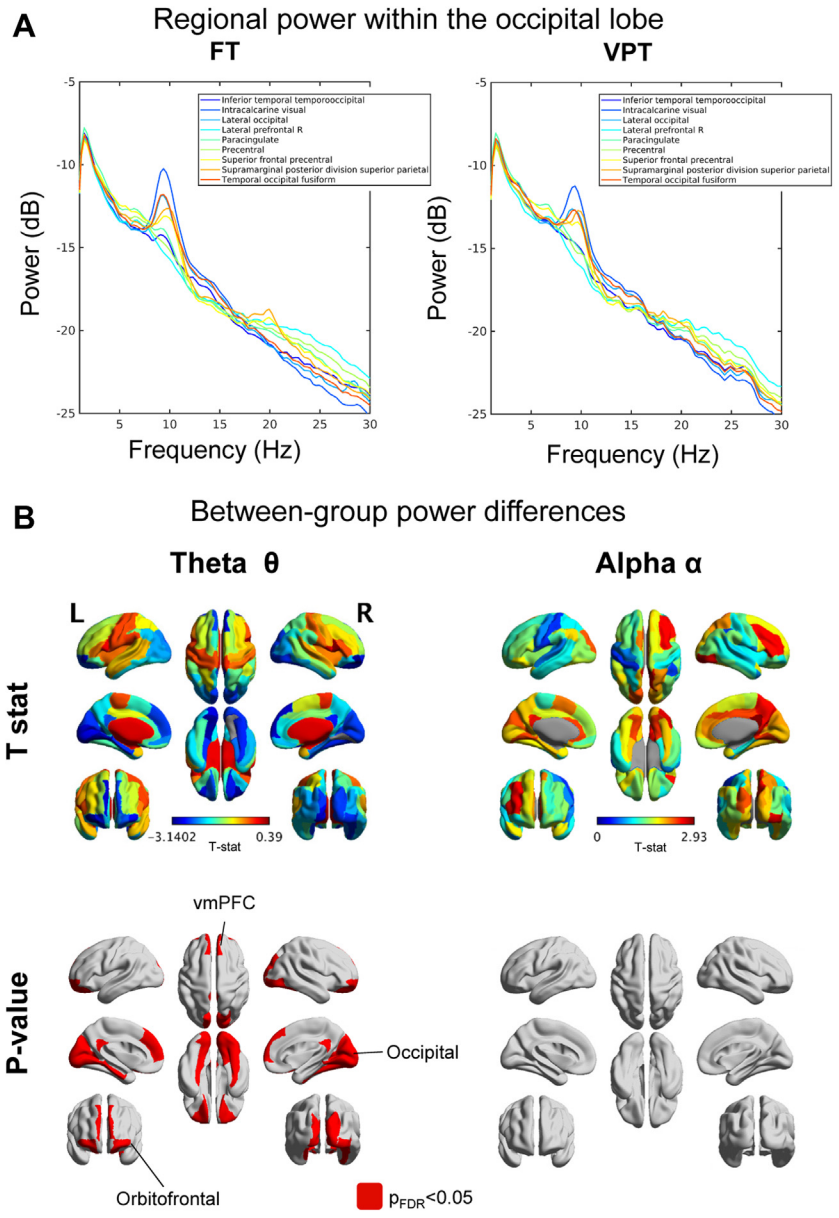

Figure 2. **(A)** Further investigation of the lobular finding (in Figure 1) by plotting bilateral regions within the occipital lobe. The region with the greatest power, and difference in power between the groups, was the inferior occipitotemporal area. **(B)** Group contrasts of regional power for the theta band (left column) and alpha band (right column), with test statistics (top row; one-tailed *t* test) and whole-brain corrected *p* values (bottom row). Contrasts revealed significant theta increases in very preterm (VPT) compared with full-term (FT) (control) children in the ventromedial prefrontal cortex (vmPFC), orbitofrontal, and occipital regions ($p < .05$, corrected), but no significant effects in the alpha band. FDR, false discovery rate; L, left; R, right.

MEG functional connectivity using AEC, implicating cortical myelination disruption as a probable consequence of VPT birth (82).

Previous studies (83,84) have noted that peak alpha frequency increases with age. Therefore, our observation of a shift in frequency might not be an active process on behalf of the children born VPT but rather a lack of cortical maturity, meaning that a normative spectral increase does not occur or is delayed. Future longitudinal studies are required to assess when and where these frequency shifts occur. Regardless, our finding of significantly attenuated AEC in the VPT cohort highlights that this shift likely disrupts functional connectivity, although causation cannot be ascertained. Moreover, if the occipital lobes of the VPT group simply shift in the dominant frequency that mediates functional coupling into the theta band, we would have identified a significant between-group difference in theta band. The absence of such a difference could be interpreted as a lack of a compensatory spectral shift in VPT children.

In terms of the functional significance of these observations, these deficits predominate in the visual cortex; we know that children born VPT are at greater risk of vision impairments, including low-level perceptual deficits, such as reduced acuity and contrast sensitivity, as well as higher-level visual dysfunction, including global and biological motion deficits coded by extrastriate/association cortices and visuomotor

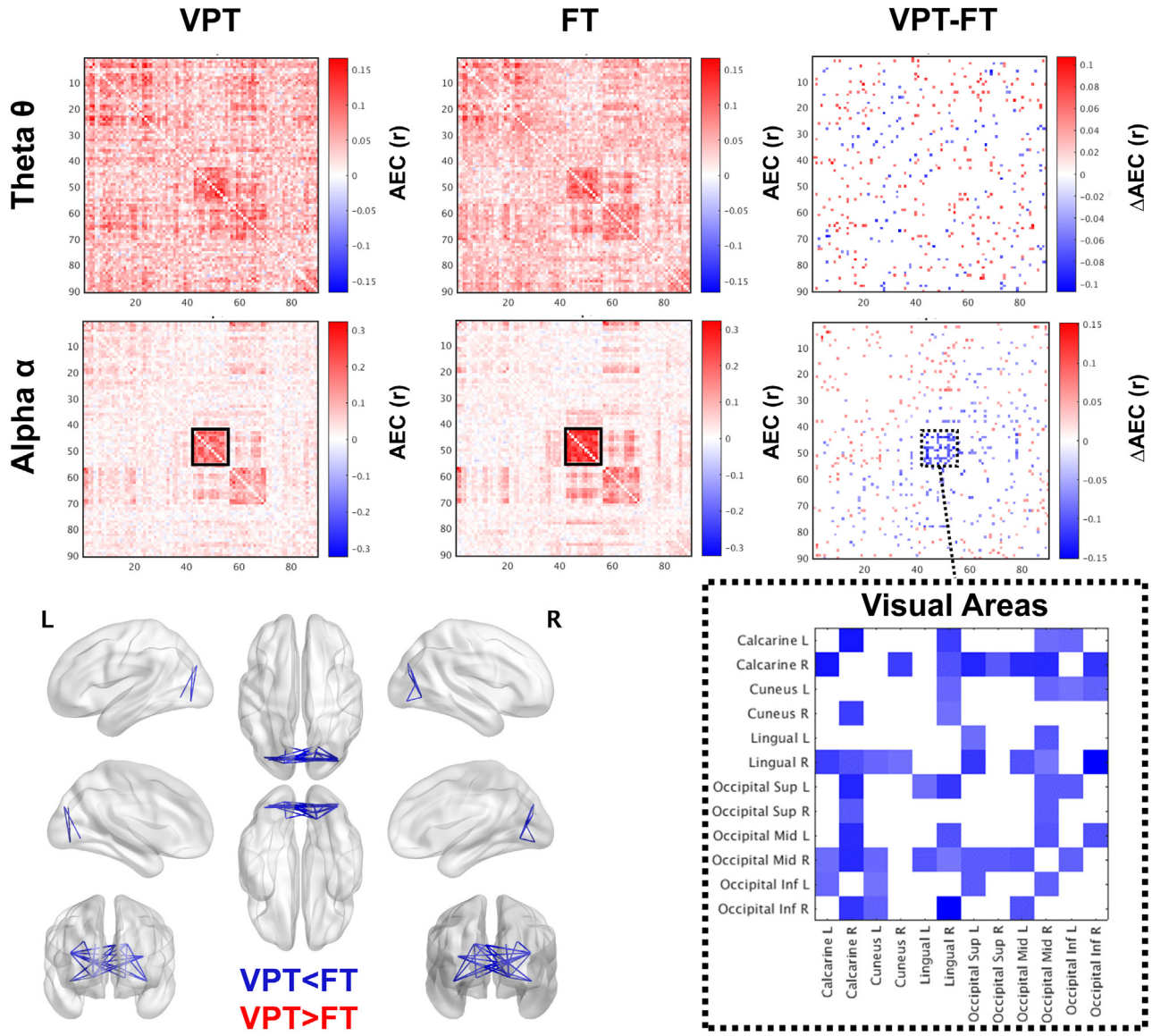

Figure 3. Alpha functional coupling was reduced in occipital cortices in very preterm (VPT) children. Functional coupling matrices are shown for low-frequency theta (top row) and alpha (middle row) in VPT (left), full-term (FT) (middle), and VPT minus FT (right) groups. Matrix elements appearing in the VPT−FT column showed statistically significant differences between groups, following false discovery rate correction for multiple comparisons, across the entire connectivity space. The glass brain showed reduced alpha amplitude envelope connectivity (AEC) in the visual cortex of the VPT group, with the individual automated anatomical labeling region names shown in the adjacency matrix (bottom right). These included primary sensory as well as extrastriate/association areas. Inf, inferior; L, left; Mid, middle; R, right; Sup; superior.

integration deficits due to selective dorsal stream dysfunction (25). Our behavioral results from the Visual–Motor Integration would support these observations, where the VPT group scored significantly lower than their FT peers in visual–motor integration abilities. These findings can serve as an early marker for future difficulties because visual and visual perceptual skills are important for appropriate academic development, including reading and math, attention, and social cognition (85). It is well known that children born preterm experience difficulties at school and academic underachievement that persist into adolescence (8,86,87), and these academic difficulties have been linked to visual processing challenges (88). Moreover, these academic challenges can contribute to the frequently reported social isolation and internalizing symptoms (including depression and anxiety) (89), all of which children born VPT experience at a significantly higher rate compared with their FT peers (90,91). Therefore, this brain–behavior link should be investigated in future studies and could provide a means to predict who would benefit from early intervention on the bases of neurobiological markers and assess whether behavioral interventions are assisting VPT children in keeping up with their FT peers, both in terms of their

academics and in indices of their mental health. Having this means of evaluating early visual dysfunction in VPT or other high-risk clinical populations, and monitoring interventions, would be an invaluable future direction of this work.

One difficulty in assessing group differences in MEG is that of signal-to-noise ratio (SNR) discrepancies between cohorts, especially when considering functional connectivity. This is because greater oscillatory power can result in a greater SNR, which may produce biased connectivity estimates. While it is possible that SNR differences were present in this analysis, the absence of significant group differences in alpha power but significant differences in the envelope coupling suggests that the alpha AEC results were not simply a product of SNR differences between groups.

In conclusion, this is an extension of previous studies showing altered regional oscillations and functional coupling that predominates in visual cortices in VPT birth. In line with these studies (45,52,53), we too see a change in spectral profiles involving the theta band in VPT children. For the first time, we report significant reductions in occipital lobe alpha-band coupling in VPT children in regions critical to complex visual processing, suggesting that disruption in early development can have an impact on the typical maturational arcs of the neural circuits in the visual system.

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ARTICLE INFORMATION

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