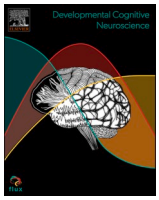
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Highlights from the 2024 annual meeting of the fetal, infant, and Toddler Neuroimaging Group (FIT'NG)

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ABSTRACT

The Fetal, Infant, and Toddler Neuroimaging Group (FIT'NG) is a scientific society advancing research on fetal, perinatal, infant, and early childhood brain and behavioral development through neuroimaging, encompassing theoretical, technical, fundamental, and clinical dimensions. It unites researchers across physics, neuroscience, cognitive science, psychology, computer science, biomedical engineering, and medicine, fostering interdisciplinary collaboration among leading laboratories in the field. The annual FIT'NG conference serves as a key forum for exchanging new ideas and methods, addressing shared challenges, and promoting best practices. It supports the society's mission of connecting complementary expertise and training the next generation of scientists in the field. This special issue compiles articles highlighting work presented at the FIT'NG conference held in September 2024 in Baltimore, MD, USA, offering an overview of recent advances in fetal, neonatal, infant, and toddler neuroimaging and their applications. A central focus of the FIT'NG community is identifying early markers of atypical neurodevelopment to support translational research and inform preventive and intervention strategies. Prematurity and other perinatal adversities, including environmental factors, serve as key models of atypical cognitive and social development and strong candidates for translational work. This focus has driven notable progress in technological and analytical methods, including high-precision functional and structural connectivity imaging, statistical innovations for large cohorts supporting hypothesis-driven longitudinal designs, and integrative modeling combining physiological and metabolic data with neuroimaging. Notably, this year's meeting featured significant advances in fetal research, increasingly enabled by deep learning, which now support individual-level analyses, paving the way for precision neuroscience and clinically relevant applications.

1. Introduction

The Fetal, Infant, and Toddler Neuroimaging Group (FIT'NG) is a scientific society dedicated to advancing research on fetal, perinatal, infant, and early childhood brain and behavioral development through neuroimaging, spanning its theoretical and technical aspects, as well as its fundamental and clinical applications. To this end, it brings together researchers in physics, neuroscience, cognitive science, psychology, computer science, biomedical engineering, and medicine. FIT'NG encourages synergies and interdisciplinary collaboration among laboratories at the forefront of the field.

The annual FIT'NG conference provides an ideal forum for discussing new ideas and methods, shared challenges, and best practices. It fosters the society's commitment to matching complementary expertise, and finally, training the next generation of scientists specializing in the field of fetal, infant, and toddler (FIT) brain imaging and neurodevelopment. This special issue brings together articles that highlights some of the work presented at the FIT'NG conference that was held in September 2024, in Baltimore MD, USA.

2. Keynote lecture

The keynote lecture was delivered by Dr. Patricia Ellen Grant, Neuroradiologist, Professor of Pediatrics and Professor of Radiology at Harvard Medical School, Director of Faculty Affairs for Radiology, Director of Research for the Maternal Fetal Care Center and founding Director of the Fetal Neonatal Neuroimaging and Developmental Science Center (FNNDSC). Dr. Grant challenged our community with this question: "Can Innovations in Imaging Enhance Perinatal Care?", offering an illuminating look at the most cutting-edge innovations in fetal imaging that shape the landscape of prenatal and perinatal care. First, she reviewed how advances in fetal and infant imaging can support survival and longer-term health in babies who experience hypoxic-ischemic encephalopathy (HIE). Her pioneering work leverages advances in artificial intelligence to directly improve clinical care. She then introduced how accurate bedside monitoring of perinatal-brain health with advanced quantitative Near-Infrared Spectroscopy (NIRS) and improved placental monitoring can further enhance acute patient management. Finally, she reviewed advances in methodologies supporting more precise "deep phenotyping" of the fetal brain and developmental outcomes, through precision in modeling of cortical folding and gyrification, and better tracking of fetal motion. This enhances data

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acquisition and provides better control of artifacts, reducing bias in imaging computation. Importantly, she also pointed out that fetal motion is a critical marker of risk and thus improving the ability to track and quantify fetal motion is likely to bring benefits for prevention and guide perinatal care. Dr. Grant has navigated pressing challenges in fetal imaging using multidisciplinary, synergistic teams that value open science to support collaboration.

3. Thematic sessions

This year's thematic sessions covered diverse approaches of FIT brain development: *Brain and Behavioral States, Early Cognitive Development, Methods Development, Sensitive Periods and Brain Plasticity,* and *Adversity and Brain Development.*

In the *Brain and Behavioral States* session, our invited speaker Mark S. Blumberg, Chair of the Department of Psychological and Brain Sciences at the University of Iowa, provided insights about early life development of the sensorimotor system during sleep. "What's the process through which we learn how to control the body we are born in?" was one of the central questions of his talk. His work combined studies in rodents and humans, focusing on muscle twitches during sleep in the first months after birth, showing that these are evolutionarily conserved features across species. These muscle twitches provide the first peripheral input to build somatotopic maps and sensorimotor pathways in the brain and potentially play a key role in the formation of internal models which constitute the building block of later predictive coding. With age, they shift from sporadic events to more organized and clustered patterns. In his talk, Dr. Blumberg presented findings demonstrating that the red nucleus plays a key role in spindle generation and shows long-distance functional connectivity with the hippocampus during active sleep, a pattern that is absent during quiet sleep, highlighting functional differences between these two sleep states. He shared insights about the development of this process over the first months after birth, with twitches first present in quiet sleep at around six months of age and synchronizing with sleep spindles. His talk closed with the proposal that sleep and distinct patterns during sleep play an important role in the cascade of cognitive development, and therefore, can potentially be an early marker of atypical development.

Another session covered *Early Cognitive Development* across its various domains, from neonatal sensory prediction to infant attention to social interactions in ecological settings, providing an overview of the diversity and complementarity of research on developmental trajectories. The session started with invited speaker Lauren Emberson, Associate Professor in Psychology at the University of British Columbia and the Djavad Mowafaghian Centre for Brain Health. She described how functional NIRS (fNIRS) can capture how infants and toddlers perceive and learn about their worlds. Her work showed that infants use predictions to anticipate learned stimuli and adapt quickly to new information. Dr. Emberson presented results from several innovative studies, such as work demonstrating top-down modulation of the visual cortex based on learned sensory predictions in neonates within two days of birth. Dr. Emberson also described work deriving functional connectivity measures from fNIRS data and results from global collaborations using fNIRS to measure changes in the developing infant brain in low- and middle-income countries, shedding light on how the brain develops in different contexts. In this session, Victoria Dumont also presented work on sensory prediction and top-down regulation, using Electroencephalogram (EEG) in preterm neonates. She showed that before term, newborns already have these abilities in the somatosensory domain, and that postnatal exposure to nociceptive stimuli accelerates their development. Sensory prediction is a prerequisite for attention development. In her selected talk, Haley Laughlin explored behavioral and EEG correlates of visual engagement in toddlers born preterm, the effects of parental education and gestational age at birth, and the links between early disruption of visual attention and attention deficits later in life (Laughlin et al., 2026). Ruohan Xia explored infants' EEG responses to emotional events during naturalistic mother-infant dyadic interactions in a large-scale longitudinal study. In this special issue, she discusses different analytic approaches of this type of data, and evaluate their effects on data from a novel, live, naturalistic mother-infant interactive task (Xia et al., 2026).

The *Methods Development* session started with a groundbreaking presentation by invited speaker Dr. Charlie Demené, Associate Professor at the School of Industrial Physics and Chemistry of the City of Paris at Paris Sciences et Lettres University (ESPCI-PSL), and a researcher at the Institute Physics for Medicine Paris, France. He introduced the community to ultrafast Doppler imaging using functional ultrasound (fUS), covering both its theoretical background and medical applications, and provided proof-of-concept of cot-side functional connectivity imaging in neonates using this method. He also presented proof of concept results from combining fUS with diffuse optical tomography (fUS-DOT) for monitoring early neurodevelopment. In this special issue, he builds on this presentation with a paper introducing an additional novel tool, that was built in his laboratory, to achieve 3D fUS imaging as a clinical tool to monitor developing brain function in high-risk infants, with high spatial resolution, at the bedside (Faure et al., 2026). Among outstanding contributions to new methods, Diego Derman presented a precision mapping approach, combining Bayesian modeling with surface-based analysis, to estimate individual resting-state networks (RSNs) using only ten minutes of fMRI data, in a large cohort of term and preterm neonates from the developing Human Connectome Project (dHCP). Individualized RSN mapping captures heterogeneous developmental trajectories and highlights higher-order association networks as promising early markers for monitoring neurodevelopmental outcomes in neonates (Derman and Ferradal, 2025).

Dr. Minhui Ouyang, Assistant Professor from the Department of Radiology at University of Pennsylvania and Children's Hospital of Philadelphia, opened the *Sensitive Periods and Brain Plasticity* session with an overview of developmental connectome studies spanning mid-gestation to early childhood, using diffusion magnetic resonance imaging (dMRI) and resting-state functional MRI (rs-fMRI). She outlined how early connectome development is characterized by a shift from segregation to integration, facilitated by initially faster growth of short-range connections followed by the later strengthening of long-range connections, along a hierarchical axis from primary to higher-order regions. Dr. Ouyang presented her work using network-based analytic approaches to characterize how brain network topology evolves during development, discussed key challenges and methodological considerations in studying the baby brain connectome, and provided perspective on how this approach allows us to understand aberrant connectome development in neurodevelopmental and neurological disorders (Wu et al., 2026). A complementary perspective on perinatal structural and functional connectivity was offered by Andrea Gondova's work. Using data from the dHCP, she found decreasing relationships between microstructural connectivity (MC) and functional connectivity (FC) with increasing corrected gestational age. In addition, inter-hemispheric non-homotopic and intra-hemispheric groups of connections maintained significant MC-FC relationships, whereas cortico-subcortical and inter-hemispheric homotopic groups showed decreasing relationships, reflecting relatively mature tissue microstructure in comparison with the still progressing functional specialization of networks. In this issue, she proposes another take on the links between brain development and gestational age: using advanced dMRI and processing methods, she presents findings suggesting differential vulnerability to prematurity among microstructurally distinct anatomical clusters, between the pre- and post-central gyri and along the somatotopic axis (Brandstaetter et al., 2025).

Our final session focused on *Adversity and Brain Development.* This topic has attracted rising interest stimulated by new multidisciplinary approaches, and the awareness that the extraordinary plasticity of the newborn and infant brain makes them particularly sensitive to environmental inputs. The session was launched with a presentation from

invited speaker Dr. Kathryn Humphreys, an Associate Professor of Psychology and Human Development at Vanderbilt University. She presented her work chronicling the diverse challenges that limit our ability to capture the complex nature of early adversity exposures, and to understand how they impact brain development. She proposed evidence-based approaches to address each of these challenges: conflation of exposure and response, oversimplification of complex experiences, informant biases, biomarker overinterpretation and inferential leaps, restricted ecological validity, genetic confounding, and limited generalizability across cultures and communities. In this issue, she provides specific recommendations for each of these challenges, making it an invaluable guide for researchers in the field (Humphreys and King, 2025). In addition, she offers perspectives on promising paths to precise, high-dimensional measures of early experiences, passive monitoring, and genetically informed protocols, for both fundamental and applied questions. She presented the randomized foster care intervention in the Bucharest Early Intervention Project (BEIP) aimed at identifying the causal mechanisms of resilience. She also presented the TotTag device she designed, an infrastructure-free wearable system that provides moment-to-moment measurement of distance between infants and caregivers. As early exposure to various forms of adversity becomes more widespread around the world and is changing at an ever-faster pace, Dr. Humphreys' work is critical to addressing practical issues and prevention efforts in pediatric health, education and public policy.

4. Elephants in the room and panel session

In Elephants in the Room (EITR) think tanks, six key challenges of our field were enthusiastically discussed by attendees in group discussions. Three of these discussions are translated in articles in the present issue: *Studying language development from different neuroimaging perspectives* (Olson et al., 2025), *Deep learning in fetal, infant, and toddler neuroimaging research* (Chin et al., 2026), and *Bridging the gap: Translating fetal, infant, and toddler neuroimaging insights into clinical practice* (Nelson et al., 2026).

Three other topics were discussed at the meeting. In *Using FIT neuroimaging to investigate neurodevelopmental disorders*, the group emphasized that prospective longitudinal cohorts are critical because phenotypic expression emerges later in development, and early trajectories are nonlinear and heterogeneous. However, under-resourced families are disproportionately lost to follow-up, introducing bias. Efforts to maintain staff continuity, relational trust and meaningful feedback to families were recognized as investments for retention. Another challenge is the gap between robust group-level effects and reliable individual-level inference. The group discussed moving toward multivariate longitudinal models that explicitly account for heterogeneity while preserving biological interpretability. Normative modeling, which estimates reference trajectories and quantifies individual deviations, may be a pathway toward precision, although its performance remains sensitive to sampling. Building models of early neural markers within this framework should account for neural plasticity, comorbidity, and developmental cascades, as well as mechanistic grounding across modalities and animal models.

During the EITR discussion on *Multimodal Neuroimaging in FIT Populations*, single-modality approaches were broadly viewed as insufficient to fully interrogate the multiscale and multicomponent nature of developmental processes. However, the distinctive challenges of FIT imaging are exacerbated in multimodal designs. When invoking "multimodality", the distinction between simultaneous versus non-simultaneous acquisition needs to be made: simultaneous multimodal imaging should be reserved for cases where temporal coupling or shared state estimation is central to the research question, while sequential multimodal designs remain sufficient and often preferable for many structure-function questions. The lack of age-specific tools, particularly for source localization and head modeling, was identified as a critical bottleneck, alongside the broader challenge of maintaining coherent pipelines across modalities. Participants highlighted that different modalities encode both distinct and shared variance, pointing toward analytic frameworks that explicitly model shared and modality-specific information. Looking forward, opportunities include advances in multimodal data fusion, wearable and low-cost technologies, EEG-MEG integration, optically pumped magnetometers (OPMs), mobile imaging units, and the integration of non-neural physiological measures to better capture brain-body interactions.

In *Harmonizing FIT cohorts across different contexts to conduct larger scale analyses*, the group discussed best practices of harmonization, considered methods such as integrative data analysis that can pool different operationalizations of similar constructs using latent modeling techniques, and how to deal with differences in data quality across sites. One topic of discussion focused on what can and should be harmonized, while distinguishing measures harmonized at a conceptual *vs.* operational level. For example, if collecting an infant neuroimaging task on emotional face processing, the faces selected should be different across sites to reflect facial features that infants would be familiar with (conceptual level). On the other hand, efforts could be made to standardize imaging parameters, stimuli latency, *etc.* (operational level). Combining smaller-scale datasets to conduct larger-scale analyses is a promising avenue to investigate individual-level differences, substantially increasing generalizability across various contexts/geographical locations.

To dig deeper into challenges of the field, the FIT'NG's trainee committee also organized a panel session on *Large cohorts in fetal, infant, and toddler neuroimaging research*, featuring leading experts in our field: Drs. Laurel Gabard-Durnam (Northeastern University College of Science), Patricia Ellen Grant (Harvard Medical School), Katherine Cole (National Institute on Drug Abuse), Jonathan O'Muircheartaigh (King's College London), Charles Nelson, III (Harvard Medical School and Graduate School of Education), and Lindsay Powell (University of California San Diego).

Large open-data cohorts enable researchers to explore questions that they could not consider without such pooling of resources. These cohorts facilitate powerful statistical analyses utilizing multidimensional data, which require large sample sizes. However, big-data projects come with limitations and biases that need to be acknowledged and if possible, addressed. There is not a global consensus yet on what to assess and at what age, using which technique. As a result, design decisions are made based on pragmatic considerations, such as the availability of equipment in each laboratory, resulting in innovative approaches such as NIRS or MEG being ruled out. Decision-making criteria based on the sensitivity-specificity ratio need to be developed. Panel members also noted that smaller or low-resource laboratories could be offered more opportunities to contribute, since consortia have roles suited to individual scientists or small groups without the data-acquisition resources. These opportunities need better advertising to reach a wider community. This raised a question: how can such contributions be recognized – particularly for early-career researchers advised to publish original research for career advancement? Principal investigator should ensure that their work is credited, otherwise young researchers may prioritize building their own scientific identity.

Harmonizing the conditions and limiting biases in multisite data acquisitions is another challenge. Inclusion criteria and acquisition conditions should be similar enough to allow pooling – or meaningful subsample comparisons – without sacrificing representativeness. This requires methods appropriate to all cultural backgrounds, harmonized acquisition training across sites, diverse research staff, and local community involvement in protocol design and peer support during acquisition. Exploratory big data and small-scale, hypothesis-driven studies are complementary, but middle-ground attempts must be avoided: the panel recommended distinguishing more clearly, in projects and articles, between these approaches, along with *a priori* statistical plans.

Finally, the panel discussed ways of combating unethical or profit-driven use by third parties, particularly as AI scours the internet;

however, this issue, which has immense implications, remains to be resolved.

5. Other contributed articles

Finally, this issue features contributions that were selected for flash talks based on the scores anonymous reviewers gave to abstract, or for Best Poster Awards based on a jury's evaluation of the poster's content and presentation.

An exciting development in our field is the emergence of methods that enable us to identify specific patterns of brain function at an individual level, and to analyze inter-individual variability as a source of information, not noise. The individual level is crucial for translating fundamental findings into clinical practice. This need for translation drives methodological development, which is why the FIT'NG society is multidisciplinary by design. Using EEG with spectral parameterization, Aline González Carpinteiro assessed the development of aperiodic activity and periodic theta power in very preterm and full-term infants, at term-equivalent age and 2 months corrected age, and examined inter-individual variability among preterm infants. In addition to describing changes with age and between groups, she showed that in preterm infants, inter-individual variability in EEG metrics at term-equivalent age was partly explained by clinical risk factors and variations in brain microstructure, as assessed with dMRI (González Carpinteiro et al., 2026). Using functional MRI to collect precision functional mapping data in term neonates, Alyssa Labonte presented evidence that participant-specific sets of cortical areas are already in place, although with lower reliability and less abrupt transitions, without variation in this individual specificity as a function of the sensorimotor-association axis, suggesting that cortical area arrangement is specific to the individual and is largely established shortly following birth (Labonte et al., 2026). Using the same approach, Julia Moser showed that responses to the auditory oddball were consistent in auditory processing areas across one-month-old infants, but differed between infants in the rest of the brain. These individual-specific response patterns appear to be relatively stable and differed from other participant's response patterns (Moser et al., 2026).

Another major development in our field is the growing number of longitudinal studies coming to fruition, enabling us to identify the structural and functional changes in the infant brain that underlie normal development and developmental disorders later in life. Chiara Capparini presented a longitudinal study of visual statistical learning in infants 3, 6 and 9 months old. Using frequency-tagging EEG, she reported evidence of neural markers of learning becoming more robust and predictive from 3 to 9 months of age, while looking times did not differ across ages, and the link between neural entrainment and behavior was visible only at 9 months (Capparini et al., 2026). Using resting-state fMRI, Yanbin Niu observed that the bed nucleus of the stria terminalis (BNST) of 1-month-old infants exhibits intrinsic connectivity with subcortical regions involved in anxiety later in life. They did not exhibit patterns observed in adults such as BNST-frontal cortex connectivity, and importantly, weaker BNST-amygdala connectivity at one month was significantly associated with greater anxiety symptoms at 18 months (Niu et al., 2025). Some longitudinal studies now also incorporate physiological and metabolic measurements to define composite biomarkers, refining the accuracy of predictions for mental health symptoms. Madelyn Nance used a novel Prognostic Respiratory Intensity Scoring Metric (PRISM) to assess the burden of respiratory support in term neonates, and saliva collection to quantify inflammation, and examined their relationships with EEG entropy in neonates. The results show complex interactions between PRISM scores, sex, and inflammation that affect EEG signal entropy. Most importantly, the interaction between non-social resting state EEG signal entropy, sex, and PRISM scores predicted risk of developing Autism Spectrum Disorders with 88% accuracy (Nance et al., 2026).

6. Conclusion

This special issue provides an overview of recent advances in fetal, neonatal, infant, and toddler neuroimaging and their applications. A major drive in the FIT'NG field is the search for early markers of atypical neurodevelopment, aiming at developing translational research and providing preventive and intervention methods. Prematurity and other perinatal adversity factors, including environmental adversity, are main models of atypical cognitive and social development, and good candidates for translational efforts. This ambition has led to remarkable advances in technological and data analytical methods, enabling high precision functional and structural connectivity imaging, large-cohorts statistical innovations informing hypothesis-driven longitudinal designs, and complex modeling combining physiological and metabolic data with neuroimaging to improve sensitivity. In addition, striking advances of this year's meeting included fetal research. These advances, some of which are made possible by deep learning, now allow the development of individual-level analyses, paving the way for precision neuroscience and clinically relevant approaches.

CRediT authorship contribution statement

Nadege Roche-Labarbe: Writing – original draft, Writing – review & editing. **Johanna Bick:** Writing – original draft, Writing – review & editing. **M. Catalina Camacho:** Writing – original draft, Writing – review & editing. **Juliette Champaud:** Writing – original draft, Writing – review & editing. **Haerin Chung:** Writing – original draft, Writing – review & editing. **Lorenzo Fabrizi:** Writing – original draft, Writing – review & editing. **Marta Korom:** Writing – original draft, Writing – review & editing. **Emma T. Margolis:** Writing – original draft, Writing – review & editing. **Julia Moser:** Writing – original draft, Writing – review & editing. **Paige M. Nelson:** Writing – original draft, Writing – review & editing. **Rebecca F. Schwarzlose:** Writing – original draft, Writing – review & editing. **Marisa Spann:** Writing – original draft, Writing – review & editing. **Lilla Zöllei:** Writing – original draft, Writing – review & editing.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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