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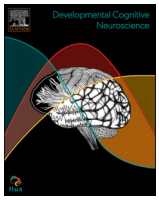

Highlights of the 2023 Fetal, Infant, and Toddler Neuroimaging Group annual meeting

Human brain function across the lifespan emerges from complex developmental cascades, with variation in cognition, emotions, and health outcomes resulting in part from individual differences in brain development. Thus, characterizing human brain development in its earliest phases is paramount for conceptualizing typical and atypical brain function. Over the past 40 years, research in fetal, infant, and toddler (FIT) neuroimaging—including magnetic resonance imaging (MRI), electroencephalography (EEG), magnetoencephalography (MEG), diffuse optical tomography (DOT), optical coherence tomography (OCT), histology, ultrasound, and functional near-infrared spectroscopy (fNIRS)—has made remarkable progress towards this goal through providing a means with which to comprehensively visualize, measure, and model the developing human brain's structure and function across a wide range of temporal and spatial scales. Recent technological innovations and large-scale, multisite collaborations have further enhanced our understanding of early brain development, providing vital insights into the origins of neurodevelopmental disorders (Spann et al., 2023).

This progress in FIT neuroimaging has been driven by collaboration across a wide range of scientific fields. The complexity of early brain development, the variety of imaging technologies, and the need to interpret findings in both a clinical and ethical context make cross-disciplinary collaboration essential for the field's continued growth and success.

Founded in 2018, the Fetal, Infant, and Toddler Neuroimaging Group (FIT'NG) is a scientific society dedicated to advancing and disseminating the latest scientific and technical knowledge in FIT neuroimaging research. FIT'NG serves as a platform for bringing together individuals from diverse fields; including those with technical expertise, such as engineers and computer scientists who design hardware and software; and those who apply these resources in clinical and research settings, including neuroscientists and medical professionals. Through fostering interdisciplinary discussion and collaboration, FIT'NG provides an ideal forum for exchanging ideas on best practices and guidelines for data collection and analysis, promoting community engagement, and educating the next generation of FIT scientists.

Since its inaugural 1-day pre-conference workshop in 2018, FIT'NG has grown rapidly, expanding to a 2-day conference in 2022 in Paris, France. The mission of the annual conference is to join together as a field to share our research, network, and discuss a range of prevalent methodological and conceptual challenges in FIT imaging. As of May 2025, the organization boasts 402 members from 24 countries, representing a diverse and dynamic community of leaders and trainees in the field.

This special issue brings together articles that reflect the progressive science and vibrant interdisciplinary community that was present at our second annual conference, hosted in Santa Rosa, California over two days in September 2023. As a true testament to the enthusiasm of the rapidly growing field, over 140 abstracts of FIT neuroimaging research were presented across the meeting by the 217 passionate scientists who attended from across the globe. In addition to acting as a key platform for cutting edge science, the meeting also represented a unique opportunity for researchers working towards a common goal to come together at a dedicated conference to learn from one another, readily exchange ideas, and establish new collaborations.

Among the many highlights of the meeting was the compelling keynote presentation delivered by Professor Rebecca Saxe who challenged us to consider "Are infant brains just little adult brains?" by taking us through a systematic tour of evidence from her pioneering research in awake infant functional MRI studies (Kosakowski et al., 2024). Thematic sessions of original research were opened by invited speakers representing research across key topics in early human brain development and behavior. These included: Characterizing the rapidly developing brain from the fetal period through infancy (Lorenzo Fabrizi); Neural correlates of early cognitive and emotional development (Santiago Morales); Effects of early adversity on neurodevelopment (Chiara Bulgarelli); Sensitive periods & brain plasticity (Rebecca Reh); and Early neural predicators of psychiatric risk (Jessica Girault).

FIT'NG is very proud of the enthusiastic and imaginative input from the trainees and early career researchers that represent not only the cutting-edge but also the future of our field. At the 2023 meeting, the trainees identified 5 key challenges for the community which were vigorously discussed by meeting attendees in "Elephants in the Room" sessions: Measuring and interpreting individual differences in neurodevelopmental trajectories; Understanding sleep & sleep state during resting-state data collection; Exploring causal mechanisms in brain-behavior relationships; Measuring and interpreting development as a construct in neuroimaging analyses; and Leveraging windows of neuroplasticity and sensitive periods to optimize early interventions. These discussions were further complemented by a hugely insightful Expert Panel discussion from leaders in our field (John Constantino, Joe Culver, Mary Dozier, Katherine MacDuffie, Koraly Pérez-Edgar and Rebecca Saxe) who considered whether developmental neuroimaging can help in the prevention of psychiatric disorders.

The articles in this special issue represent a subset of the topics and talks discussed at the annual meeting. The goal of this special issue is to capture examples of the wide range of themes and conversations afforded by the annual FIT'NG meeting, thereby providing a space for previously unconnected members to work together to publish novel exchanges of ideas. To reflect the organization of the conference, articles are organized based on (1) discussions arising from the trainee-led

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Elephants in the Room, (2) themes that emerged from the Expert Panel on whether neuroimaging is poised to help with prevention of psychiatric disorders, and (3) scientific advances noted in the talks in the thematic sessions.

1. Elephants in the room

Two articles derived from the Elephants in the Room portion of the meeting, a trainee-led set of discussions on key challenges in FIT neuroimaging. Margolis et al. (2025) identify the challenge that much of FIT neuroimaging currently focuses on individuals from global minority countries with limited representation of culturally and politically marginalized populations, thereby hindering our ability to accurately capture the full dimension of human neural development. The article identifies specific causes and concrete solutions to this challenge, with detailed tables for different FIT methodologies including MRI, EEG, MEG, fNIRS, and ultrasound. The article provides concrete directions that FIT neuroimagers can take to address challenges surrounding representation as well as specific resources to help educate families, to learn more about exclusionary practices in neuroimaging research, and to give recommendations for inclusive science. Together, the article serves as an incredible resource summarizing current challenges, crafting concrete solutions, and providing specific resources.

Olson et al. (2025) identify the key challenge that FIT neuroimaging studies require detailed, testable models of brain development and sources of individual variation, as well as methods and experimental designs that can test these models. The article posits distinct ways in which developmental brain trajectories could differ among individuals, including variability in phase, slope, shape, or asymptote. The authors describe how different FIT neuroimaging approaches may be best suited to capture different types of individual variability. Key elements of experimental design are emphasized, including selecting a developmental time window in which variability and validity of behavior and brain metrics are maximized, using large representative samples, and pre-registration of hypotheses. Altogether, this article provides an essential framework for conceptualizing and designing FIT neuroimaging studies to best capture individual differences, based on testing cogent developmental models and considering key statistical principles unique to FIT populations.

2. Expert panel on FIT neuroimaging informing preventative measures in psychiatry

A highlight of the 2024 meeting was the Expert Panel that weighed in on whether FIT neuroimaging has the potential to inform the treatment and prevention of psychiatric illnesses. FIT neuroimaging may play a key role here, as many psychiatric illnesses appear to include brain alterations starting near birth or even in-utero, with cascading impact on subsequent brain development. The two articles from the Expert Panel provide visionary frameworks for advancing FIT neuroimaging to clinical relevance.

Perez-Edgar et al. (2025) focus on four elements from this Expert Panel discussion. First, they stress the need for randomized controlled trials (RCTs) with imaging before and after an intervention, to provide evidence for causality. Second, they emphasize that hypothesis pre-registration and broad data sharing are important for integrity and replication of results, key elements in developing clinical tools. Third, they suggest that researchers work to develop neuroimaging metrics that link to specific behaviors or phenotypes and towards identifying accurate biomarkers that can predict risk versus normative development. Finally, the Expert Panel notes situations in which there may be an ethical obligation to provide ancillary care to participants in research studies or triaging them into studies that provide treatment.

Constantino and Constantino-Pettit (2025) provide an in-depth account of the Expert Panel discussion regarding using FIT neuroimaging to establish causation and how to distinguish whether imaging results capture causes versus effects of behavioral differences. The authors identify three study designs that can provide evidence of causation: intervention studies; twins, siblings, or family studies; and prospective longitudinal designs. The authors also stress how known demographic and epidemiological features of psychiatric illnesses are key to study designs aiming to unravel causality. For example, they highlight that many psychiatric disorders are highly comorbid and share genetic risk. They argue that underlying causative neural correlates must also be shared across illnesses, and so researchers should consider the use of trans-diagnostic phenotypes to get at shared mechanisms. The authors explicate the specific advantage of twin studies to disentangle genetic versus environmental causes. Echoing McDuffie et al., they stress the approach of developing intermediate phenotypes that can be identified early in development and that might have strong neural correlates; and then testing whether specific combinations of these neural correlates predict psychiatric symptoms later in development. Finally, the authors highlight precision neuroimaging, which captures reliable brain measures in individuals before and after an intervention, as another key avenue in working towards evidence of causality.

3. Scientific advances in FIT from thematic sessions: conceptualizing brain function in early development

Five articles in this special issue derive from the thematic sessions from FIT'NG 2024, including three that center around how to conceptualize brain function in early development. Champaud et al. (2025) provide a thoughtful article on metastable brain dynamics, working from the framework that the brain tends to shift into different states, each characterized by a specific pattern of activity or connectivity. EEG, fMRI, ultrasound, and other FIT modalities are all able to capture brain states, at different spatial and temporal scales. These states emerge as a function of the brain's underlying connectivity and physiology, and so the set of available states and the properties governing states transitions vary with developmental age and depend on environmental insults. They propose a specific sequence of development of brain states during in-utero development and note that the consequence of preterm birth may be to disrupt this sequence, with potential lingering implications on brain function. They suggest that development over infancy and beyond might include an expansion of available states and faster and easier state transitions, which together may improve cognitive flexibility. Overall, this work provides a powerful framework for how brain structure and physiological changes over development link to age-specific metastable brain dynamics, how dynamics are influenced by the environment, and the behavioral and health correlates.

The articles by Whitehead (2025) and Mueller et al. (2025) highlight the importance of sleep in the developing brain and for contextualizing results from FIT neuroimaging studies. Whitehead reviews sleep states (including wake, quiet sleep, and active sleep) present during early development and note that each sleep state has a characteristic pattern of spontaneous movements and brain responsiveness to external stimuli. Because sensory input is primarily experienced during sleep in early development, including from self-generated movements and sounds, brain activity during sleep has a key role in how developing brain circuits are ultimately shaped. Thus, the balance of different sleep states, and the sensory inputs experienced in different states appear to be critical for healthy brain development. Key inferences are that health issues or external factors that alter sleep or sensory input (e.g., intrauterine growth restriction) are likely to have consequences on brain development; and also that it is important for FIT neuroimagers to consider sleep state when measuring brain activity.

Measuring sleep state during some FIT modalities, such as fMRI, is particularly challenging because the gold-standard approach for measuring sleep, EEG, is technically difficult to measure in the MRI environment. Mueller at al. demonstrate one approach to tackling this issue, using respiration traces to quantify active versus quiet sleep during fMRI in 11 infants younger than 47 weeks post-menstrual age.

Out of the 49 available fMRI runs that they acquired across the 11 infants, infants were in active sleep in 36 of the runs and in quiet sleep during the other 13 runs. While further data are needed with more subjects and using additional methods to measure sleep state, this innovative study provides a couple of very important guideposts: infants vary in sleep state during fMRI, and initial evidence indicates active is more common than quiet sleep. Given the differences in functional brain responses across sleep states noted by Whitehead et al., these results underscore the high importance for FIT neuroimagers to measure and consider sleep state when measuring brain activity.

4. Scientific advances in FIT from thematic sessions: developmental cascades impacting behavior and psychiatric risk

Two articles deriving from the thematic sessions demonstrate the unique ability of FIT neuroimaging studies to delineate how behavioral outcomes of psychiatric risk could emerge from neurodevelopmental cascades. Girault (2025) provides a compelling model of how disruptions in the visual system in neonates and infants could initiate an altered neurodevelopmental trajectory that includes altered attention later in life and ultimately results in developing symptoms of autism. This model is motivated by studies showing altered expansion, white matter development, and functional connectivity of visual cortex in infants at high risk for developing symptoms of autism. Heeding the advice of the two articles in the Expert Panel, Girault reviews work that longitudinally links early developmental alterations in visual cortex to intermediate phenotypes associated with autism risk including attention orienting, joint attention, and social cognition. She then provides specific interventions that could be studied to correct this altered neurodevelopmental cascade, including infant massage and attention training. Altogether, this article provides a compelling hypothesis of a developmental cascade that results in psychiatric symptoms and specific interventions to intervene in this altered trajectory.

Finally, Morales and Buzzell (2025) review studies that provide insights into neurodevelopmental mechanisms of cognitive control, and how disruptions in these trajectories can increase risk for psychiatric illnesses. The review focuses largely on time frequency analysis of EEG data, a technique that is able to capture changes that are not perfectly time-locked to an event and are thus variable in latency. Such an approach may be key in FIT samples where latency of brain responses might be more variable and depend on developmental age. Using this method, Morales and Buzzell review studies that test a developmental model of cognitive control in which midline frontal cortex detects the need for cognitive control and lateral frontal cortex is involved in implementing control. Aspects of this model are supported by developmental studies using time-frequency analysis of EEG, as mid-frontal theta activity links to the need for cognitive control, and synchronization of mid-theta activity with lateral brain regions links to instantiation of control. The authors then nicely review how these EEG-measured correlates of cognitive control vary with development; and how variation in these brain metrics are linked to later variation in behavior and psychiatric risk.

5. An exciting future

The articles in this review provide an overview of the opportunities, challenges, and promise of FIT neuroimaging. By bringing together scientists and clinicians of a wide array of backgrounds, FIT neuroimaging has the potential to develop and test powerful models of healthy and atypical human neurodevelopment. FIT'NG has helped to crystallize the momentum of hundreds of groups around the world and is a growing community with focuses on research, training, and promoting the careers of the next generation of FIT scientists. We look forward to an exciting future as we work together to uncover principles of human neurodevelopment, leveraging advances to promote health in vulnerable developing brains.

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Declaration of Competing Interest

The authors declare no competing interests.

References

Champaud, J.L.Y., Asite, S., Fabrizi, L., 2025. Development of brain metastable dynamics during the equivalent of the third gestational trimester. Dev. Cogn. Neurosci. 73, 101556. https://doi.org/10.1016/j.dcn.2025.101556. PMCID:PMC12023897.

Constantino, J.N., Constantino-Pettit, A.M., 2025. Causation, trait correlation, and translation: developmental brain imaging in research on neuropsychiatric conditions of childhood. Dev. Cogn. Neurosci. 72, 101513. https://doi.org/10.1016/j.dcn.2025.101513. PMCID:PMC11847081.

Girault, J.B., 2025. The developing visual system: a building block on the path to autism. Dev. Cogn. Neurosci. 73, 101547. https://doi.org/10.1016/j.dcn.2025.101547. PMCID:PMC11964655.

Kosakowski, H.L., Cohen, M.A., Herrera, L., Nichoson, I., Kanwisher, N., Saxe, R., 2024. Cortical face-selective responses emerge early in human infancy. eNeuro 11. https://doi.org/10.1523/ENEURO.0117-24.2024. PMCID:PMC11258539.

Margolis, E.T., Nelson, P.M., Fiske, A., Champaud, J.L.Y., Olson, H.A., Gomez, M.J.C., Dineen, A.T., Bulgarelli, C., Troller-Renfree, S.V., Donald, K.A., Spann, M.N., Howell, B., Scheinost, D., Korom, M., 2025. Modality-level obstacles and initiatives to improve representation in fetal, infant, and toddler neuroimaging research samples. Dev. Cogn. Neurosci. 72, 101505. https://doi.org/10.1016/j.dcn.2024.101505. PMCID:PMC11875194.

Morales, S., Buzzell, G.A., 2025. EEG time-frequency dynamics of early cognitive control development. Dev. Cogn. Neurosci. 73, 101548. https://doi.org/10.1016/j.dcn.2025.101548. PMCID:PMC11999349.

Mueller, I., Rodriguez, R.X., Pini, N., Holland, C.M., Ababio, R., Inala, S., Delapenha, K., Mahmoodi, V., Khaitova, M., Hao, X., Fifer, W.P., Scheinost, D., Spann, M.N., 2025. Infant sleep state coded from respiration and its relationship to the developing functional connectome: a feasibility study. Dev. Cogn. Neurosci. 72, 101525. https://doi.org/10.1016/j.dcn.2025.101525. PMCID:PMC11876745.

Olson, H.A., Camacho, M.C., Abdurokhmonova, G., Ahmad, S., Chen, E.M., Chung, H., Lorenzo, R.D., Dineen, A.T., Ganz, M., Licandro, R., Magnain, C., Marrus, N., McCormick, S.A., Rutter, T.M., Wagner, L., Woodruff Carr, K., Zollei, L., Vaughn, K. A., Madsen, K.S., 2025. Measuring and interpreting individual differences in fetal, infant, and toddler neurodevelopment. Dev. Cogn. Neurosci. 73, 101539. https://doi.org/10.1016/j.dcn.2025.101539. PMCID:PMC11930173.

Perez-Edgar, K., Dozier, M., Saxe, R., MacDuffie, K.E., 2025. How will developmental neuroimaging contribute to the prediction of neurodevelopmental or psychiatric disorders? Challenges and opportunities. Dev. Cogn. Neurosci. 71, 101490. https://doi.org/10.1016/j.dcn.2024.101490. PMCID:PMC11721882.

Spann, M.N., Wisnowksi, J.L., HBCD Phase I Scanning Young Populations Working Group, Smyser, C.D., Fetal, Infant, and Toddler Neuroimaging Group (FIT'NG), Howell, B., Dean, D.C., 3rd, 2023.

Whitehead, K., 2025. Co-developing sleep-wake and sensory foundations for cognition in the human fetus and newborn. Dev. Cogn. Neurosci. 71, 101487. https://doi.org/10.1016/j.dcn.2024.101487. PMCID:PMC11699341.

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