

The Art, Science, and Secrets of Scanning Young Children

Marisa N. Spann, Jessica L. Wisnowski, HBCD Phase I Scanning Young Populations Working Group, Christopher D. Smyser, Fetal, Infant, and Toddler Neuroimaging Group (FIT'NG), Brittany Howell, and Douglas C. Dean III

Millions of people worldwide have health conditions arising from altered brain development. Treatments for these conditions must be optimized through mechanistic understanding from rigorous and replicable research. Magnetic resonance imaging (MRI) can visualize and quantify brain structure and function throughout development. MRI is safe and noninvasive and can provide quantitative measurements of brain growth and maturation at high spatial resolution. Thus, MRI is a powerful and flexible tool for characterizing neurodevelopment (1).

An impediment to characterizing neurodevelopmental insights from MRI comes from the unique challenges of conducting MRI in children, particularly those younger than 3 years of age (2). In this commentary, we highlight that acquiring high-quality MRI data in young children is a science in and of itself—though it may feel more like an art than a science to those newer to the field. In addition, we emphasize the importance of adapting MRI acquisition in children to meet the unique needs of young participants and the communities from which they are recruited (Figure 1).

Advances in MRI Acquisition. A primary challenge in MRI is motion, which can degrade image quality. As a result, infants and young children—who have difficulty lying still inside the scanner—often require alternative strategies such as sedation or scanning during natural sleep (2) to generate high-quality images. While helpful in reducing motion artifacts, these approaches limit task-evoked and natural/nonsedated functional brain activity imaging; restrict comparability imaging done during wakeful periods, which is typically performed in older participants; require extended and off-hour scan times; and do not guarantee a lack of motion artifacts. Emerging motion correction strategies, including prospective methods that track real-time head motion and retrospective methods that correct for motion during image reconstruction, can reduce motion-related artifacts and improve the quality of developmental MRI.

Imaging acquisition during a short period of time is integral to developmental MRI (3). Shorter sequences can improve successful imaging of natural sleep and awake states. Acceleration with undersampling methods (e.g., compressed sensing, partial Fourier, and parallel imaging) and simultaneous multislice imaging methods that acquire multiple slices at a time reduce scan times while preserving image quality. Nevertheless, quicker acquisition times may necessitate corrections for confounds, such as physiological noise and head motion.

Loud acoustic noise poses another challenge in developmental MRI because it can wake sleeping infants and scare or startle children. Quiet and silent imaging sequences and other measures to reduce acoustic noise (e.g., MRI-compatible headphones) have great potential, particularly for imaging during natural sleep. These strategies are forthcoming.

Custom developmental head coils are another recent advance leading to novel brain function discoveries in young infants who are awake. Using custom size-adaptive developmental coils can increase the quantity of low-motion functional MRI data collected from sleeping and awake infants.

Advances in Acquisition Protocols. Including preparation time, child scanning sessions can take 3 hours or longer, often occurring after parents' workdays, at bedtime, or on weekends (4). The scanner must therefore be a welcoming environment. Thus, researchers have conceptualized a "research home" with various child-friendly themes and MRI-compatible furnishings. These also increase infrastructural requirements at the scanner, such as a dedicated space that allows the child being imaged to fall asleep while allowing safe transportation to the scanner. MRI-compatible, low-cost alternatives to hospital furniture (e.g., resin rocking chairs, playpens made of PVC piping, and mesh) help keep the infant comfortable. Recently, MRI-compatible cribs have also advanced, and these typically snap directly onto the scanner bed.

In addition to providing practical and physical accommodations for families in the scanning environment (e.g., places to sit and rock infants), researchers have learned to consider participants' social and psychological needs. For example, families are mailed packets of materials (e.g., ear protection, an audio recording of scanner sounds) to help acclimate young participants to novel sensory experiences before the scan day. During the scan, families interact with trained researchers—fondly called "baby whisperers"—who are attuned to the infant and family cues throughout the session and adapt accordingly in a semistructured approach (e.g., changing tone of voice or style of interaction, suggesting breaks in the protocol, offering preselected MRI-compatible toys or comfort objects). In addition, scanning environments can include dimmable lights and familiar sounds (e.g., lullabies) played in the background, and participants can wear noise-canceling headphones, all of which help increase participant comfort.

Another strategy that supports families in meeting participants' emotional responses and needs, particularly those of older babies and young toddlers, is using interactive social



Figure 1. Schematic of the areas of innovation that are pivotal to successful high-quality neuroimaging with magnetic resonance imaging in young children.

stories to prepare participants to the expectations during the scan. For example, images of age-matched participants at the various steps throughout the visit are taken and compiled into a short story using simple language. A few weeks prior to the scan, participant families prepare by reading this story and modeling the use of the equipment that was mailed. In addition, trained researchers encourage the families to use the participants' names when interacting and using the social story.

To further acclimate participants to the scanning experience and help them prepare both mentally and physically for their scanning session, young participants may be given a mock scan session before entering the actual scanner. Mock scanners have evolved from low-tech rolling seats underneath a table to child-size scanners in a dedicated room with family-friendly décor. Prebuilt small-to-large toy mock scanners can also be sent to the participant's home before scanning (5).

Additional items such as pellet-filled positioning devices and custom-made weighted blankets filled with beans help increase participant comfort during scanning and reduce participant movement.

Advances in Public Awareness and Community Engagement. Human subject research requires willing participants. For developmental imaging, this includes the willingness of both children and their families. Preconceptions of MRI based on direct experiences (i.e., previous involvement in research, clinical MRI, and medical training) or information from media, friends, and family can reduce willingness to participate in an MRI session. Typical concerns include scanner noise and (mistakenly) radiation exposure (2), which must be addressed during recruitment. Thus, successful developmental MRI requires that researchers educate and engage with participants and their communities to reduce misunderstanding that can impede potential participation. Examples of

successful outreach include community interactions through educational events about MRI (e.g., videos of stuffed animals being scanned) or partnering with local children's venues (e.g., children's museums and libraries) to develop education programs targeted to families (Figure 1). If these outreach efforts continue to be prioritized, they will aid developmental MRI research (and MRI research more broadly) by increasing public awareness and access to accurate information.

Increasing the accessibility of MRI research has received more attention to ensure greater participation in MRI research across the lifespan. A recent example is the availability of mobile MRI units (6) that allow MRI research to be feasible in all parts of the world, including remote regions. Successful collaboration within these regions requires scientists to proactively engage with remote communities with meaningful, bidirectional information exchanges between scientists and the participant population (7).

Conclusions. This commentary highlights the state-of-the-art science required to address the unique complexities and challenges of MRI research with infants and young children. Not only is there a need for hardware, software, and equipment tailored to this developmental population, but scientists' attitudes, attention, and efforts must be adapted and tuned to these young participants, their families, and their broader communities. Through this combination of science, and the art of human interaction, developmental MRI will continue to advance our understanding of brain growth, maturation, and function, opening essential avenues of research into both typical and atypical neurodevelopment.

Acknowledgments and Disclosures

The Fetal, Infant, and Toddler Neuroimaging Group (FIT'NG) is supported by the Eunice Kennedy Shriver National Institute of Child Health and Human Development of the National Institutes of Health Grant No. R13HD108938.

The authors report no biomedical financial interests or potential conflicts of interest.

Article Information

From the Vagelos College of Physicians and Surgeons, Columbia University, New York, New York (MNS); New York State Psychiatric Institute, New York, New York (MNS); Children's Hospital Los Angeles, Los Angeles, California (JLW); Keck School of Medicine, University of Southern California, Los Angeles, California (JLW); Washington University in St. Louis, St. Louis, Missouri (CDS); Fralin Biomedical Research Institute at Virginia Tech Carilion, Roanoke, Virginia (BH); Department of Human Development and Family Science, Virginia Tech, Blacksburg, Virginia (BH); Departments of Pediatrics and Medical Physics, School of Medicine and Public Health, University of Wisconsin–Madison, Madison, Wisconsin (DCD); and the Waisman Center, University of Wisconsin–Madison, Madison, Wisconsin (DCD).

HBCE Phase I Scanning Young Populations Working Group (in alphabetical order): Banu Ahtam (Fetal-Neonatal Neuroimaging & Developmental Science Center, Division of Newborn Medicine Boston Children's Hospital, Department of Pediatrics, Harvard Medical School), Wei Gao (Department of Biomedical Sciences, Cedars-Sinai), Hao Huang (Department of Radiology, Children's Hospital of Philadelphia, University of Pennsylvania), Mary Beth Nebel (Center for Neurodevelopmental and Imaging Research, Kennedy Krieger Institute), Elizabeth S. Norton (Department of Communication Sciences and Disorders, Department of Medical Social Sciences, Northwestern University), Minhui Ouyang (Department of Radiology, Children's Hospital of Philadelphia, Perelman School of Medicine, University of Pennsylvania), Vidya Rajagopalan (Department of Radiology, Children's Hospital Los Angeles, Keck School of Medicine, University of Southern California), Tracy Riggins (University of Maryland), Zeynep M. Saygin (The Ohio State University), Lisa Scott (Department of Psychiatry, University of Florida), Christopher D. Smyser (Washington University Neonatal Development Research Lab, Washington University School of Medicine in St. Louis), Moriah E. Thomason (Department of Child and Adolescent Psychiatry, New York University Langone Health), and Lauren S. Wakschlag (Department of Medical Social Sciences, Fienberg School of Medicine, Institute for Innovations in Developmental Sciences, Northwestern University).

Fetal, Infant, and Toddler Neuroimaging Group (FIT'NG) is composed of the following members (in alphabetical order): Sahar Ahmad (Department of Radiology and Biomedical Research Imaging Center, The University of North Carolina at Chapel Hill), Ezra Aydin (Vagelos College of Physicians and Surgeons, Columbia University Irving Medical Center), James A. Barkovich (Department of Radiology, University of California, San Francisco), Evelyn Berger-Jenkins (Division of Child & Adolescent Health, New York Presbyterian, Columbia University Irving Medical Center), Johanna Brick (Laboratory of Early Experience and Development, University of Houston), Lindsay C. Bowman (Center for Mind and Brain, University of California Davis), Catalina M. Camacho (Cognitive Control and Psychopathology Laboratory, Washington University in St. Louis), Claudia Lugo-Candelas (Columbia University Irving Medical Center, New York State Psychiatric Institute), Rhodri Cusack (Trinity College Institute of Neuroscience, Trinity College), Jessica DuBois (NeuroDiderot, INSERM, Université Paris Cité, CEA, Neurospin, Université Paris Saclay), Alexander J. Dufford (Department of Medical Social Sciences, Feinberg School of Medicine, Institute for Innovations in Developmental Sciences, Northwestern University), Jed T. Elison (Institute of Child Development, Department of Pediatrics, University of Minnesota), Cameron T. Ellis (Department of Psychology, Stanford University), Silvina L. Ferradal (Department of Intelligent Systems Engineering, Indiana University), Courtney Filippi (National Institute of Mental Health, University of Maryland), Aiden Leigh Ford (Emory University), Mahshid Fouladivanda (Shiraz University of Technology), Nadine Gaab (Harvard University), Dawn Gano (Department of Neurology and Pediatrics, University of California San Francisco), Melanie Ganz-Benjamin (Neurobiology Research Unit, Copenhagen University Hospital, Department of Computer Science, University of Copenhagen), Simona Ghetti (Center for Mind and Brain, University of California Davis), Orit Ariel Glenn (University of California, San Francisco), Maria Jose Castro Gomez (Neuroscience and Mental Health Institute, Department of Biomedical Engineering, University of Alberta), Alice Graham (Department of Behavioral Neuroscience, Oregon Health and

Science University), Cassandra L. Hendrix (New York University Langone Health), Cristin M. Holland (Vagelos College of Physicians and Surgeons, Columbia University Irving Medical Center), Kathryn Humphreys (Department of Psychology and Human Development, Vanderbilt University), Marta Korom (Department of Psychological and Brain Sciences, University of Delaware), Heather L. Kosakowski (Harvard University), Gang Li (Department of Radiology and Biomedical Research Imaging Center, The University of North Carolina at Chapel Hill), Angela Gigliotti Manassis (Teachers College, Columbia University), Saara Nölvi (Turku Institute for Advanced Studies, The FinnBrain Birth Cohort Study, Department of Psychology and Speech-Language Pathology, Department of Clinical Medicine, University of Turku), Roberta Pineda (Chan Division of Occupational Science and Occupational Therapy, Keck School of Medicine, Department of Pediatrics, University of Southern California), Angeliki Pollatou (Developing Brain Institute, Children's National Hospital), Caroline Rae (Neuroscience Research Australia, University of New South Wales, Sydney), Jerod M. Rasmussen (University of California, Irvine), Dustin Scheinost (Radiology and Biomedical Imaging, Yale School of Medicine), Sara Shultz (Division of Autism and Department of Pediatrics, Emory University School of Medicine), Cristina Simon-Martinez (Institute of Informatics, University of Applied Sciences and Arts of Western Switzerland), Kathrine Skak Madsen (Danish Research Center for Magnetic Resonance, Center for Functional and Diagnostic Imaging and Research, Copenhagen University Hospital), Sooyeon Sung (Institute of Child Development, University of Minnesota), Chad M. Sylvester (Department of Psychiatry, Washington University in St. Louis), Ted K. Turesky (Harvard Graduate School of Education), Kelly A. Vaughn (University of Texas Health Science Center at Houston), Lauren Wagner (Neuroscience Interdepartmental Program, University of California, Los Angeles), Li Wang (University of North Carolina at Chapel Hill), Fleur L. Warton (Department of Human Biology, Neuroscience Institute, University of Cape Town), Sylia Wilson (Institute of Child Development, University of Minnesota), Pia Wintermark (Division of Newborn Medicine, Department of Pediatrics, McGill University), Ye Wu (School of Computer Science and Engineering, Nanjing University of Science and Technology), Pew-Thian Yap (University of North Carolina at Chapel Hill), Tristan S. Yates (Department of Psychology, Yale University), Elizabeth Yen (Tufts Medical Center), Xi Yu (State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University), Hongtu Zhu (New York State Psychiatric Institute), and Lilla Zöllei (Harvard University).

Address correspondence to Marisa N. Spann, Ph.D., M.P.H., at mns2125@cumc.columbia.edu, or Doug Dean III, Ph.D., at deaniii@wisc.edu.

Received Sep 20, 2022; accepted Sep 21, 2022.

References

- Pollatou A, Filippi CA, Aydin E, Vaughn K, Thompson D, Korom M, *et al.* (2022): An ode to fetal, infant, and toddler neuroimaging: Chronicling early clinical to research applications with MRI, and an introduction to an academic society connecting the field. *Dev Cogn Neurosci* 54:101083.
- Korom M, Camacho MC, Filippi CA, Licandro R, Moore LA, Dufford A, *et al.* (2022): Dear reviewers: Responses to common reviewer critiques about infant neuroimaging studies. *Dev Cogn Neurosci* 53:101055.
- Kozak BM, Jaimes C, Kirsch J, Gee MS (2020): MRI techniques to decrease imaging times in children. *Radiographics* 40:485–502.
- Hendrix CL, Thomason ME (2022): A survey of protocols from 54 infant and toddler neuroimaging research labs. *Dev Cogn Neurosci* 54:101060.
- Almli CR, Rivkin MJ, McKinstry RC, Group BDC (2007): The NIH MRI study of normal brain development (Objective-2): Newborns, infants, toddlers, and preschoolers. *Neuroimage* 35:308–325.
- Deoni SCL, D'Sa V, Volpe A, Beauchemin J, Croff JM, Elliott AJ, *et al.* (2022): Remote and at-home data collection: Considerations for the NIH HEALTHy Brain and Cognitive Development (HBCE) study. *Dev Cogn Neurosci* 54:101059.
- Shen FX, Wolf SM, Bhavnani S, Deoni S, Elison JT, Fair D, *et al.* (2021): Emerging ethical issues raised by highly portable MRI research in remote and resource-limited international settings. *Neuroimage* 238:118210.